Root growth dynamics and grain yield of ten new plant type of rice lines under aerobic and flooded condition

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Abstract. Root growth dynamics of ten New Plant Type (NPT) of Rice lines under aerobic and flooded condition have been evaluated. This pot experiment involved two factors, i.e. NPT of rice (10 lines) and soil condition (aerobic and flooded). Variations between lines were found in root fresh weight, root volume and shoot dry weight. Aerobic condition significantly scaled down all parameters observed, except for root length. The interaction between NPT of rice line and soil condition was only significant in root dry weight. From the ten NPT rice lines evaluated, root dry weight of six lines (G1, G3, G7, G8, G9, G10) were significantly decreased in aerobic condition, whereas line G2 and G4 did not show any significant reduction. The other two lines (G5 and G6), on the contrary, showed higher root dry weight in flooded condition, but the values were lower than that of line G2. The highest harvest index (HI) value in flooded condition was shown by line G6, whereas in aerobic soil condition it was shown by line G4 and G5. The correlation value between shoot dry weight and grain weight per clump \( r = 0.65 \) was strong, and it was significantly and positively correlated.

1. Introduction
Rice is able to fulfill over 20% of the total calorie consumption of the global human population [1]. For the reason of having huge rice consumers, it is very easy to find rice fields in most Asian countries including Indonesia. The farmers of these rice producing countries commonly and traditionally cultivate this crop in flooded condition, which creates anaerobic system to the plant during its growth and development. However, some emerging problems such as climate change and fresh water scarcity may lead the gradual shifting of anaerobic rice cultivation system to aerobic system [2, 3, 4].

Rice production in 2013 increased by 2.22 million tons (3.22%) compared to the previous year [5]. Although there was an increase in rice yield and production, efforts to improve its quantity and quality should be continuously done in order to cover its increasing demand from time to time. Modifying the architecture or type of rice plant could be a promising alternative to improve yield [3]. The result of this modification, which is done by a plant breeder, refers to as New Plant Type (NPT) of rice. It is the result of hybridization between Indica and Japonica subspecies or their descendants [6].

Another potential factor defining the success of improving rice yield is cultivation technique. Rice is a semiaquatic plant which has the capability of maintaining its growth and development under oxygen limitation [7]. In other words, rice can actually be grown in either flooded condition (anaerobic) or unflooded condition (aerobic), especially in tropical areas. Some studies have shown that either aerobic or anaerobic soil condition, which is associated with water supply, is a critical factor during plant growth.
These different soil conditions would determine the performance of hybrid rice lines in terms of root and shoot development, yield, and harvest index. The performance of root systems and yield components have been evaluated on 10 NPT of rice lines of UNSOED in both aerobic and flooded conditions. It was suspected that these two different soil conditions would result in different root anatomy and morphology of the rice lines evaluated, as found in previous study [4]. These various responses might indicate adaptation of the new rice trait under aerobic condition.

This research aimed to: 1) assess the agronomic performance on ten NPT of rice lines, 2) examine the effects of soil condition (aerobic and flooded) on root systems and yield components, 3) examine the interaction between NPT of rice lines and soil conditions, 4) find an NPT of rice line with the highest harvest index, and 5) assess the correlation between plant growth and yield.

### 2. Materials and methods

This study was an experimental pot conducted at the Screen house (without shades) of the Faculty of Agriculture, University of Jenderal Soedirman (UNSOED), Karangwangkal, North Purwokerto, Banyumas Regency with the altitude of 110 m above sea level. It was completed approximately in 5 months, from September 2014 to January 2015.

The materials used in this experiment included 10 NPT of rice lines of Unsoed (Table 1), soil, water, and fertilizers (Urea, KCl, and SP-36). Some instruments used during the work were screen house, hoe, polybag, bucket, water hose, ruler, plastic rope, thermo-hygrometer, analytical balance, graduated pipette, scissors, plastic bag, paper bag, measuring tube, beaker glass, sprayer, self-adhesive label, test tube, and stationary.

| Line Code | Lines   | Parents            |
|-----------|---------|--------------------|
| G1        | 5-7-3-3-3 | Cimelati × Fatmawati |
| G2        | 5-7-2-3-4 | Cimelati × Fatmawati |
| G3        | 5-7-4-3-3 | Cimelati × Fatmawati |
| G3        | 16-4-3(6-4-2) | INPARI13 × Fatmawati |
| G5        | 16-4-3(9-4-1) | INPARI13 × Fatmawati |
| G6        | 4-4-5(2-4-5) | INPARI13 × Fatmawati |
| G7        | 16-4-2(5-4-6) | INPARI13 × Fatmawati |
| G8        | 21-4-2(18-4-2) | INPARI13 × Fatmawati |
| G9        | 21-4-2(14-4-3) | INPARI13 × Fatmawati |
| G10       | 17-4-2(15-4-4) | INPARI13 × Fatmawati |

This factorial experiment was arranged in a completely randomized block design (CRBD). The first factor was 10 NPT of rice lines and the second factor was soil condition i.e. flooded/anaerobic soil condition (A1) and aerobic soil condition (A2). There were 20 combinations of the treatments with 3 replicates, so that the total of 60 experimental units were prepared. As each unit comprised of 5 plants, the total of 300 plants were involved in this experiment.

The parameters observed were root length (cm), root fresh weight (g), root volume (ml), root dry weight (g), shoot dry weight (g), grain weight per clump (g), and harvest index. All data collected were analysed by F-test and it was continued to Duncan’s Multiple Range Test (DMRT) at 5% of significant level when differences occurred. Correlation test was also done to know the relation between two target variables.
3. Results and discussions

3.1. Variance analysis
The results of variance analysis (table 2) showed that there were differences in 10 NPT of rice lines examined in root fresh weight, root volume, root dry weight, and shoot dry weight, but there was no difference in root length and grain weight per clump. The treatment of soil condition (aerobic and flooded) caused differences in root fresh weight, root volume, root dry weight, and shoot dry weight, but it did not affect root length. Significant effect of interaction between line and soil condition was only found in the variable of root dry weight.

| Parameter                  | Treatment                     | L x SC |
|----------------------------|-------------------------------|--------|
| Root length                | ns                            | ns     |
| Root fresh weight          | vs                            | vs     |
| Root volume                | vs                            | vs     |
| Root dry weight            | s                             | s      |
| Shoot dry weight           | vs                            | vs     |
| Grain weight per clump     | ns                            | ns     |

vs = Very significantly different  
s = Significantly different  
ns = Not significantly different

3.2. Agronomic performance of 10 NPT of rice lines
The ten NPT of rice lines examined varied in terms of root fresh weight, root volume, and shoot dry weight (table 3). Similar findings were also found in some previous studies. These variations could be the result of different genetic potency of each variety/line in responding to the growing environment [11,12].

Average values followed by the same letter in the same row do not differ significantly by DMRT at 5%.

The results presented in table 3 defined that the root fresh weight of line G3 was higher than that of the other lines. The variations found in root fresh weight of the 10 lines evaluated could be caused by the most dominant genetic factor. The formation of total root system is controlled more genetically than that of environmental mechanism [13]. Nevertheless, soil environment could also affect the root morphology [4, 8].
In the parameter of root volume (Table 3), line G3 showed higher result compared to the other lines. The increase of root fresh weight in line G3 was also followed by the increase of root volume. This result indicates that root growth and development in line G3 is mostly controlled by the genetic factor.

Table 3 also shows that line G3 produced greater dry shoot weight compared to the other lines. Plants with high photosynthetic intensity are able to gain more dry weight. The increase in plant dry weight can mean that the plant grows and develops [4]. However, the increase in dry weight is not always followed by the increase of grain yield [11].

Agronomic performance shown by the 10 NPT of rice lines examined varied for each line in the variables of root fresh weight, root volume, and shoot dry weight. The line with a higher value of these evaluated parameters compared to the other lines was shown by line G3. However, this line did not show a better performance in the variables of root length and grain weight per clump. This might be caused by the presence of the most dominant genetic factor which gives effects on each line.

3.3. The effect of soil condition on plant growth

Table 4 shows that both aerobic and flooded conditions could cause differences in the variables of root fresh weight, root volume, and shoot dry weight. The line with a higher value of these evaluated parameters compared to the other lines was shown by line G3. However, this line did not show a better performance in the variables of root length and grain weight per clump, but there was no difference in the variable of root length.

| Soil condition | Root Fresh Weight (g) | Root Volume (ml) | Shoot Dry Weight (g) | Grain Weight/Clump (g) | Root Length (cm) |
|----------------|-----------------------|------------------|----------------------|------------------------|-----------------|
| Flooded        | 48.05 a                | 69.20 a          | 74.22 a              | 64.71 a                | 45.22           |
| Aerobic        | 22.86 b               | 35.27 b          | 51.45 b              | 44.32 b                | 44.20           |

Average values followed by the same letter in the same row do not differ significantly by DMRT at 5%

Table 4 shows that root fresh weight increased as much as 48.05 g in flooded soil condition. This improvement might be related to water absorption. Root fresh weight could be used to evaluate the ability of plants to absorb water [14]. This parameter is suitable for defining the total biomass of the root in the soil. The need of water in plants can be satisfied through water absorption mechanism performed by the roots. Water availability in soil and the ability of roots to absorb water will affect how much water can be absorbed by the roots in such a way that it highly affects the root fresh weight.

Root volume also increased as much as 69.20 ml in flooded soil condition (table 4). It is presumed that it was the result of rice root system which forms more root fibers in anaerobic state than that of aerobic condition. The increase of root volume also strongly related to the effects of genotypic (G) and environmental (E) factors. Every factor of the environment has a potency to cause different performance associated with G x E interaction [10].

Shoot dry weight presented in table 4 also increased as much as 74.22 g in flooded soil condition. It leads to the assumption that the shoot growth was optimum in the given condition. As water is one of the essential raw materials for photosynthesis, its deficiency will suppress photosynthesis rate, which is mainly caused by its effect on the turgidity of stomatal guard cells and push the stomata to close [13]. Many studies showed the result of photosynthesis will determine plant dry weight. If assimilate translocation inside the plant is maintained proportionally, plant dry weight will also increase.

Grain weight per clump (table 4) was high in flooded soil condition, which was 64.71 g. This yield increase might due to the availability of sufficient water for the plant during its growth. Crops need water constantly for their consistent growth and development. The effects of water deficiency on the yield may vary. During vegetative stage, any water deficiency will suppress the rate of leaf expansion and leaf area index in the next stage. Water deficiency during grain filling decreases grain yield as the photosynthesis process becomes slower. Extreme water deficiency will cause the stomata to close, which then reduce the supply of CO2 and decrease dry weight production [15].
Based on the result of this study, flooded soil condition was able to improve root fresh weight, root volume, shoot dry weight, and grain weight per clump. The reason is because the surrounding water fulfilled the plant need during the period of growth. Physiological process occurred in plants is mostly related to the supply of water and other materials (molecules or ions) that dissolved in water [13]. Water deficiency will disturb physiological and morphological activities in such a way that the growth is adversely affected. Continuous water deficiency will lead to irreversible changes and plants will die eventually [15]. Another benefit of flooded soil condition if compared to aerobic condition is its ability to suppress the growth of weeds [16].

3.4. Interaction effect between lines and soil condition on root dry weight

Plant growth is controlled by two main factors, i.e. genetics and environment. Genetic factor is related to the character/behaviour inheritance of the plant, whereas environmental factor is related to the condition where the plant grow. Each plant variety has different ability in utilizing growth facilities and the ability to adapt with surrounding environment, and it affects plant yield potency [10]. The interaction between lines and its environment (aerobic and flooded soil condition) is presented in table 5.

Table 5. Interaction effect between lines and soil conditions on root dry weight

| Line Code | Soil Condition | Flooded | Aerobic |
|-----------|----------------|---------|---------|
|           |                | G1      | G2      | G3      | G4      | G5      | G6      | G7      | G8      | G9      | G10     |
|           |                | 26.33   | 27.10   | 43.37   | 13.47   | 7.97    | 15.41   | 23.22   | 15.40   | 16.77   | 14.37   |
|           |                | abx     | bx      | bx      | bx      | c       | bcx     | bxc     | bx      | bxc     | bxc     |
|           |                | 9.50    | 20.67   | 12.80   | 8.33    | 15.07   | 19.53   | 6.80    | 4.53    | 7.97    | 5.90    |
|           |                | aby     | by      | aby     | abx     | bx      | bx      | by      | bx      | abx     | bx      |

Average values followed by the same letter in the same row do not differ significantly by DMRT at 5%.

The interaction between lines and both aerobic and flooded conditions occurred in line G1, G3, G7, and G8 on the parameter of root dry weight. In flooded soil condition, there was an increase in root dry weight, which followed by the increase in root fresh weight and root volume among the lines and soil conditions examined. It shows that the line with adaptive ability in flooded soil condition was able to increase root weight.

A previous study also found that root system in flooded soil condition was better compared to that of aerobic condition in a way that water needed by plants in flooded soil condition was fulfilled. Conversely, water supply in aerobic condition is limited. Although aeration and oxygen supply in aerobic soil condition are better, but weeds grow well and causes competition of nutrients and water between them and the crops. It eventually suppresses the growth of the plant because nutrients and water which can be absorbed become limited [16].

3.5. Harvest index average value of ten NPT of rice lines

The average value of harvest index presented in Table 6 shows that the highest harvest index value in flooded soil condition was shown by line G6, which was 0.45. In aerobic soil condition, whereas, it was shown by line G4 with the value of 0.46. Both values were categorized quite high. The highest harvest index of rice is 0.56 out of 0.17 – 0.56 in a range. This variation occurs due to differences in plant cultivation system [17]. The lines which have high harvest index are expected to produce high grain weight, because harvest index determines the ratio of assimilate distribution between harvested biomass and total biomass [15].
Table 6. Harvest index average value of ten NPT of rice lines in different soil conditions

| Line Code | Flooded | Aerobic |
|-----------|---------|---------|
| G1        | 0.33    | 0.31    |
| G2        | 0.36    | 0.34    |
| G3        | 0.39    | 0.30    |
| G4        | 0.35    | 0.46    |
| G5        | 0.42    | 0.43    |
| G6        | 0.45    | 0.43    |
| G7        | 0.41    | 0.38    |
| G8        | 0.40    | 0.44    |
| G9        | 0.43    | 0.38    |
| G10       | 0.40    | 0.35    |

Numbers followed by the highest value at the same row define the greatest harvest index average value.

This high harvest index value defined that the photosynthetic rate is more efficient in producing yield biomass. The crop with high photosynthesis efficiency and harvest index will produce the high economic weight. Harvest index could also be used as an indicator to improve more effective result as it is related to the yield [2][4]. The accumulation of dry biomass reflects the ability of plants to capture energy from sunlight through photosynthesis, as well as the interaction with the environmental factor for plant growth [13].

3.6. Correlation

Correlation is a single number that describes the direction and degree of relation between two or more variables. The direction is determined by positive or negative relation, whereas the degree of relation is defined by the value of correlation coefficient (Steel and Torrie, 1980). The relation between two or more variables is positive if the value of both variables moves in tandem, so if one variable increases, the other variable also increases, and if the value of one variable decreases, the other value also decreases.

Table 7. Correlation between shoot dry weight, root dry weight, root volume, and grain weight per clump.

| Agronomic Character                  | Correlation Coefficient |
|--------------------------------------|-------------------------|
| Shoot dry weight-Grain weight per clump | 0.65 *                  |
| Root dry weight-Grain weight per clump     | 0.49 ns                  |
| Root Volume-Grain weight per clump        | 0.45 ns                  |

s = significantly different  
ns = not significantly different

In this study, correlation test was done to evaluate the relation between an agronomic character i.e. grain weight per clump with some other agronomic characters including shoot dry weight, root dry weight, and root volume (Table 7). The value presented in Table 7 showed a significant and positive correlation between shoot dry weight and grain weight per clump. However, grain weight per clump did not correlate with both root dry weight and root volume. The criteria of correlation strength are divided into some categories i.e. no linear relationship (0), a weak uphill (positive) relationship (+0.30), a moderate uphill (positive) relationship (+0.50), strong (+0.70) and perfect uphill (positive) relationship (Exactly +1) [19].

Table 7 shows that shoot dry weight was significantly and positively correlated with grain weight per clump \( r = 0.65 \), and this correlation was categorized as strong. It means that shoot dry weight
affects strongly on the grain weight per clump. The correlation shown by these two characters was positive, which determined that the increase in shoot dry weight was followed by the increase in grain weight per clump. Distribution of dry mass in plants is apportioning of photosynthetic products into plant organs both vegetative and generative structures. The photosynthate translocated into vegetative organs including leaf, shoot, and root is stored as a food storage when the plant reaches generative stage. Some of the photosynthates are used to develop generative organs such as tassel, and the rest is translocated into the grain [15].

4. Conclusions and recommendations
Among all ten lines evaluated, line G3 presented a better agronomic performance compared to the other lines. Flooded soil condition was able to improve the variables of root fresh weight, root volume, shoot dry weight, and grain weight per clump. The interaction between line and soil condition was only found in the variable of root dry weight. The highest harvest index value in flooded soil condition was shown by line G6, whereas in aerobic soil condition was shown by line G4. The correlation value between shoot dry weight and grain weight per clump \((r = 0.65)\) was strong, and it was significantly and positively correlated. Further study on these rice lines both in screen house and field by considering the water level is needed to obtain more consistent results.

References
[1] Chaudary R C and Tran D V 2001 Speciality Rices of the World: Breeding, Production and Marketing (Plymouth, UK: Science Publishers, Inc.) pp 3–14
[2] Kato Y, Kamoshita A, Yamagishi J and Abe J 2006 J. Plant Prod. Sci. 9 422–34
[3] Haryanto T A D, Suwarta S and Yoshida T 2008 J. Plant Prod. Sci. 11 96–103
[4] Phule Amol S, Kalyani M, Barbadikar, Madhav M S, Subrahmanyam D, Senguttuvel P, Prasad Babu M B B and Ananda K P 2019 J. Physiol.Molec. Biol. of Plants 25 197–205
[5] Central Bureau of Statistics 2014 The Production of Maize, Rice, and Soybean (Prediction Value 1 Year 2014) Retrieved from http://www.bps.go.id/brs_file/ aram_01juli14.pdf. Accessed on 2 Sept 2014
[6] Abdullah B S, Tjokrowidjojo and Sularjo S 2008 J Litbang Pertanian 27 1–9
[7] Das A and Uchimiya H 2002 J. Plant Res. 115 315–20
[8] Bengough A G, Mc.Kenzie B M, Hallett P D and Valentine T A 2011 J. Exp. Bot. 62 59–68
[9] Zaman N K, Abdullah M Y, Othman S and Zaman N K 2018 J. Rice sci. 25 82–93
[10] Fehr W R 1987 Principles of Cultivar Development: Theory and Technique (London: Collier Macmillan Publishers) pp249–59
[11] Sreedhar S, Reddy T D and Ramesha M S 2011 Intl. J. Plant Breeding and Genetics 5 194–208
[12] Satoto, Rumanti J A and Widayastuti Y 2016 J. Agrivist 38 33–9
[13] Salisbury F B and Ross C W 1995 Plant Physiology-Indonesian version (Bandung: ITB) p 241
[14] Hazrat Ali M, Khatun M M, Mateo L G 2004 J. Geo-Env. 4 23–30
[15] Gardner F, Pierce P R B and Mitchel R L 1991 Physiology of Crop Plants-Indonesian version (Jakarta: Universitas Indonesia Press) p 428
[16] Ismail A M, Johnson D E, Ella E S, Vergara G V and Baltazar A M 2012 AoB Plants 10.1093/aobpla/pls019
[17] Yang J and Zhang J 2010 J.Exp. Botany 61 3177–189
[18] Steel R G D and Torrie J H 1980 Principles and Procedures of Statistics: A Biometrical Approach (New York: McGrow-Hill) pp 401–437
[19] Rumsey D J Statistics for Dummies Retrieved from www.dummies.com/education/math/ statistics/statistics-workbook-for-dummies-cheat-sheet/ Accessed on 2 Sept 2018