NITROGEN TRANSPORT AND DISTRIBUTION ON PADDY RICE SOIL UNDER WATER EFFICIENT IRRIGATION METHOD *)

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ABSTRACT

Supplementing grain of food crops with organic and inorganic N fertilizers has long been recognized as a key for improving crops yield and production. This study aims to determine pattern of nitrogen transport and distribution in paddy rice soil under water-efficient irrigation (WEI) method. The study was conducted in the greenhouse of Soil Physics Laboratory, the Faculty of Agriculture UGM. A certain rice variety (*Oriza sativa*) was planted on the experimental box with size of 29 x 29 cm2 and 60 cm hight. Soil for plant media was taken from Banguntapan, Bantul, Yogyakarta. Experiments were done in two ways irrigation method: full flooded irrigation (FFI) and water-efficient irrigation (WEI) and, two ways of fertilization : organic (manure) and : chemical combined with manure fertilizer. Movement and distribution of nitrogen were observed based on the movement and distribution of nitrate in the soil water. A Convective Dispersion Equation (CDE) model is used for predicting of nitrate and ammonium concentrations in the rooting zone of the soil.

The results show that concentration and distribution of nitrate in the root zone (30 Cm) showed different patterns between WEI method and the conventional irrigation method (FFI). Nitrate concentration under water-efficient irrigation (WEI) is higher than under full flooded irrigation(FFI) methods. While ammonium concentration under the FFI is higher than under the WEI methods. The rate of nitrate movement vertically upward on the soil under the WEI is higher than under the FFI method. While the rate of vertical downward movement of ammonium under the FFI is higher than under the WEI methods.

The prediction of nitrate and ammonium concentrations using the CDE model showes that the the model could be used for predicting ammonium concentration on irrigated paddy rice soil, but less sensitive for nitrate prediction. The nitrate and ammonium concentration which is expressed in relative concentration (C / Co) is tend to decrease in accordance with the increasing soil depth and time, both for the FFI and WEI methods.

Key words: Water-efficient irrigation, flow rate and distribution of nitrate and ammonium, Convective Dispersion Equation (CDE) model.

INTRODUCTION

Nitrogen (N), along with carbon and oxygen is the most complex and crucial of the essential elements for life. Supplementing grain of food crops with organic and inorganic N fertilizers has long been recognized as a key for improving crops yield and production. Nitrogen is the most limiting factor in food crops production. Nitrogen availability in soil is frequently limited due to some natural and human intervention process such as erosion, runoff, leaching and gaseous losses. Supplementing N through fertilizer is one choosed

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method however, it very often is less effective and efficient due to improper method, timing and amount.

Nitrogen transport and distribution in unsaturated soil is significantly different with saturated and flooded (ponded) soil. In flooded soil, generally has three distinct zones established by the prevailing oxidation–reduction or redox potential of the system (Keeney and Sahrawat, in Antonopoulos, 2009). The soil profile is therefore divided into three zones, and transformation reactions and distribution of nitrogen that occur in each redox zone of an idealized flooded soil water system is as follows:

(i) a layer of flood water of about 50–70 mm thickness in which the dominant N-transformation processes are urea hydrolysis, nitrification and ammonia volatilization.

(ii) an oxidized top soil layer of thickness of about few mm to 10 mm below the soil surface, and very often is also called aerobic layer. Within this layer, nitrat ($NH4^+$) will be transformed to become $NO3^-$ as a result of oxidation process,

(iii) a reduced layer in the rest of the root zone in which the dominant processes are mineralization, denitrification, immobilization, leaching and plant uptake.

Though some nitrification takes place in the layer of oxidation, it is ignored in this study because of the relatively small thickness of the zone. In each layer, the soil properties, water content, and nitrate concentration are considered homogenous. The thickness of the total root zone is normally about 30 cm under irrigated and ponded conditions. The N available for plant uptake and leaching out of the root zone depends on the transport and transformations of different N species that undergo in the soil–water–plant–atmosphere system .

Percolation process which is a mass movement of water vertically, bringing the dissolved elements, including nitrogen, from the top layer to layer underneath which is an anaerobic layer, and known as leaching process. At this layer, NO_3^- will be transformed through denitrification and formed N_2 gas that will evaporate into the atmosphere. Meanwhile, under the anaerobic layer is the accumulation of $NH4^+$ which some move into the lower layers when the percolation process continues. Semi-impermeable layer which usually prevail in paddy rice field and known as *hard pan* can usually prevent or minimized the percolation process, which therefore hampered the transportation of nitrogen.

The greatest nitrogen losses in paddy soils with the range of 20% - 45% occurs through a process of volatilization and denitrification (Kyuma, 2004). As a result, most of irrigated and flooded rice fields will experience a shortage of nitrogen, so as to maintain its availability should always be done by the addition of nitrogen fertilizer. Thus, the need for N fertilizer for irrigated and flooded paddy fields tended to be higher both the dose and frequency, as compared with dryland (unirrigated).

Recently, a method of water-efficient irrigation method by minimizing the high of ponded water (minimum ponded) at rice fields and intermittent water supply have been introduced and developed in some irrigated areas and has been adopted by many farmers in East and South East Asia, including Indonesia. Water-efficient irrigation methods are often combined with organic fertilizer and the method known as SRI (System of Rice Intensification). Transport and distribution of nitrogen in irrigated paddy fields under SRI method is probably different as compared with the conventional irrigation methods, and has not been much studied by researchers. This study aims to determine transport phenomena, transformation and distribution of nitrogen in irrigated paddy soils under SRI methods. The analysis focused on the intensity (flux) of nitrogen movement, distribution and availability in the root zone of paddy rice fields.

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METHODS OF STUDY

An experimentation was conducted in greenhouse of the Faculty of Agriculture UGM. Soil used for the experiment is sandy loam texture derived from paddy rice fields in Banguntapan, Bantul. Two different methods of irrigation water that is full flooded (15-20 cm) and minimum flooded (WEI) and with 2 ways fertilizer which are organic (manure) fertilizer and a combination of manure and chemical fertilizers with the standard dose and interval as has been recommended by the Departement of Agriculture.

Content or concentration of nitrate (NO_3 -) and ammonium (NH_4^+) were observed by taking soil samples at a depths of 0 Cm, 15Cm, 30 Cm and 45 Cm from the soil surface at two weekly intervals. While the distribution of moisture content of soil was observed by sensors installed at each required depth. Observations are used to determine the flow of soil moisture and fluxes of dissolved nitrogen in the soil. Analysis of nitrates and ammonium levels was done by filtering and weighing methods, and using the spectrophotometer. Measurement of nitrate and ammonium concentration in the percolation water also performed by analyzing the collected water at the buttom of the soil tubs.

Determination of flow intensity (flux) of water and disolved nitrate and ammonium were done using the Darcy equation for water flow in saturated soil by assuming that the flow is steady and the soil layers is isotrophic. Furthermore, we also performed predictions of nitrate and ammonium concentration using the CDE model which has been developed by van Genuchten and Wierenga (1989).

RESULTS AND DISCUSSION

1. Nitrate Distribution

Concentration and distribution of nitrate in the root zone showed different patterns between WEI method and the conventional irrigation method (FFI). Addition of organic (manure) on paddy rice field under minimum ponding (WEI) was effective for increasing nitrate availability, especially in the soil layers of 15 cm to 30 cm (Figure 3.1). At a depth of 30 cm, the pattern was quite similar. Nitrate concentration increases both on FFI and WEI condition, however in soil under FFI the increase is slightly higher than the soil under WEI. Meanwhile, at a depth of 40 cm or more, the addition of organic fertilizers, although still able to raise the nitrate availability in the soil, but the increase was not significant. This shows that the addition of organic manure is effective only to raise the level and availability of nitrate for a depth of 30 cm. At a depth of more than 30 cm, the increase was not significant. The results of this study also provides evidence that the addition of nitrogen fertilizer by buried method at more than 30 cm is less effective to increase the availability of nitrate in the root zone.

The process of nitrate leaching from the upper layer to lower layer also occurs more frequently in areas with flooded irrigation (FFI). Consequently, the nitrate availability has decreased started a week after fertilizing. A different patterns of nitrat distribution and availability also occur in the combination fertilizer. At a depth of 15 cm, nitrate concentrations increase significantly only at week of 8. The nitrate concentrations increase until reaching 450 ppm at week of 15 on soil under FFI. While in the soil under WEI is decreasing. At a depth of 30 cm or more, indeed there is an increase of nitrate concentration began at week of six, but the increase only reached 200 ppm and then tends to falling down

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again in the following week. The results (Figure 3.1) also show that under WEI, nitrate concentrations higher than the FFI method only up to the depth of 15 Cm. Under the depth, the nitrate concentration in the FFI method is higher than the WEI. This because, under flooded irrigation, there is an oxidized soil layer below the soil surface, and called aerobic layer. Within this layer, nitrat ($NH4^+$) will be transformed to become $NO3^-$ as a result of oxidation process. Nitrification process in this layer also produces a lot of nitrate.

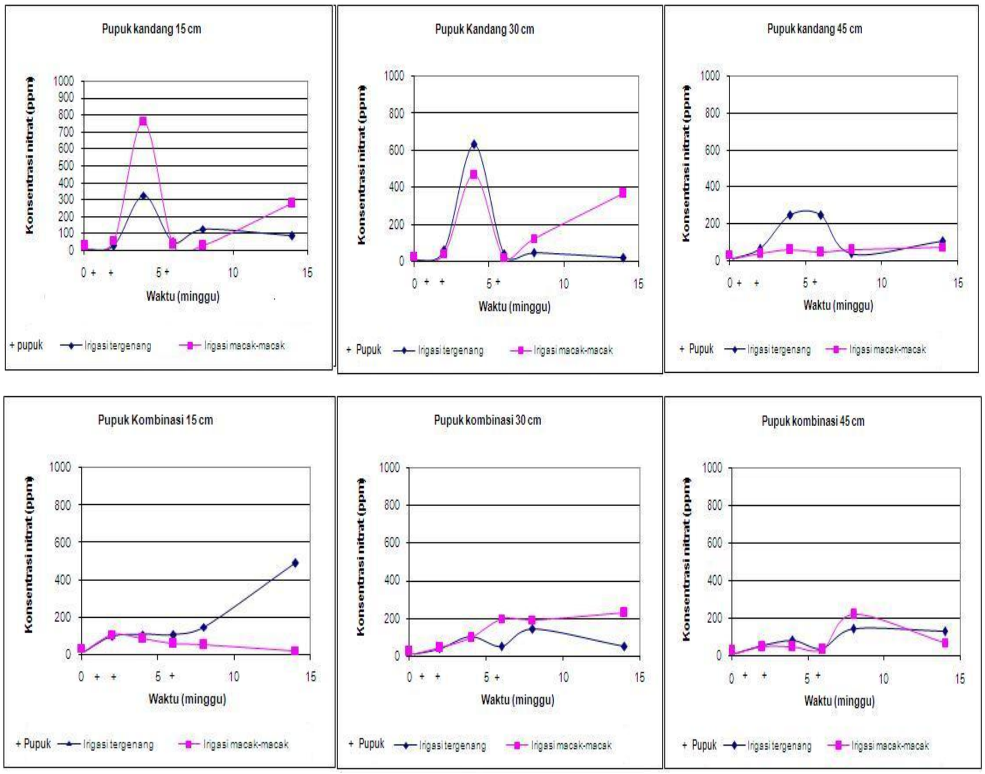

Figure 3.1. Distribution of nitrate concentration under two different irrigation methods on paddy rice soil.

2. Ammonium Distribution

Distribution of ammonium concentration for both WEI and FFI irrigation method showed a pattern that was not much different from the distribution of nitrate concentrations. Significant differences occurred only on layers of 15 cm. In this layer, concentration of ammonium increases sharply to reach 325 ppm after the second fertilization until week of 5th on FFI irrigation method. While for WEI methods, although there was an increase, but not as sharp as on the method of FFI. The peak of ammonium concentration occurred during the second week, and then at the fifth week it decreased sharply. At a depth of 30 cm or more, the pattern of ammonium concentration almost similar between WEI and FFI irrigation methods. The increase in ammonium concentration occurred several days after fertilization, but not so sharply, and only reach 100-150 ppm.

The increase in ammonium concentration for the second fertilizer treatment also show same pattern between FFI and WEI irrigation method. At 15 cm layer, there is an increase of ammonium concentrations up to 250 ppm and 200 ppm respectively for the WEI and FFI

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irrigation methods, then experienced a sharp decline at 5th week. In the next few weeks, the addition of fertilizer is less impact on the concentration of ammonium in the soil up to a depth of 30 cm. Only in the soil layer of 45 cm or more, there is an increase of ammonium concentration sharply up to 300 ppm at the 15th week, especially for WEI irrigation method.

Phenomenon as mentioned above indicates that the ammonium contained in organic (manure) fertilizer applied in flooded soil is relatively more stable and not immediately converted into nitrate under aerobic conditions. Moreover, under this condition, may occur ammonium diffusion from the lower layer to the upper layer due to concentration difference between the layers. In this case the concentration of ammonium in the lower layers is higher than the upper layer, resulting in a diffusion process of ammonium. Thus, there is an upward movement of ammonium.

At the depth of 30 cm, the concentration distribution of ammonium was almost similar between FFI and WEI irrigation methods. This because at the depth of 30 cm there was an accumulation of clay minerals which could bind the ammonium so that it not easy to be leached out or not being transformed into nitrate. Similar thing is at the depth of 45 cm. However, after the 8th week, there was a sharp increase of ammonium concentration up to 250 ppm in the period of early harvest, especially for the WEI irrigation method. While for the FFI method, a leveling-off of the ammonium concentration occured at 50 ppm level. This is due to part of the available ammonium was leaching out and some other utilized by plants, resulting in decreased levels of ammonium. Addition of N through organic fertilizers would increase the ammonium concentration on the respective layer.

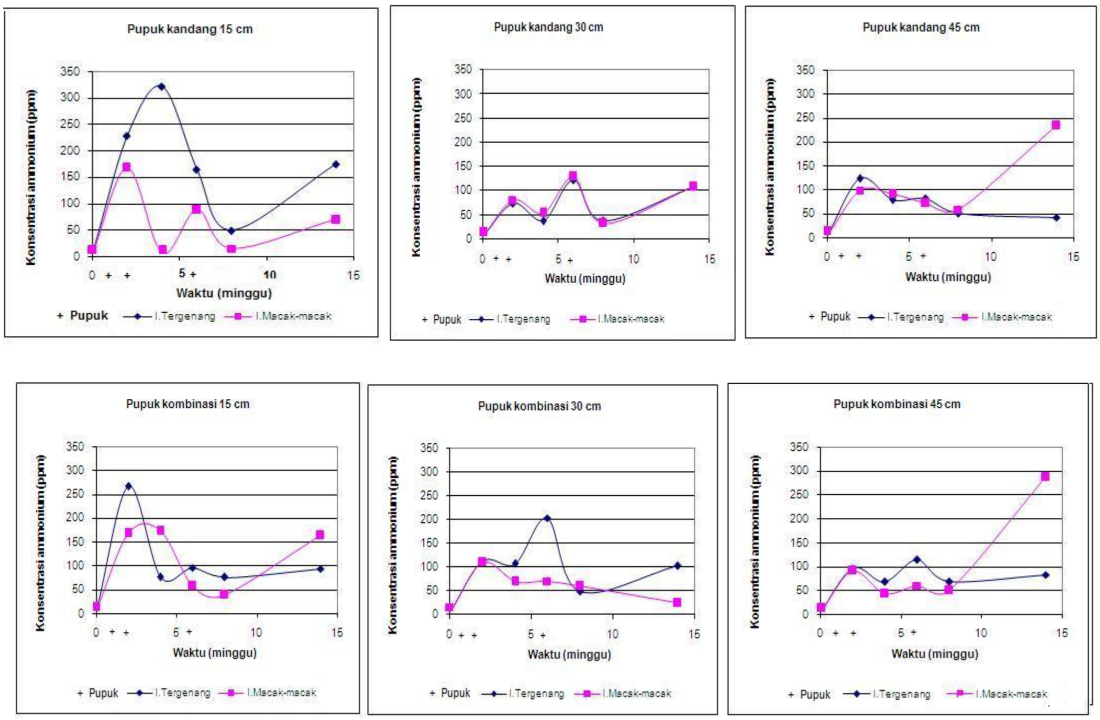

Figure 3.2 Distribution of ammonium concentration under two different irrigation methods of paddy rice soil

3. Rate of nitrate flow

Nitrate is another form of nitrogen in the soil and dissolves easily and can be carried away by the flow of mass water. Therefore, the movement of N in the saturated soil is dominated by the mass flow of water containing nitrate in a convective way. In saturated soil, the rate (flux) of water flow is determined by the gradient of energy potential and soil hydraulic conductivity. The hydraulic potential energy of water-soil system consists of pressure energy and the concentration of soil solution (soil water). The greater the gradient of hydraulic potential energy between two points of interest, the greater the flux (rate) of water flow occurs. Results of the experiment showed the principle that has been mentioned above.

There was a vertical downward movement of water containing nitrates from the upper layer to the lower layer. Since the hydraulic head of the FFI method is higher than the WEI method (indicated by the height of water ponding), so that the flux of water flow was also higher. Because the flowing water contains dissolved elements including nitrate, the flux of nitrate flow in the FFI method was also higher than the WEI method (Figure 3.3). This occured in both organic and combination fertilizer. For the combination of fertilizer, the flo rate difference is not significant.

These results also provide us indicators concerning effectiveness and the efficiency of fertilization. Organic fertilizer is more effective when combined with water-efficient irrigation methods (minimum flooded). For FFI method, most of nitrate transported downward away from the root zone of plants by the mass of water through percolation process, so can not be utilized by plants. Percolation process is more intensive, especially on new paddy rice fields, on which hard pan has not been formed yet. Therefore, N fertilizer requirement for a new developing paddy rice fields are relatively higher compared with the old developed rice fields.

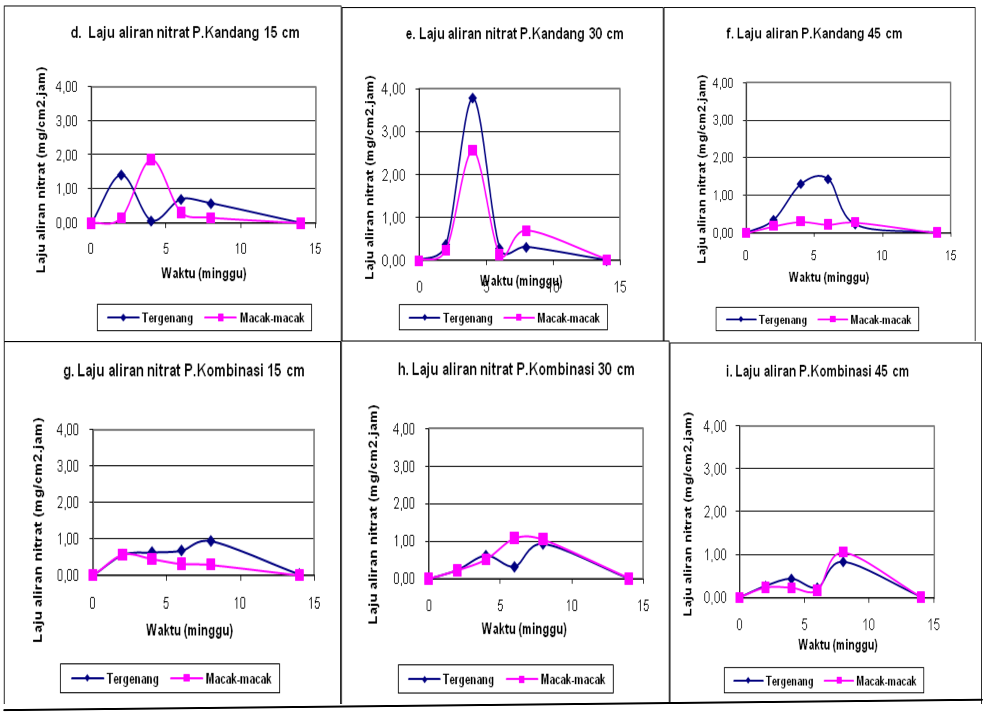

Figure 3.3. Rate of nitrate flow under two different irrigation methods of paddy soil

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4. Rate of ammonium flow

The rate of movement of ammonium was not much different from the rate of nitrate movement. Organic fertilizer on the soil under FFI method performs higher ammonium rate flow compared with the WEI method. This is especially true in the soil layer of 15 cm. At the the soil layers of 30 and 45 cm, show a similar flow rate pattern of ammonium, except at 45 cm layer at the beginning of week 10, the rate of ammonium flow was somewhat distorted. Flow rate of ammonium at WEI method is higher compared with the FFI method. The equilibrium principle of potential energy and water flow rate as that happened on nitrate movement, occures also in the the flow rate of ammonium.

The highest ammonium flow rate occures on the FFI method with manure fertilizer at a depth of 15 Cm, by 0.018 mg/cm^2-jam at vertical downward. This downward high flow rate of ammonium has lead a consequency of ammonium loss in the root zone, so that there was almost no chance for the crop to absorb the ammonium. The rate of ammonium flow is much influenced by the soil structure and water condition. Under high water flooding and there was no hard pan layer in the soil layer, the rate of downward flow of ammonium will tend to increase, pararel with the increase of water flow. Meanwhile, as there was an accumulation of caly mineral in the hardpan, some of the ammonium will be held by the clay mineral and hence not available for crops.

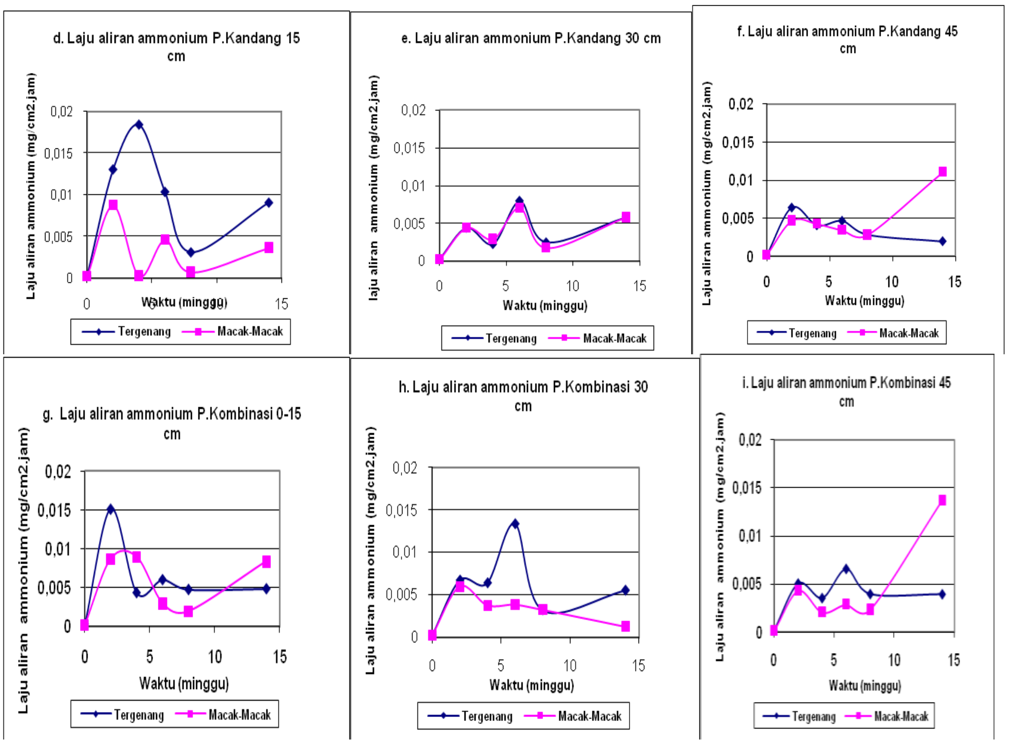

Figure 3.4 Rate of ammonium flow under two different irrigation methods of paddy soil

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5. Prediction of nitrate and ammonium concentration

Pattern of nitrate and ammonium concentration is then predicted by using the CDE model under value of K = 0.84 cm/hour, D = 24.62 cm^2/hour and R = 1.8, and the result is presented in Figure 3.5 and 3.6. The results show that the CDE model could be used for predicting ammonium concentration on the irrigated paddy soil for whole soil depths. However, the model only sensitive for predicting nitrate concentration for upper layer of the soil up to the depth of 15 cm. Modification some of the model parameters may be required in order to increase sensitivity of the model.

Relative concentration (C/Co) as an indicator of nitrate and ammonium concentration in the soil is still below the unity. This value indicates that there was an active chemical and biological transformation process in the soil layers below the soil surface. The graphs show that a peak of C/Co occured during the week of two and then decrease as the time increase. The nitrate concentration also increase as the increasing soil depth and reach a peak concentration at the soil depth of 20 cm, then the concentration decreases sharply as the increase of soil depth. There was no significant different in C/Co between the WEI and FFI irrigation method. This is because the prediction uses the same value of hydarulic coductivity and soil diffusivity under water saturated condition. Therefore, the different of the flux density between the two irrigation methods is relatively small.

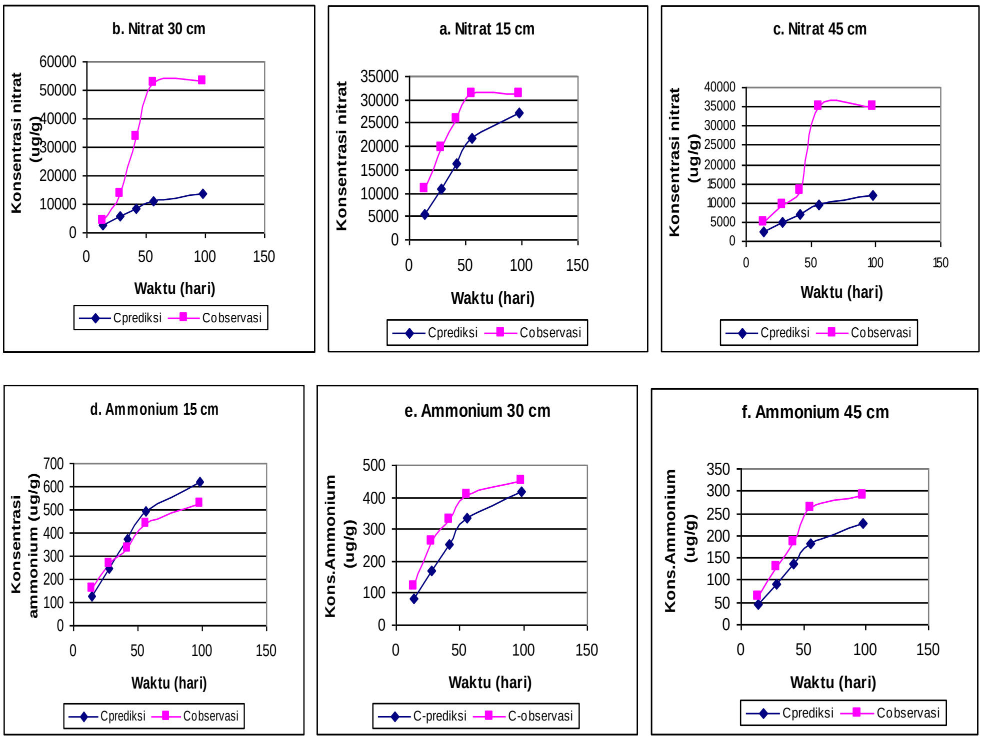

Figure 3.5 Prediction and observation of nitrate and ammonium concentration

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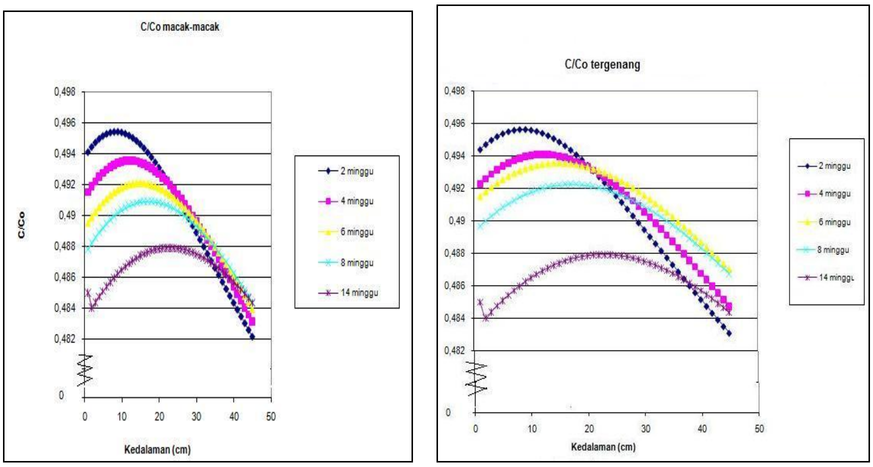

Figure 3.6 Prediction of nitrate as C/Co by using CDE model

CONCLUSIONS

1. The concentration and distribution of nitrate in the root zone (30 Cm) showed different patterns between WEI method and the conventional irrigation method (FFI). Nitrate concentration and availability for the crops under water-efficient irrigation (WEI) is higher than under full flooded irrigation (FFI) methods. However the ammonium concentration under the FFI is higher than under the WEI methods.
2. The rate of nitrate movement vertically upward on the soil under the WEI is higher than under the FFI method. While the rate of vertical downward movement of ammonium under the FFI is higher than the WEI methods.
3. The CDE model could be used for predicting ammonium concentration on irrigated paddy rice soil, but less sensitive for nitrate prediction. The nitrate and ammonium concentration which is expressed in relative concentration (C / Co) is tend to decrease in accordance with the increasing soil depth and time, both for the FFI and WEI methods.

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