

CRITICAL VARIABLES OF MORPHO-PHYSIOLOGICAL RICE PLANT UNDER STAGNANT FLOODING CONDITIONS

Variabel Kritis Morfologi Tanaman Padi pada Kondisi Cekaman Genangan

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ABSTRACT

Stagnant flooding (SF) stress has contributed decreasing rice production in Indonesia. The study aimed to explore critical variables of rice growth that contribute to the decreasing grain yield under SF conditions and a common irrigation system (control). The experiment was arranged in a complete randomized block design with four replications to test 10 rice genotypes (Inpari 30 Ciherang Sub-1, Inpara 3, Inpara 4, Inpara 8, IRR1119, IRR1154, IR42, IR14D121, IR14D157, and Tapus). The water depth was managed according to the farmer's practices for control, while for SF plots the standing water depth was gradually increased from 35 days after transplanting and was maintained at 50 cm until harvest. Results showed that plant height, tillering ability, leaf greenness, panicle number per hill and grain filling percentage were critical growth variables that affect grain yield at optimal conditions. The yield of the 10 genotypes decreased by 25–50% under SF conditions. Inpara 3 had the stable yield in those two watering conditions. Therefore, it could be used as a check variety for SF condition. Inpara 9 and IRR1119 experienced decreased yield of more than 50% under SF conditions. The key factors determining the decreased yield were tillering ability and green leaf level. Optimization of the two variables at SF conditions will largely determine rice yield associated with panicle number per hill and grain number per panicle. Results of the study are useful as preliminary recommendations for designing new variety and cultivation techniques to reduce the impact of SF stress on rice yield.

[Keywords: critical variable growth, rice, stagnant flooding stress, submergence tolerant genotype]

ABSTRAK

Cekaman rendaman memberikan kontribusi terhadap penurunan produksi padi di Indonesia. Penelitian bertujuan untuk mengetahui variabel kritis pertumbuhan tanaman padi yang berkorelasi positif terhadap hasil, baik pada lahan sawah irigasi pada umumnya (kontrol) maupun dalam kondisi tercekam rendaman. Perlakuan disusun menggunakan rancangan acak kelompok empat ulangan untuk menguji 10 genotipe padi (Inpari 30 Ciherang Sub-1, Inpara 3, Inpara 4, Inpara 8, IRR1119, IRR1154, IR42, IR14D121, IR14D157, dan Tapus). Pengaturan air pada kontrol dilakukan sesuai praktik petani. Sementara untuk perlakuan rendaman, ketinggian air dinaikkan

secara bertahap sejak 35 hari setelah tanam dan dipertahankan pada 50 cm hingga panen. Hasil penelitian menunjukkan bahwa tinggi tanaman, pembentukan anakan, tingkat kehijauan daun, jumlah malai per rumpun, dan persentase gabah isi merupakan variabel kritis pertumbuhan yang mempengaruhi hasil gabah pada kondisi optimal.

Hasil gabah sebagian besar genotipe yang diuji menurun 25–50% pada kondisi cekaman genangan. Hasil gabah Inpara 3 pada kedua kondisi lingkungan tumbuh relatif setara dan berpotensi menjadi varietas cek pada kondisi genangan. Sementara Inpara 9 dan IRR1119 hasilnya menurun lebih dari 50% pada kondisi terendam. Faktor kunci yang menjadi penentu penurunan hasil padi pada kondisi cekaman genangan ialah kemampuan tanaman membentuk anakan dan kehijauan daun. Optimalisasi kedua variabel tersebut pada kondisi tercekam genangan sangat menentukan hasil gabah, khususnya untuk komponen jumlah malai per rumpun dan jumlah gabah per malai. Hasil penelitian ini bermanfaat untuk membuat rekomendasi awal dalam merancang varietas baru dan teknik budidaya untuk mengurangi dampak cekaman genangan terhadap hasil padi..

[Kata kunci: variabel kritis pertumbuhan, padi, cekaman genangan, genotipe toleran genangan]

INTRODUCTION

Stagnant Flood (SF) is one of the obstacles that decreases rice production in Indonesia. A total of 102,000 ha of rice fields were flooded in the planting period of October–March 2015 and in 2016 the flooded area reached 31,900 ha (Rachman 2016). It indicates the increasing submergence phenomenon facing Indonesian agriculture, since this stress reported to have significant yield reduction (Singh, Mackill and Ismail 2011; Nugraha et al. 2013), especially in plant growth (Yu et al. 2012; Vergara et al. 2014).

Submerged conditions inhibit photosynthesis and aerobic respiration in plants, thus forcing plants to move to anaerobes as a survival mechanism (Fukao and Bailey-Serres 2004; Fukao et al. 2019). Lack of molecular oxygen (O₂) changes cellular metabolism and further decreases plant productivity (Fukao et al. 2019). Various

morphological and physiological characters contributing to high yield include the amount of “zinc” shown by the spikelet number, large leaf area and leaf area index, high net assimilation rate, slow senescence process, lodging resistance, high biomass accumulation, and large carbohydrates able to translocate from the vegetative part to panicles during the grain filling phase (Zhang et al. 2009). Different patterns shown when submergence stress occur on plant mechanism relating to lower ADP-glucose pyrophosphorylase activity; it significantly reduced starch accumulation and carbohydrate as well as the main factor for yield pinalty (Adak et al. 2011). Under submerged conditions, survival rate, root elongation, root dry weight, and chlorophyll content were the first signal regarding on plant response (Bui et al. 2019). However, submerged conditions have more effect on delaying root growth recovery than leaves (Luo et al. 2011).

Rice varieties tolerant to submerged conditions had been released in Indonesia such as Inpari 30 Ciherang Sub1 (Nugraha et al. 2017) and Inpara (for swampy ecosystem) such as Inpara 1 to Inpara 8 (Sasmita et al. 2020). Sub1 is a tolerant gene for submergence occurring at early seedling stage up to a week before flowering (Ismail et al. 2013). However, there was no adequate information related to sub1 enactment (Sarkar et al. 2009) especially critical variables that cause these varieties to adapt to submerged conditions (Adak et al. 2011; Bui et al. 2019).

The study aimed to evaluate critical variables of rice plant under optimum and SF conditions which have correlation to yield. This information is useful for breeders as a selection criterion for obtaining lines tolerant to SF environment and preliminary recommendations for designing cultivation techniques to reduce the impact of SF on rice production.

MATERIALS AND METHODS

The research was carried out in two irrigation environments (SF artificial pond and regular irrigated lowland paddy field as a comparison) in Sukamandi Field Station, Subang, West Java (6°21'1.71" S Latitude and 107°39'17.44" E Longitude) at two seasons (2015/2016 and 2017/2018). The rice genotypes in each irrigation environment were arranged in a randomized complete block design (RCBD) with four replications. The rice genotypes tested were Inpari 30 Ciherang Sub-1, Inpara 3, Inpara 4, Inpara 8, IRRI119, IRRI154, IR42, IR14D121, IR14D157, and Tapus which known as submergence tolerant genotypes.

The plot size for each treatment was 2.8 m x 5.0 m. Rice seedlings were transplanted at 21 days after sowing, 2–3 seedlings per hole using 20 cm x 20 cm planting

distance. The applied fertilizer dosage consisted of 90 kg ha⁻¹ N, 22 kg ha⁻¹ P₂O₅, and 41 kg ha⁻¹ K₂O. P and K fertilizers were applied entirely at 7–10 days after transplanting (DAT), while 55% N was applied at the first and 45% at the second application (30 DAT). Watering in regular field was carried out according to farmers' practice, while for SF treatment, the standing water was increased from 0 to 35 DAT and maintaining at 50 cm until harvest (Figure 1).

Parameters observed were plant height, tiller number, leaf greenness by SPAD Minolta 502, panicle number per hill, grain number per panicle, grain filling percentage, 1000 grain weight and grain yield (t ha⁻¹). Different environments were tested using the T test. Spearman correlation test was carried out for all observed variables to find out the critical variables during growth stage in each environment (control/regular irrigation and SF).

RESULTS AND DISCUSSION

Yield Comparison Between Control and Sutagnant Flood Stress

Stagnant Flood (SF) stress significantly reduced rice yield compared to control. T-test results from two seasons showed that the average yield of the 10 rice genotypes under SF conditions was significantly lower than that of the control, which was 4.49 t ha⁻¹ compared to 6.70 t ha⁻¹ in the first season and 3.45 t ha⁻¹ compared to 6.09 t ha⁻¹ in the second season (Table 1).

Several genotypes were able to provide relatively equal yield in both watering conditions (Figure 2). The 1:1 diagram showed the yield comparison of control and SF conditions. The point closed to the 1:1 line meant that the yield in both conditions were equal. The decreasing yield under submerged conditions was indicated by the shifting of point position to the left of the 1:1 line. Most of the genotypes experienced 25–50% decreasing yield under SF conditions compared to the control, except Inpara 8

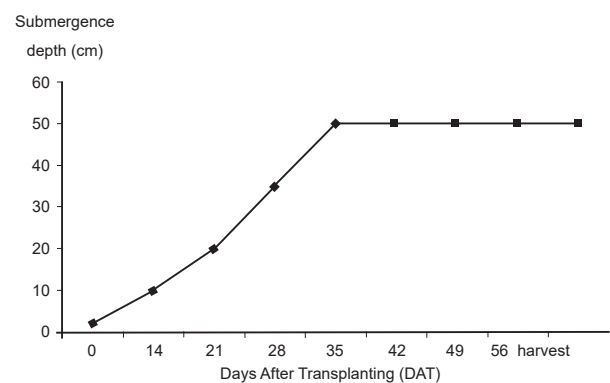


Fig. 1. Stagnant Flood (SF) level adjustment chart.

Table 1. T-test results of the rice yield (t ha⁻¹) under stagnant flood (SF) and optimum irrigation.

| | 2015–2016* | | 2017–2018** | |
|------------------------------|------------|-------|-------------|-------|
| | Control | SF | Control | SF |
| Mean | 6.705 | 4.490 | 6.087 | 3.454 |
| Variance | 1.273 | 0.285 | 0.424 | 0.282 |
| Observations | 10 | 10 | 10 | 10 |
| Pooled variance | 0.353 | | | |
| Hypothesized mean difference | 0 | | | |
| df | 13 | | 18 | |
| t Stat | 5.613 | | 9.911 | |
| P (T<=t) one-tail | 4.22 E-05 | | 5.12 E-09 | |
| t Critical one-tail | 1.771 | | 1.734 | |
| P(T<=t) two-tail | 8.44 E-05 | | 1.02 E-08 | |
| t Critical two-tail | 2.160 | | 2.101 | |

*t-Test: two-sample assuming unequal variances

**t-Test: two-sample assuming equal variances

and IRRI119 which the yield decreased more than 50% in 2017–2018 and Inpara 3 which had nearly equal yield in both conditions in 2015–2016.

Critical Growth Variables on Irrigated Fields (Control)

Spearman correlation test showed that growth variables (plant height, tillering ability, leaf greenness, panicle number per hill, and grain filling percentage) had a positive correlation with grain yields (Table 2). Furthermore, these variables were correlated with grain number per panicle and 1000 grains weight. Micro-environmental conditions would influence plant mechanism processes during growth stages which could be seen in differences in posture, dry matter accumulation, leaf greenness, etc (Roy et al. 2012; Li et al. 2015). Leaf greenness at the early vegetative phase turned out to have a positive correlation to the leaf greenness afterwards. Leaf greenness correlated with N availability (Wang et al. 2014) and chlorophyll content (Lin et al. 2010). Nitrogen controlled some important growth and physiological processes affecting yield such as light interception and photosynthesis capacity, dry matter partitioning, and leaf area index (Wang et al. 2014).

To increase assimilate accumulation, leaves and panicles were the most important “source” and “sink”, especially in the filling phase until maturity (Wei et al. 2018). Meanwhile, panicle number per hill and grain filling percentage were found to be correlated with grain yield. Low grain filling percentage was one of the cultivation problems that reduces yield by 20–30%. This void was caused by genetic and non-genetic factors. Genetic factors could be improved through breeding, while non-genetic

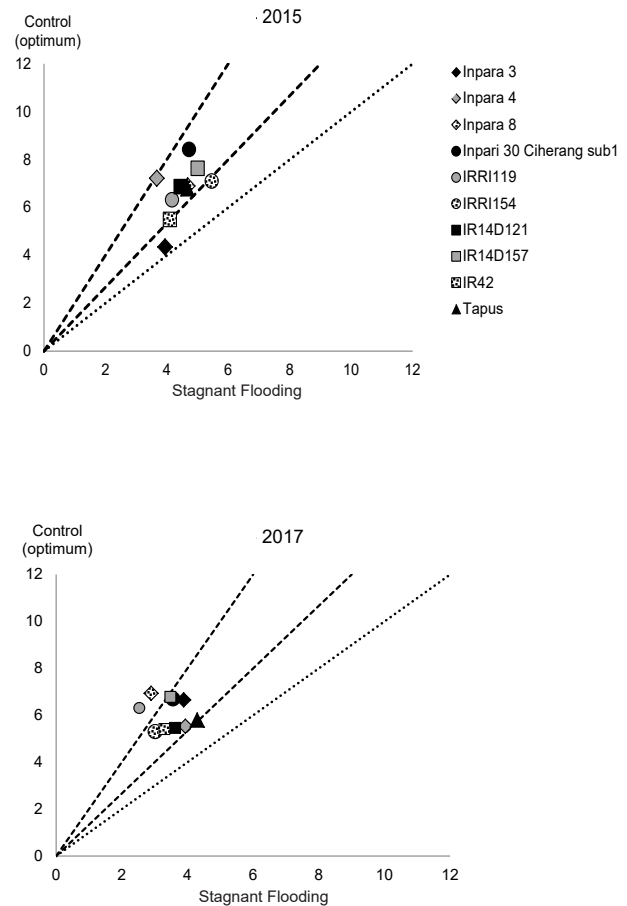


Fig. 2. Grain yield of some rice genotypes under optimum irrigation and stagnant flooding conditions, 2015/2016 and 2016/2017.

factors through environmental management or cultivation technique (Abdullah, Tjokrowidjojo and Sularjo 2008; Agustiani and Hikmah 2017).

Critical Growth Variables on Stagnant Flooding (SF) Stress

The growth variables that significantly correlated with yield were tillering ability, leaf greenness, panicle number per hill, and grain number per panicle (Table 3). The declining yield in SF conditions was significantly due to decreasing panicle number (Kato et al. 2014). A small panicle number will be significantly followed by an increase in grain number per panicle. The grain number per panicle is an important index in screening new varieties (Gong et al. 2018). This variable was also linearly influenced by tillering ability during the growing period.

The interaction between environmental factors and cultivation techniques significantly affected tiller number (Anggraini et al. 2013; Moeller et al. 2014)

Tabel 2. The Spearman correlation test result on various rice plant growth variables in both water condition, 2015.

| SF 2015 | AN14 | AN21 | AN28 | AN35 | AN42 | AN49 | SPAD14 | SPAD21 | SPAD28 | SPAD35 | SPAD42 | SPAD49 | TI | MARP | ISI100 | GBHMA | B1000 | GKG |
|---------|------|--------|--------|--------|--------|--------|--------|---------|---------|---------|--------|--------|---------|---------|--------|---------|---------|---------|
| AN14 | 1 | 0.80** | 0.69** | 0.63** | 0.57** | 0.61** | -0.33* | -0,2 | -0,28 | -0.30* | -0,28 | -0,02 | -0,16 | 0.32* | 0,12 | -0,15 | -0.37* | 0,09 |
| AN21 | | 1 | 0.68** | 0.76** | 0.71** | 0.72** | -0,2 | -0,28 | -0.38* | -0.41** | -0.32* | -0,02 | -0,27 | 0.53** | 0,08 | -0,29 | -0.36* | 0,21 |
| AN28 | | | 1 | 0.74** | 0.70** | 0.69** | -0,16 | -0,17 | -0,25 | -0,16 | -0,2 | -0,18 | -0,11 | 0.53** | 0,28 | -0.34* | -0,29 | 0,24 |
| AN35 | | | | 1 | 0.86** | 0.88** | -0,21 | -0.36* | -0.42** | -0.42** | -0,24 | -0,08 | -0,22 | 0.63** | 0,07 | -0,26 | -0.34* | 0.32* |
| AN42 | | | | | 1 | 0.98** | -0.32* | -0.46** | -0.43** | -0.44** | -0,27 | -0,18 | -0,1 | 0.53** | 0,04 | -0,17 | -0,28 | 0.31* |
| AN49 | | | | | | 1 | -0.33* | -0.41** | -0.44** | -0.48** | -0,29 | -0,14 | -0,13 | 0.57** | 0,02 | -0,21 | -0.33* | 0,29 |
| SPAD14 | | | | | | | 1 | 0.3* | 0.50** | 0.35* | 0,15 | 0,15 | -0.30* | -0,01 | -0,07 | -0,24 | 0,01 | -0,28 |
| SPAD21 | | | | | | | | 1 | 0,27 | 0.59** | 0,01 | 0.47** | -0,17 | -0.34* | 0,15 | 0,03 | 0,06 | -0,24 |
| SPAD28 | | | | | | | | | 1 | 0.58** | 0.55** | 0,13 | -0,19 | -0.43** | -0,16 | 0,01 | 0,02 | -0.49** |
| SPAD35 | | | | | | | | | | 1 | 0.42** | 0,29 | -0,28 | -0.44** | -0,09 | 0,08 | 0,05 | -0.37* |
| SPAD42 | | | | | | | | | | | 1 | 0,05 | -0,18 | -0,28 | -0,05 | 0,02 | 0,06 | -0,29 |
| SPAD49 | | | | | | | | | | | | 1 | -0.44** | -0,03 | -0,07 | -0,12 | -0,05 | 0,01 |
| TI | | | | | | | | | | | | | 1 | -0.32* | 0,02 | 0.40* | 0.47** | 0,14 |
| MARP | | | | | | | | | | | | | | 1 | 0,2 | -0.53** | -0.2656 | 0.53** |
| ISI100 | | | | | | | | | | | | | | | 1 | -0.41** | 0.35* | 0,29 |
| GBHMA | | | | | | | | | | | | | | | | 1 | -0,01 | 0,06 |
| B1000 | | | | | | | | | | | | | | | | | 1 | 0,29 |
| GKG | | | | | | | | | | | | | | | | | | 1 |

| OPTIMUM 2015 | AN14 | AN21 | AN28 | AN35 | AN42 | AN49 | SPAD14 | SPAD21 | SPAD28 | SPAD35 | SPAD42 | SPAD49 | TI | MARP | ISI100 | GBHMA | B1000 | GKG |
|--------------|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|--------|---------|---------|--------|
| AN14 | 1 | 0.76** | 0.52** | 0.67** | 0.50** | 0.49** | 0,12 | 0,14 | 0,13 | 0,06 | 0,08 | 0,07 | -0.31* | 0,17 | 0.36* | 0,13 | -0.34* | 0,12 |
| AN21 | | 1 | 0.74** | 0.84** | 0.75** | 0.75** | 0,14 | 0,01 | 0,08 | 0,04 | 0,2 | 0,26 | -0.51** | 0.41** | 0,2 | 0,06 | -0.58** | 0,21 |
| AN28 | | | 1 | 0.72** | 0.72** | 0.67** | 0,00 | -0,08 | 0,07 | -0,11 | 0,17 | 0,35 | -0.51** | 0.48** | 0,08 | -0,01 | -0.54** | 0,24 |
| AN35 | | | | 1 | 0.89** | 0.84** | 0,12 | -0,01 | 0,14 | 0,24 | 0,28 | 0.32* | -0.5517 | 0.4728 | 0,1031 | -0.0106 | -0,716 | 0,15 |
| AN42 | | | | | 1 | 0.85** | 0,05 | 0,08 | 0,15 | 0,22 | 0,28 | 0,30 | -0.48** | 0.40* | -0,04 | 0,03 | -0.69** | 0,07 |
| AN49 | | | | | | 1 | 0,11 | 0,03 | 0,20 | 0,24 | 0.38* | 0.38* | -0.63** | 0.53** | 0,02 | -0,12 | -0,71 | 0,14 |
| SPAD14 | | | | | | | 1 | 0,29 | 0,09 | 0.54** | 0,25 | 0,15 | -0,23 | 0,11 | 0,18 | 0,12 | -0,15 | 0,26 |
| SPAD21 | | | | | | | | 1 | 0.38* | 0.42** | 0,18 | -0,07 | 0,01 | 0,04 | -0,01 | 0,06 | -0,05 | 0,09 |
| SPAD28 | | | | | | | | | 1 | 0.33* | 0,01 | 0.44** | 0,13 | 0,0 | -0,18 | 0.32* | -0,07 | 0,06 |
| SPAD35 | | | | | | | | | | 1 | 0,21 | 0,15 | -0,12 | 0,14 | -0,06 | 0,09 | -0.32* | 0,1 |
| SPAD42 | | | | | | | | | | | 1 | 0,28 | -0.32* | 0.33* | -0,02 | -0,15 | -0.37* | 0,08 |
| SPAD49 | | | | | | | | | | | | 1 | -0,10 | 0,12 | -0,13 | 0,21 | -0,23 | 0,05 |
| TI | | | | | | | | | | | | | 1 | -0.72** | -0,07 | 0.31* | 0.65** | -0.32* |
| MARP | | | | | | | | | | | | | | 1 | 0,19 | -0.58** | -0.44** | 0.64** |
| ISI100 | | | | | | | | | | | | | | | 1 | -0,22 | 0,24 | 0.59** |
| GBHMA | | | | | | | | | | | | | | | | 1 | -0,01 | -0,19 |
| B1000 | | | | | | | | | | | | | | | | | 1 | 0,12 |
| GKG | | | | | | | | | | | | | | | | | | 1 |

AN14 = tiller number per hill at 14 DAT, AN21 = tiller number per hill at 21 DAT, AN28 = tiller number per hill at 28 DAT, AN35 = tiller number per hill at 35 DAT, AN42 = tiller number per hill at 42 DAT, AN49 = tiller number per hill at 49 DAT, AN56 = tiller number per hill at 56 DAT, AN70 = tiller number per hill at 70 DAT, AnSP = tiller number per hill at harvest, SPAD14 = Greenness leaves at 14 DAT, SPAD21 = Greenness leaves at 21 DAT, SPAD28 = Greenness leaves at 28 DAT, SPAD35 = Greenness leaves at 35 DAT, SPAD42 = Greenness leaves at 42 DAT, SPAD56 = Greenness leaves at 56 DAT, SPAD70 = Greenness leaves at 70 DAT, TI = Plant height, MARP = Panicle number per hill, ISI100 = Filling percentage, GBHMA = grain number grains per panicle, B1000 = 1000 grainweight, dan GKG = yield 14% (t ha⁻¹) at moisture content.

Table 3. The Spearman correlation test result on various rice plant growth variables in both water condition, 2017.

| SF 2017 | AN14 | AN28 | AN42 | AN56 | AN70 | ANSP | SPAD14 | SPAD28 | SPAD42 | SPAD56 | SPAD70 | TI | MARP | ISI100 | GBHMA | B1000 | GKG |
|---------|------|--------|--------|--------|--------|--------|--------|--------|---------|--------|--------|---------|--------|--------|---------|---------|--------|
| AN14 | 1 | 0.75** | 0.52** | 0,1 | 0,01 | -0.34* | -0,07 | -0,01 | -0,25 | -0,25 | -0,09 | 0,24 | 0,04 | -0,22 | -0,04 | 0,06 | -0,08 |
| AN28 | | 1 | 0.85** | 0.47** | 0,24 | 0,04 | -0,1 | -0,16 | -0,3 | -0,22 | -0,07 | 0.34* | 0,27 | -0,18 | -0,01 | -0,02 | 0,25 |
| AN42 | | | 1 | 0.72** | 0.32* | 0,25 | -0,23 | -0,16 | -0.40** | -0.31* | -0,28 | 0.51** | 0,21 | -0,13 | 0,1 | 0,07 | 0.44** |
| AN56 | | | | 1 | 0.53** | 0.65** | -0,3 | -0,01 | -0,22 | -0,03 | -0,22 | 0,22 | 0,27 | 0,17 | 0,06 | -0,25 | 0.38* |
| AN70 | | | | | 1 | 0.69** | 0,07 | 0,06 | -0,01 | -0,03 | 0,07 | -0,18 | 0.56** | 0,28 | -0,29 | -0.60** | -0,03 |
| ANSP | | | | | | 1 | 0,00 | 0,22 | 0,01 | 0,08 | 0,05 | -0,05 | 0.41** | 0.38* | -0,06 | -0.46** | 0,16 |
| SPAD14 | | | | | | | 1 | 0,01 | -0,05 | -0,01 | 0,26 | -0,16 | 0,10 | 0,23 | -0,17 | -0,15 | 0,05 |
| SPAD28 | | | | | | | | 1 | 0,30 | -0,05 | 0,11 | -0,07 | -0,18 | -0,18 | 0,07 | -0,04 | -0.33* |
| SPAD42 | | | | | | | | | 1 | 0.43** | 0,10 | -0.50** | -0,14 | -0,04 | 0,02 | -0.33* | -0,24 |
| SPAD56 | | | | | | | | | | 1 | 0,1 | -0.41** | 0,14 | 0,17 | 0,07 | -0,26 | -0,03 |
| SPAD70 | | | | | | | | | | | 1 | -0,18 | 0.31* | -0,07 | -0,14 | -0,26 | -0.32* |
| TI | | | | | | | | | | | | 1 | -0,18 | -0.38* | 0.37* | 0.56** | 0,19 |
| MARP | | | | | | | | | | | | | 1 | 0,22 | -0,19 | -0.30* | 0,03 |
| ISI100 | | | | | | | | | | | | | | 1 | -0.55** | -0.51** | -0,05 |
| GBHMA | | | | | | | | | | | | | | | 1 | 0,29 | 0.38* |
| B1000 | | | | | | | | | | | | | | | | 1 | 0,23 |
| GKG | | | | | | | | | | | | | | | | | 1 |

| OPTIMUM 2017 | AN14 | AN28 | AN42 | AN56 | AN70 | ANSP | SPAD14 | SPAD28 | SPAD42 | SPAD56 | SPAD70 | TI | MARP | ISI100 | GBHMA | B1000 | GKG |
|--------------|------|--------|--------|--------|--------|--------|--------|---------|--------|--------|--------|--------|---------|--------|---------|---------|-------|
| AN14 | 1 | 0.54** | 0,28 | 0.40* | 0.31* | 0,11 | 0,04 | -0,08 | -0,02 | 0,06 | 0,00 | 0,03 | 0,19 | -0,05 | -0,11 | -0,20 | 0,10 |
| AN28 | | 1 | 0.68** | 0.48** | 0.52** | 0.32* | -0,02 | -0.41** | -0,17 | -0,14 | -0,29 | -0,19 | 0,21 | 0,00 | -0,03 | -0.39* | -0,01 |
| AN42 | | | 1 | 0.65** | 0.70** | 0,29 | -0,02 | -0,14 | -0,04 | -0,11 | -0,18 | -0,31 | 0.35* | 0,19 | -0,23 | -0.40* | 0,24 |
| AN56 | | | | 1 | 0.89** | 0.66** | 0,09 | 0,07 | 0,04 | 0,15 | -0,02 | -0,28 | 0.59** | 0,19 | -0.40** | -0.44** | 0.37* |
| AN70 | | | | | 1 | 0.63** | 0,18 | 0,10 | 0,00 | 0,16 | 0,09 | -0.37* | 0.56** | 0,22 | -0.41** | -0.53** | 0.39* |
| ANSP | | | | | | 1 | 0,23 | -0,03 | 0,09 | 0,01 | 0,13 | -0,24 | 0.40* | 0,08 | -0,23 | -0.40* | 0,15 |
| SPAD14 | | | | | | | 1 | 0.40* | 0.32* | 0.32* | -0,10 | -0,23 | 0,12 | 0,06 | -0,08 | -0,21 | 0,09 |
| SPAD28 | | | | | | | | 1 | 0.56** | 0.57** | 0,22 | 0,07 | 0,1 | 0,02 | -0,04 | -0,06 | 0.38* |
| SPAD42 | | | | | | | | | 1 | 0.42** | -0,12 | 0,2 | 0,11 | 0,00 | 0,14 | -0,12 | 0,18 |
| SPAD56 | | | | | | | | | | 1 | -0,02 | -0,16 | 0,29 | 0,17 | -0,27 | 0,07 | 0,26 |
| SPAD70 | | | | | | | | | | | 1 | -0,16 | 0,03 | 0,04 | 0,03 | -0,15 | -0,13 |
| TI | | | | | | | | | | | | 1 | -0.56** | -0,43 | 0.47** | 0,28 | 0,06 |
| MARP | | | | | | | | | | | | | 1 | 0.54** | -0.64** | -0,14 | 0,19 |
| ISI100 | | | | | | | | | | | | | | 1 | -0.59** | 0,18 | 0,06 |
| GBHMA | | | | | | | | | | | | | | | 1 | -0,10 | -0,12 |
| B1000 | | | | | | | | | | | | | | | | 1 | -0,14 |
| GKG | | | | | | | | | | | | | | | | | 1 |

An14 = tiller number per hill at 14 DAT, An21 = tiller number per hill at 21 DAT, An28 = tiller number per hill at 28 DAT, An35 = tiller number per hill at 35 DAT, An42 = tiller number per hill at 42 DAT, An49 = tiller number per hill at 49 DAT, An56 = tiller number per hill at 56 DAT, An70 = tiller number per hill at 70 DAT, AnSP = tiller number per hill at harvest, SPAD14 = Greenness leaves at 14 DAT, SPAD21 = Greenness leaves at 21 DAT, SPAD28 = Greenness leaves at 28 DAT, SPAD35 = Greenness leaves at 35 DAT, SPAD42 = Greenness leaves at 42 DAT, SPAD56 = Greenness leaves at 56 DAT, SPAD70 = Greenness leaves at 70 DAT, TI = Plant height, MARP = Panicle number per hill, ISI100 = Filling percentage, GBHMA= grain number per panicle, B1000 = 1000 grain weight, dan GKG = yield 14% (t ha⁻¹) at moisture content.

and influences light interception to affect plant and crop performance. Near-isogenic lines (NILs). On the other hand, leaf greenness also consistently influenced the yield. Leaf color was an indicator of plant nutrition that easiest to detect, especially N (Lin et al. 2010; Wang et al. 2014). Nitrogen plays a role in stimulating vegetative growth and is associated with chlorophyll formation. Under submergence stress, decreasing photosynthesis rate was related with lower chlorophyll and carbohydrate content and stomatal conductance (Gautam et al. 2016). Optimization of these two variables (leaf greenness and tillering ability) would greatly determine the yield, especially panicle number per hill and grain number per panicle under submergence stress.

Increasing tillering ability and panicle number per hill could be treated by arranging population through plant spacing and reducing plant posture. High population will increase panicle number per hill and grain yield per unit area (Hayashi et al. 2006; Agustiani et al. 2018), while plant height reduction could increase light interception by leaves during grain filling phase and prevent lodging before harvest (Confalonieri et al. 2011) e.g., lodging, floodwater effect on leaves temperature, crop-weeds competition for radiation interception. In this paper we present a new model for the simulation of rice plant height based on the integral of the percentage of biomass partitioned to stems. The model was compared with four alternative approaches using data collected during eight experiments carried out in Russia, Japan and US between 1991 and 2000, proving to be the most accurate in reproducing plant height during the whole crop cycle. RRMSE ranged between 8.02% and 20.87%, modelling efficiency was always close to one and the absolute value of coefficient of residual mass never exceeded 0.16. It resulted also the most robust and the less complex (according to the Akaike's Information Criterion). Short posture is one of the important characters of superior varieties, besides better tillering ability and upright leaf character that could increase light absorption capacity and photosynthetic rate (Suprihatno and Daradjat 2009).

CONCLUSION

Plant height, tillering ability, leaf greenness, panicle number per hill, and grain filling percentage were critical growth variables that affect grain yield in optimum rice field conditions. The yield of the 10 rice genotypes tested decreased by 25–50% under stagnant flood (SF) stress conditions. Inpara 3 has the most stable yield in SF conditions and a common irrigation system, therefore it could be used as a check variety for SF stress. Inpara 9 and IRRI119 experienced the decreased yield of more than 50% under SF conditions. The study is useful as

preliminary recommendations for designing new variety and cultivation techniques to reduce the impact of SF stress on rice production.

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