Dynamics of nitrogen nutrients in lowland soils with some irrigation conditions to increase rice crop productivity

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Abstract. The level of water management influenced the efficiency of N-Urea fertilization for rice plants because rice plants could utilize only about 30-40% of the N fertilizer and the rest would be lost. The use of 15N isotope was one method to predict the movement of nitrogen from fertilizers. The objectives of this study were to study the dynamics of N nutrients in soil and plants with N-isotopes and to calculate the efficiency of water use in upland rice plants. This study used a Split Plot Design with the first factor level of water management and the second was N dose level. The N fertilizer was Urea fertilizer which was given an N15 tracer. P and K doses were determined based on soil nutrient status. The rice plants were Situpatenggang and DT15 Batan. The results of the study showed that soil water management with conventional irrigation was significantly better than cut irrigation. The maximum dose of N fertilizer in interrupted irrigation was reached at a dose of 228 kg/ha, and conventional irrigation doses reached 180 kg N/ha. Whereas the maximum dosage of N fertilizer in interrupted irrigation treatment was 198 kg/ha and conventional irrigation treatment was 159 kg N/ha.

1. Introduction
Sustained crop productivity and constant renewal become important when the supply of nutrients constraint to plant growth and development. Application of chemical fertilizers is necessary for enhancing crop yields but sustaining soil fertility and must be of the right type, dosage, time and method of fertilization. For example, nitrogen fertilization technology must pay attention to changes in N nutrient behaviour in paddy so that fertilization is more efficient. The source of N fertilizer is recommended in the form of ammonium (NH4+), put into the reduction layer and given 2-3 times. The main source of soil N is organic material which decomposes and produces anions that are able to form complex compounds with Fe and Al, so that these cations do not react with phosphate. The organic anion is capable of releasing phosphate which is fixed by Fe and Al. The application of P fertilizer should be carried out in conjunction with organic fertilizers so that nutrient P is not fixed by clay minerals or Ca ions. This decomposition process is carried out by fungi, bacteria and actinomycetes. At low pH bacteria and actinomycetes are less active while fungi are active. This resulted in a slow decomposition of organic matter so that the soil content of N was small. At neutral to high pH, bacterial activity, fungi and actinomycetes, so that the decomposition of organic matter is rapid.
The nutrient balance of paddy fields is highly dependent on plant varieties, level of management, nutrient supply and climate. The efficiency of N fertilizer in rice plants is relatively low, only around 60-70%. Nitrogen loss is mainly caused by denitrification, volatilization, leaching, and is washed away by surface flow. In Japan, N loss through denitrification is around 38%, washed 10% and a small portion through surface runoff. In addition, immobilization and fixation of ammonium cause nitrogen temporarily unavailable to plants and loss of N through both processes can reach 70%. Therefore, N fertilization must be given into the reduction layer several times to reduce N loss so that efficiency increases.

To improve the efficiency of N fertilization in rice plants, labelled N fertilizer (N15) will be used, which is useful for tracing N nutrient traces absorbed by plants and left in the soil. Using N15 isotopes can be known quantitatively and proportionally to the amount of nitrogen absorbed by plants, both from the soil and from N. Fertilizers. In N-fertilized soils, all N absorbed by plants originates from the soil, while on N-fertilized soils, then N nutrients absorbed by plants come from soil and fertilizer.

The limited availability of water for agriculture is caused by partial or total damage to vegetation that covers the land, which results in a decrease in soil retention against rainfall. Rainfall that is not evenly distributed according to space and time in most parts of Indonesia in many cases greatly affects the availability of water. Drought and water scarcity have occurred in almost all parts of Indonesia so that agricultural development requires an efficient, applicative and participatory water management strategy and the selection of food crops that are tolerant of water stress. The objectives of this study were (1) to study N dynamics in soil and plants with N-isotopes, (2) to calculate the efficiency of N fertilization in wetland rice, (3) to study water management to improve water use efficiency.

2. Materials and Method
The research of N nutrient management in lowland rice was using a Randomized Complete Block Design factorial of two factors. This research was conducted at greenhouse of ISRI Bogor and the field. The first factor was water management i.e: (1) intermittent, (2) conventional. The second factor was 4 N dose levels i.e: 0.45, 90, 135 kg N/ha using Urea fertilizer plus N15 tracer which was given to all treatments with the same dose. All treatments were repeated five times. Inpari 15 variety was used as rice plant indicator.

| Code | Water Management | Dosage of N Fertilizer |
|------|------------------|-----------------------|
| First Factor |                          |                       |
| D1    | Intermittent      | 0 kg N/ha             |
| D2    | Conventional      | 45 g N/ha             |
| Second Factor |                      | 90 g N/ha             |
| N0    |                   | 135 kg N/ha           |
| N4    |                   | 180 kg N/ha           |

The fertilizer of N in the form of urea was given twice, at 7-10 days after planting and at the formation of maximum tillers (30-35 days). The need for N plants was then monitored by the BWD. N15 fertilizer as a tracker was given in a dose of 20 mg / pot for all treatments. If the color of the leaves was below the scale of 4, urea fertilizer was needed to be added with the appropriate amount indicated on the BWD. P and K fertilizers were used as basic fertilizers in the form of SP-36 and KCl. The soil has low soil P
nutrient status (dose of 100 kg SP-36 / ha) and low soil K status (100 kg KCl/ha). Fertilizing P and K were given at the same time when planting. Fertilizers were given by spreading on the soil surface and then mixed to a depth of about 5cm.

Water management was carried out in two methods namely intermittent (5-7 days irrigated then 5-7 days dried). Water was given after the surface conditions in the pot have cracked hair (1-2 mm) or at a moisture content of about 25%. Conventional watering was done by inundating the surface of the pot with 2-3 cm high water until about 2 weeks before harvest. Prevention of pests, weeding and irrigation were carried out preventively by hand picking. Observations were made on: (1) growth (plant height and number of paddy tillers observed at 30, 60 and before harvest and (2) crop yields in the form of dry grain water content of 14% and dry weight of straw, (3) N nutrient uptake, P, K plants, (4) soil analysis before planting namely soil texture, pH of H$_2$O and KCl extract, organic C (Walkley and Black method), N-total (Kjeldahl method), P and K-HCl 25%, P available (Bray I), exchange cation (NH$_4$Ac extract pH 7), base saturation and cation exchange capacity (NH$_4$Ac extract pH 7). Analysis of soil after planting is pH H$_2$O and KCl, organic C (Walkley and Black method), N-total (Kjeldahl method), potential P and K (25% HCl extract), P available (Bray I extract), K-dd NH$_4$Oac extract; (5) fertilizing efficiency N, P, K. Plant response data and changes in soil properties were analyzed descriptively to see the relationship between the variables of soil chemistry and crop yield responses. This research was used Analysis of Variance (ANOVA) to find out the difference between treatments, followed by DMRT test at the level of 5% using the SPSS 16. To see the response of plants and determine the optimum dose, it was tested with multiple regression equations [1].

3. Results and Discussion

3.1. Characteristic of soil at green house
The used soil for the study was classified as Typic Haplaquerts [2], clay soil with the composition of 14% sand, 24% silt and 62% of clay, with neutral soil pH (6.7), high potential soil P (98 mg/100g) and K (32 mg/100 g), high available P (65.80 mg/kg), low soil-N, medium soil organic matter, high CEC and base saturation. [3] showed in flooded soils in Rhinau, France an increase in the content of soil organic matter decreased the value of soil redox potential with a correlation value of $r = -0.87$ caused by the consumption of large amounts of oxygen in the oxidation process that occurs in the soil to form organic compounds, so that soil conditions became increasingly reductive. The potential reduction in redox caused changes in macronutrient availability and H$_2$S production.
Table 2. The result of initial analysis of soil at green house of ISARI

| Parameter of soil      | value |
|------------------------|-------|
| pH H₂O                 | 6.74  |
| Carbon organic (%)     | 1.32  |
| Total of nitrogen (%)  | 0.09  |
| Ratio C/N              | 15    |
| P₂O₅ (mg 100 g⁻¹)      | 98    |
| K₂O (mg 100 g⁻¹)       | 32    |
| P-Bray1 (mg/kg)        | 65.80 |
| CEC (cmol/ kg⁻¹)       | 38.82 |

3.2. Plant Height at green house
Table 3 showed that Nitrogen fertilizer application was significantly different to increase plant height at three months after planting, especially for AWD irrigation treatment, but it was not significantly different for flooding irrigation dose. Increasing the level of the dose to 180 kg N / ha was not significantly increase the height of the plant

Table 3. The plant height of rice plant at 3 months after planting (MAP) (g/pot)

| Treatment | Water management | AWD irrigation | Flooding irrigation |
|-----------|-----------------|----------------|---------------------|
| 0 kg N/ha |                 | 96.67 b*)      | 108.27 a           |
| 45 kg N/ha|                 | 101.23 ab      | 110.13 a           |
| 90 kg N/ha|                 | 104.13 a       | 111.80 a           |
| 135 kg N/ha|                | 104.20 a       | 110.97 a           |

3.3. Weight of dry grain at green house
Weight of dry grain of Cianjur was presented in Table 4. Fertilization of N significantly increased the weight of dry grain. In line with the weight of dry straw, dried grain weight in flooding irrigation significantly higher than alternate wet and dry irrigation. N fertilization until a dose of 180 kg / ha has also significantly increased the weight of dry grain. An increase in grain dry weight by 74% compared to flooding irrigation without fertilizer N markedly better than AWD irrigation, it is because of textured soil heavy clay and clay minerals containing 2: 1 which will shrink when dry and when wet will swell. In the irrigation treatment when the soil in the dry condition, it would be cracked due to shrinking. It would interfere with the growth of the rice plant roots, so the flooding irrigation would be better than alternate wet and dry irrigation.
Table 4. Weight of dry grain of rice plant at 3 months after planting (MAP) (g/pot)

| Treatment   | Water management | AWD irrigation | Flooding irrigation |
|-------------|------------------|----------------|--------------------|
| 0 kg N/ha  |                  | 17.40 c       | 28.40 c            |
| 45 kg N/ha |                  | 25.13 b       | 36.00 bc           |
| 90 kg N/ha |                  | 26.40 ab      | 37.03 b            |
| 135 kg N/ha|                  | 32.37 ab      | 38.33 ab           |

The relationship between the dose of fertilizer N by weight of dry grain was shown by the following quadratic regression equation: $Y_{D1} = -0.0003x^2 + 0.1367x + 17.909$ ($R^2 = 0.96$) and $Y_{D2} = -2E-06x^2 + 0.0827x + 29.685$ ($R^2 = 0.89$). Increasing doses of fertilizer N in irrigation alternate wet and dry irrigation for up to 180 kg N / ha was still increasing the weight of dry grain. The maximum dose of fertilizer N was achieved at a dose of 228 kg / ha. While in flooding irrigation treatment fertilization until the dose 180 kg N / ha was still increasing the weight of dry grain (Figure 1).

![Figure 1](image_url)

**Figure 1.** The relationship between the dose of fertilizer N by weight of dry grain at green house

3.4. Characteristic of soil at field

Soil for field experiment activities had a clay texture, neutral pH, P and high potential, high P-available, low N-soil, medium soil organic matter, CEC and high KB. This land was classified as fertile soil.
### Table 5. The result of initial analysis of soil at field

| Parameter          | Value |
|--------------------|-------|
| Texture            | Clay  |
| Sand (%)           | 14    |
| Silt (%)           | 24    |
| Clay (%)           | 62    |
| pH H₂O             | 6.74  |
| 1 N KCl            | 6.21  |
| Organic material   |       |
| Organic-C (%)      | 1.32  |
| N-total (%)        | 0.09  |
| C/N                | 15    |
| HCl extract 25%    |       |
| P₂O₅ (mg 100 g⁻¹) | 98    |
| K₂O (mg 100 g⁻¹)  | 32    |
| P-Bray1 (mg/kg)    | 65.80 |
| 1 N NH₄OAc pH 7    |       |
| Ca (cmol⁺ kg⁻¹)    | 31.49 |
| Mg (cmol⁺ kg⁻¹)    | 6.75  |
| K (cmol⁺ kg⁻¹)     | 0.69  |
| Na (cmol⁺ kg⁻¹)    | 0.66  |
| CEC (cmol⁺ kg⁻¹)   | 38.82 |
| BS (%)             | >100  |

### 3.5. Plant Height at field

There was no real interaction between the dose of N fertilizer and the irrigation system for 4-week high growth parameters. The results showed that the height of rice plants increased with an increasing dose of N, but if the dose was excessive, it actually inhibits plant growth. In the interrupted irrigation condition, the highest plant height was achieved in the N3 treatment that was significantly different from the control. In continuous submerged systems, N1 treatment gave the best plant height. According to [4], Nitrogen was the most essential for plant development, growth and grain quality. Nitrogen was the most important nutrient constraint to the productivity of lowland rice. Nitrogen was the major input for higher productivity of rice. Low recovery of applied Nitrogen by the crop had been attributed to losses through denitrification, ammonia volatilization, runoff and immobilization. Nitrogen was the most essential for plant development, growth and grain quality. The highest plant height was reached at a fertilizer dose of around 90-135 kgN / ha. Conventional irrigation systems provide growth in plant height tend to be better than intermittent irrigation.

Based on Table 6, at 30 HST observations, the response of fertilizing N up to a dose of 180 kgN/ha to the number of Inpari 15 rice tillers tended to increase except in the treatment of N2 (90 kgN/ha). The best treatment for the interrupted irrigation system is the dose of N3, whereas in stagnant irrigation was the dose of N4. The number of tillers in the flooded water system was better than interrupted irrigation. N fertilization significantly increased the height of rice plants at 3 months after planting (BST) in interrupted irrigation treatment, whereas in conventional irrigation had no significant effect, although the height of rice plants in conventional irrigation was significantly higher than interrupted irrigation. Increasing the
dose of 90 kg / ha markedly increased plant height at 3 BST. A subsequent increase in dose to 180 kg N / ha did not significantly increase plant height.

Table 6. N fertilization response to the rice height of Inpari 15 rice plant age at harvest with two water management systems

| No | Treatment | Water management | Water management | Average |
|----|-----------|------------------|------------------|---------|
|    |           | Flooding irrigation | AWD irrigation |         |
| 1  | 0 kg N/ha | 96.67 b*)          | 108.27 a        | 102.47 B|
| 2  | 45 kg N/ha| 101.23 ab          | 110.13 a        | 105.68 AB|
| 3  | 90 kg N/ha| 104.13 a           | 111.80 a        | 107.97 A|
| 4  | 135 kg N/ha| 104.20 a        | 110.97 a        | 107.58 A|
| 5  | 180 kg N/ha| 104.77 a         | 110.13 a        | 107.45 A|
|    | Average   | 102.20 B        | 110.26 A        |         |

Remarks: Data in the column followed by the same letter means not significantly different at the 5% level based on the DMRT test.

N fertilization increased the number of Inpari 15 rice tillers, the higher the N dose, the higher the plant. The best N dose for interrupted and submerged irrigation systems was N4 (180 kgN / ha). Inundated irrigation systems tended to provide a higher number of tillers than interrupted systems. When compared to the response of N fertilization on the condition of clay and sandy soil, the response of N on clay soil was higher. This could be explained because on clay soil, nutrients such as N would be absorbed more strongly so that it was not easily lost due to the washing process. Conversely, sandy soil experiences Fe toxicity which could be seen from the physiological characteristics of the leaves.

3.6. Rice Yield

Weight of dry straw in nutrient and water management research for nitrogen fertilizer efficiency using soil was presented in Table 7. Fertilization of N significantly increased the weight of dry straw. The weight of a dry straw in conventional irrigation was significantly higher than interrupted irrigation. Fertilizing N up to a dose of 180 kg/ha markedly increased the weight of a dry straw.

Table 7. Weight of dry straw in nutrient and water management research for nitrogen fertilizer efficiency (g / pot)

| No | Treatment | Water management | Water management | Average |
|----|-----------|------------------|------------------|---------|
|    |           | Flooding irrigation | AWD irrigation |         |
| 1  | 0 kg N/ha | 27.77 b*)         | 35.67 b         | 31.72 C|
| 2  | 45 kg N/ha| 34.77 ab          | 41.33 b         | 38.05 B|
| 3  | 90 kg N/ha| 32.60 ab          | 43.67 ab        | 38.13 B|
| 4  | 135 kg N/ha| 37.27 a         | 43.40 ab        | 40.33 AB|
| 5  | 180 kg N/ha| 40.53 a         | 50.43 a         | 45.48 A|
|    | Average   | 34.59 B       | 42.90 A         |         |

Dry grain weight in nutrient and water management research for the efficiency of nitrogen fertilization using soil from Cianjur was presented in Table 8. Fertilization of N significantly increased the weight of dry grain. In line with the weight of dry straw, the weight of dried unhusked rice in conventional irrigation was significantly higher than interrupted irrigation. Fertilizing N up to a dose of 180 kg / ha also significantly increased the weight of the dry grain. An increase in dry grain weight by 74% compared to
without fertilizing N. Conventional irrigation was significantly better than interrupted irrigation, this was because the soil from Cianjur had a heavy clay texture and contained 2:1 clay minerals which when dry will shrink and when wet will expand. In the irrigation treatment was interrupted, if the soil is dry, it would be cracked due to contracting so that it will disturb the growth of the roots of rice plants, so the conventional irrigation treatment in Cianjur soil was better than interrupted irrigation.

Table 8. Weight of dry unhusked rice in nutrient and water management research for nitrogen fertilizer efficiency (g/pot)

| No | Treatment      | Water management | Average |
|----|----------------|------------------|---------|
|    |                | Flooding irrigation | AWD irrigation |         |
| 1  | 0 kg N/ha      | 17.40 c*)         | 28.40 c | 22.90 C |
| 2  | 45 kg N/ha     | 25.13 b           | 36.00 bc | 30.57 B |
| 3  | 90 kg N/ha     | 26.40 ab          | 37.03 b | 31.72 B |
| 4  | 135 kg N/ha    | 32.37 ab          | 38.33 ab | 35.35 AB |
| 5  | 180 kg N/ha    | 34.10 a           | 45.77 a | 39.93 A |
|    | Average        | 27.08 B           | 37.11 A |       |

The relationship between N fertilizer fertilization and dry grain weight was shown by the quadratic regression equation as follows: Y D1 = -0.0003 x^2 + 0.1367 x + 17,909 (R^2 = 0.96) and Y D2 = -2E-06x^2 + 0.0827x + 29,685 (R^2 = 0.89). Increasing the dose of N fertilizer in interrupted irrigation treatment up to 180 kg N/ha still increased the weight of the dry grain. The maximum dose of N fertilizer was reached at a dose of 228 kg/ha. Whereas in conventional irrigation treatment fertilization up to a dose of 180 kg N/ha still increase the weight of the dry grain (Figure 2).

Figure 2. Relationship between dose of N fertilizer with dry grain weight in nutrient and water management research for the efficiency of nitrogen fertilization
4. Conclusion
Soil water management with conventional irrigation was significantly better than cut irrigation. The maximum dose of N fertilizer in interrupted irrigation was reached at a dose of 228 kg/ha and conventional irrigation doses reached 180 kg N/ha, which improved the yield of harvested dry grain. Whereas the maximum dosage of N fertilizer in interrupted irrigation treatment is 198 kg / ha and conventional irrigation treatment is 159 kg N/ha. Saturated irrigation produced is the most efficient of water use and considered as alternative irrigation for upland rice area with water scarcity problem.

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