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RESEARCH ARTICLE

# Additive intercropping with peanut relay-planted between different patterns of rice rows increases yield of red rice in aerobic irrigation system

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## ABSTRACT

Rice yields under conventional techniques are very low without high doses of commercial fertilizer application, while intercropping with legumes can increase yields. This research aimed to examine the effect of relay-planting peanut between rice rows of different patterns on yield of red rice in aerobic irrigation systems, by conducting a field experiment designed according to Split Plot design with two treatment factors, i.e. intercropping as main plots (T0 = without; T1 = intercropping with peanuts), and rice row patterns as sub-plots (P1 = normal or single-row; P2 = double-row; P3 = triple-row). In T1, one row of peanut was relay-planted (additive series) between single, double, or triple rows of red rice plants three weeks after seeding red rice on raised-beds. Results indicated that additive intercropping with peanut significantly increased clump size, dry straw weight, filled panicle number, panicle length, total biomass, filled grain number, grain yield per clump, and harvest index, and reduced percentage of unfilled grains of red rice, while patterns of rice rows only affected dry straw weight, percentage of panicle number, and weight of 100 grains. However, there were significant interactions between the treatment factors on dry straw weight and percentage of panicle number, which under single-row, they were low in monocropping but high and no differences between row patterns in intercropping system. Similarly, grain yield was lower in single or double row than triple row pattern under monocropping but significantly higher and no differences between row patterns under intercropping, indicating the highest benefits of intercropping under single row pattern.

**Keywords:** Raised-bed; Red rice; Intercropping; Additive series; Peanut

## INTRODUCTION

In Indonesia, rice plants on irrigated ricelands are normally cultivated under conventional techniques of growing rice, i.e. under flooded irrigation systems, and irrigation water even flows between paddy fields. Therefore, irrigation water requirement is high due to the requirement for flooding the land since the beginning of land preparation process prior to transplanting the rice seedlings until close to maturity, i.e. few weeks before harvest. Yaligar et al. (2017) reported that conventional techniques of growing rice required irrigation water of up to 20260 $m^3$/ha, while dry seeded direct planting technique only required 4260 $m^3$/ha. Therefore water productivity for rice production is low under the conventional technique, and rice productivity is also getting lower due to adverse effects of continuous flooding. Like in most Asian countries, rice is the main staple food in Indonesia, and according to the newspaper "The Jakarta Post" of 27 August 2018[1], until 2018 Indonesia still imported rice from several countries, which amount was even higher than the previous years. In September 2019, Indonesian government also agreed to import rice and sugar from India.[2] This means that the domestic production of rice has not been able to meet the domestic needs for rice. Therefore, rice productivity must be increased through the discovery of production technologies that are more productive than

1 The Jakarta Post, 27-08-2018. Indonesia reaffirms plan to import 2m tons of rice this year. https://thejakartapost.com/news/2018/08/27/Indonesia-reaffirms-plan-to-import-2m-tons-of-rice-this-year.html

2 https://economictimes.indiatimes.com/news/economy/foreign-trade/indonesia-agrees-to-import-indian-rice-sugar-to-push-trade-volume-to-50-billion/articleshow/71163618.cms?from=mdr

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the conventional techniques of rice cultivation, but are sustainable in the long-term and save water for extending rice production to other areas of non-ricelands.

The conventional techniques of rice cultivation, in addition to wasting irrigation water, are also less productive than some other non-conventional techniques of growing rice. It has been proven in Madagascar that rice productivity is constantly low under the conventional techniques, and there is even a tendency of getting lower from year to year if intensive inorganic inputs are not applied. In addition, the conventional wetland systems are highly dependent on the applications of inorganic fertilizers, especially N fertilizers. However, with the SRI (System of Rice Intensification) technique, which applies an intermittent irrigation between short-flooding and long drying during the vegetative phase followed with thin flooding during the reproductive phase, rice productivity can be increased, especially when followed by organic fertilization (Uphoff, 2003). Based on the country reports from 10 countries, rice productivity in each country was a lot higher under SRI compared with under conventional technique. In Sri Lanka, for example, average rice yield under the conventional technique was only 3.6 t/ha while the average under SRI technique was 7.8 t/ha with the highest yield was up to 17.0 t/ha (Uphoff, 2003).

In addition to the SRI techniques, another non-conventional technique of growing rice that has been developed in more recently is the aerobic rice systems (ARS), which are much more efficient in using irrigation water, since rice is grown on non-puddled, non-flooded and non-saturated soil conditions (Bouman 2001). However, if the aerobic rice is grown in monoculture in rice after rice areas, rice yields generally declined from year to year (Bouman 2001; Prasad 2011). Fortunately, because there is no flooding and no puddling, then aerobic rice system has some advantages over the conventional systems. One of the advantages is that rice plants can be grown in mixed cropping or intercropping with legume crops to maintain or increase soil fertility, especially in terms of increasing nitrogen content of the rice soil. This is because legume crops have the potential to fix atmospheric $N_2$ through symbiosis with *Rhizobium* bacteria and to increase N content of their rhizosphere through rhizodeposition of the biologically fixed N (Pustec et al., 2010).

Wangiyana et al. (2018), for example, reported that growing rice plants in pot culture under aerobic irrigation system, even though the base of the pots was immersed in water on an irrigation tube with the water surface of up to 3 cm above the side holes of the pot base, the rice plants can be grown together with soybean plants. The presence of soybean plants growing together with those rice plants resulted in higher tiller number, leaf number and filled panicle number, and greener leaves, indicating better nitrogen nutrition of the rice plants growing together with soybean plants, compared with the rice plants in monocrop (Wangiyana et al., 2018). Based on the results of the field and pot experiments conducted by Chu et al. (2004), the rice plants in intercropping with peanut var. Zhenyuanza 9102 produced higher weights of spikelet per plant and 1000 seed weight compared with those in monocropped rice. Dulur et al. (2016) also reported that growing red rice under aerobic irrigation system in intercropping with soybean resulted in higher tiller number, panicle number, and grain yield, compared with growing rice under conventional technique. Inal et al. (2007) reported higher availability of various nutrients in rhizosphere of maize-peanut intercrop compared with in that of maize or peanut. In addition, sweetcorn plants intercropped with peanut were much greener and resulted in higher dry stover and fresh cob weight compared with monocropped sweetcorn plants (Wangiyana et al., 2021b). Under aerobic irrigation system, intercropping with soybean also resulted in higher anthocyanin concentration in the grains in addition to higher grain yield of upland red rice genotypes (Wangiyana et al., 2021a).

The aim of this research was to examine the effect of additive intercropping of red rice plants with peanut plants relay-planted between rows of the red rice plants, the effect of different row patterns of the red rice plants, and their interactions, on growth and yield components of an amphibious promising line of red rice grown under aerobic irrigation systems on permanent raised-beds established in an irrigated paddy field.

## MATERIAL AND METHODS

### Treatments and design

In this study, the field experiment was carried out in an entisol irrigated rice-land in Beleke village, Gerung, West Lombok, Indonesia (116°7'54" E; 8°39'29" S), from May to August 2018, as part of a series of large experiments of different cropping systems under a three-year research project. This experiment was arranged according to Split Plot design in three blocks (replications) with two treatment factors i.e. additive intercropping of red rice with peanuts (T) grown on raised-beds as the main plot factor, consisting of two treatments (T0= without intercropping; T1= additive intercropping with peanuts), and patterns (P) of rice rows as the sub-plot factor, consisting of three treatments (P1= normal row or single row; P2= double-row; P3= triple-row pattern), as explained in Dulur et al. (2019). In the intercropping beds, one row of peanut plants was relay-planted additively between single, double or triple rows of red rice plants.

### Implementation of the experiment

The rice genotype used, i.e. AM-4 (F2BC4A86-3), is one of the promising lines of red rice resulted from hybridization, selection, and backcrossing with one of the parents "Kala Isi Tolo (KIT)", and based on a multi-location yield test, the AM-4 promising line was identified as an amphibious promising line of red rice (Aryana and Wangiyana, 2016). The entire procedures and materials used in this research were as explained in Dulur et al. (2019), except for the application of soil amendments, in which all raised-beds reported in Dulur et al. (2019) received no soil amendment, while the surface of all raised-beds in this research were supplied with a spread of rice husk ash and cattle manure of 12 liters each per raised-bed of 3 x 1 $m^2$.

### Observation variables and data analysis

Observation variables are listed in Table 1. The percentage of unfilled grain number was the percentage fraction of unfilled grain number divided by total spikelet number per clump, while harvest index was the percentage fraction of dry filled grain weight per clump divided by total dry above-ground biomass per clump. The data were analyzed with analysis of variance (ANOVA) and Tukey's HSD (Honestly Significant Difference) test at 5% level of significance using "CoStat for Windows" ver. 6.303. The correlation analysis between variables was done using "Minitab for Windows Rel. 13".

**Tabel 1: Summary of ANOVA results for plant height at anthesis, clump size (stem number per clump), dry straw weight, filled panicle number, panicle length, percentage of panicle number, total biomass, filled grain number, percentage of unfilled grains, grain yield per clump, weight of 100 grains, and harvest index**

| No. | Observation variables | Intercropping | Row pattern | Interaction |
|---|---|---|---|---|
| 1 | Plant height at anthesis | ns | ns | ns |
| 2 | Stem number per clump (clump size) | * | ns | ns |
| 3 | Dry straw weight (g/clump) | ** | ** | ** |
| 4 | Filled panicle number per clump | * | ns | ns |
| 5 | Average panicle length | * | ns | ns |
| 6 | %-Panicle number | ns | * | * |
| 7 | Total biomass | * | ns | ns |
| 8 | Filled grain number per clump | * | ns | ns |
| 9 | %-Unfilled grain number | * | ns | ns |
| 10 | Dry grain yield (g/clump) | * | ns | ns |
| 11 | Weight of 100 grains (g) | ns | * | ns |
| 12 | Harvest index (%) | * | ns | ns |

Remarks: ns=non-significant; *, ** = significant at p-value <0.05 and p-value <0.01, respectively

## RESULTS AND DISCUSSION

Growth performance of the red rice at 7 weeks after seeding, prior to Urea fertilization, is shown on Photograph 2 and Photograph 3. The leaves of the red rice plants in intercropping with peanut (Photograph 2) were much greener than those in monocrop (Photograph 3).

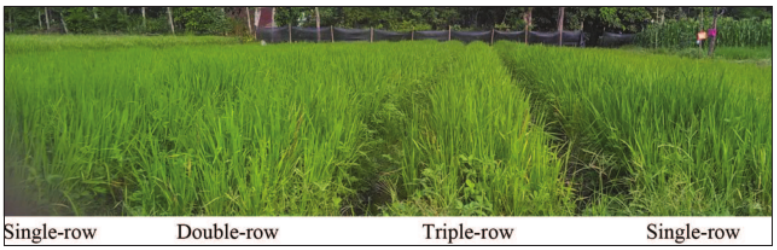
The results of data analysis showed that between the two factors tested in this experiment, intercropping had more significant effects on growth and yield components of the red rice compared with different patterns of rows of the rice plants on the raised-beds. However, the interactions effects were significant only on dry straw weight per clump and percentage of panicle number (Table 1).

In relation to growth variables, there were no significant effects of additive intercropping of red rice plants with peanut plants on plant height of the red rice at anthesis, as well as on the percentage of panicle number at harvest, although there were slight increases in the mean values of both variables due to intercropping with peanut. However, intercropping with peanuts resulted in significantly higher averages of clump size (tiller number per clump), filled panicle number per clump, and average panicle length in intercropped than in monocropped rice plants (Table 2). Thus, the non-significant effect of intercropping on the percentage of panicle number seems to be due to similar amount of increase in clump size and panicle number per clump. In relation to clump size and panicle number per clump, Chu et al. (2004) also showed higher number (22.8%) of filled tillers due to intercropping rice plants with peanut plants, although it was not significant.

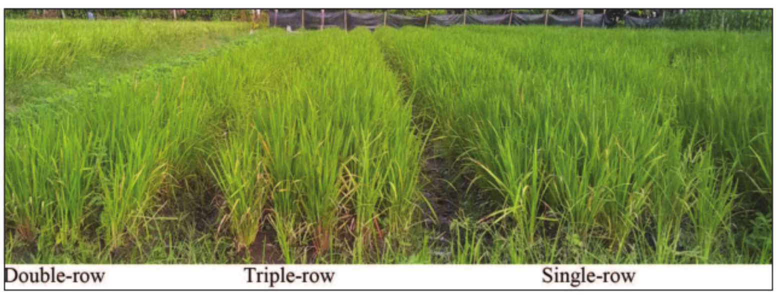
In relation to grain yield, filled panicle number per clump should be one of the yield components determining grain yield. From Table 2, it can be seen that filled panicle number is significantly higher in the intercropped than in monocropped red rice plants (29.06 *versus* 22.61 panicles per clump). Similarly, grain yield per clump is also significantly higher in the intercropped than in monocropped rice plants (69.48 *versus* 36.77 g/clump), i.e. almost doubled in the intercropped rice plants (Table 3). When correlation analysis was run between these observation variables, the overall correlation coefficient was highly significant, with an r= +0.891 (*p-value* <0.001), but when the correlation analysis was run separately between monocropped and intercropped rice plants, the correlation coefficient was significant only on monocropped rice plants (Table 4), which indicates that the intercropping treatments affected grain yield of the red rice plants differently.

Based on the correlation coefficients in Table 4, the levels of grain yield per clump on the monocropped red rice

**Photograph 1.** Growth performance of the direct-seeded red rice during the first weeding at 20 days after seeding, before relay-planting peanut at 3 weeks after seeding rice.




**Photograph 2.** Performance of red rice plants at 7 weeks after seeding (prior to Urea fertilization) on the raised-beds intercropped with peanut.




**Photograph 3.** Performance of red rice plants at 7 weeks after seeding (prior to Urea fertilization) on the raised-beds without intercropping with peanut (monocropped rice).

**Table 2: Mean values of rice plant height, stem number per clump (clump size), dry straw weight, filled panicle number, panicle length, and percentage of panicle number per clump between intercropping and between row pattern treatments**

| Treatments | Plant height (cm) | Stem number per clump | Dry straw (g/clump) | Panicle number per clump | Panicle length (cm) | %-Panicle number |
|---|---|---|---|---|---|---|
| T0: monocrop | 93.09 a | 23.28 b | 30.37 b | 22.61 b | 18.37 b | 97.07 a[1]) |
| T1: intercrop | 98.72 a | 29.28 a | 39.83 a | 29.06 a | 19.49 a | 99.25a |
| HSD 0.05 | 22.63 | 2.71 | 1.46 | 3.45 | 0.86 | 6.06 |
| P1:Single row | 95.87 a | 26.50 a | 32.57 b | 25.67 a | 18.53 a | 96.53 b |
| P2:Double row | 95.88 a | 25.50 a | 35.29 a | 25.25 a | 19.25 a | 98.96 a |
| P3:Triple row | 95.97 a | 26.83 a | 37.44 a | 26.58 a | 19.02 a | 99.00 a |
| HSD 0.05 | 10.12 | 2.37 | 2.67 | 2.43 | 1.35 | 1.98 |

The same letters indicate non-significant differences between levels of a treatment factor

**Table 3: Mean values of total biomass weight, filled grain number, percentage of unfilled grain number, grain yield per clump, weight of 100 grains, and harvest index between intercropping and between row pattern treatments**

| Treatments | Total biomass (g/clump) | Filled grain number per clump | %-unfilled grain number | Grain yield (g/clump) | Weight of 100 grains (g) | Harvest index (%) |
|---|---|---|---|---|---|---|
| T0: monocrop | 67.14 b | 1475.22 b | 13.21 a | 36.77 b | 2.49 a | 54.71 b[1)] |
| T1: intercrop | 109.31 a | 2763.56 a | 4.48 b | 69.48 a | 2.51 a | 63.43 a |
| HSD 0.05 | 18.55 | 691.96 | 5.52 | 18.00 | 0.07 | 7.39 |
| P1:Single row | 85.10 a | 2157.00 a | 9.25 a | 52.53 a | 2.44 b | 60.70 a |
| P2:Double row | 86.08 a | 2052.17 a | 9.02 a | 50.79 a | 2.46 b | 57.50 a |
| P3:Triple row | 93.48 a | 2149.00 a | 8.29 a | 56.05 a | 2.60 a | 59.02 a |
| HSD 0.05 | 9.93 | 321.49 | 4.95 | 10.00 | 0.12 | 4.86 |

[1)]The same letters indicate non-significant differences between levels of a treatment factor

**Table 4: Results of correlation analysis between grain yield per clump as the Y variable and rice yield components as the X variables showing significant correlation**

| Intercrop-ping treat-ment | Grain yield (Y) | Clump size | Panicle number per clump | Dry straw weight | %-panicle number | Panicle length (cm) | Filled grain number | %-unfilled grains | Harvest index |
|---|---|---|---|---|---|---|---|---|---|
| Overall | rXY | 0.881 | 0.891 | 0.857 | 0.550 | 0.577 | 0.989 | -0.922 | 0.919 |
| | *p*-value | **0.000** | **0.000** | **0.000** | **0.018** | **0.012** | **0.000** | **0.000** | **0.000** |
| | $R^2$ | 0.776 | 0.794 | 0.734 | 0.303 | 0.333 | 0.978 | 0.850 | 0.845 |
| Monocrop | rXY | 0.664 | 0.696 | 0.623 | 0.426 | -0.279 | 0.976 | -0.723 | 0.481 |
| | *p*-value | 0.051 | **0.037** | 0.073 | 0.253 | 0.467 | **0.000** | **0.028** | 0.190 |
| | $R^2$ | 0.441 | 0.484 | 0.388 | 0.181 | 0.078 | 0.953 | 0.523 | 0.231 |
| Intercrop | rXY | -0.091 | -0.036 | -0.470 | 0.229 | 0.369 | 0.858 | -0.634 | 0.986 |
| | *p*-value | 0.816 | 0.926 | 0.201 | 0.554 | 0.328 | **0.003** | 0.067 | **0.000** |
| | $R^2$ | 0.008 | 0.001 | 0.221 | 0.052 | 0.136 | 0.736 | 0.402 | 0.972 |

plants is significantly correlated with panicle number per clump, filled grain number per clump, and percentage of unfilled grain number, which is most probably due to the relatively low number of panicle per clump in the monocropped red rice plants. In contrast, the average filled panicle number per clump is significantly higher (about 29% higher from the monocropped rice plants). It is then logical that grain yield is more correlated with rates of partition of photosynthates (in addition to high photosynthetic rates) to the grains during the grain filling stage, which is indicated by higher $R^2$ between grain yield and harvest index (Table 4).

One of the indicators of photosynthetic capacity of rice plants, in addition to the total number of green leaves at anthesis between intercropping treatments, is level of chlorophyll content in the leaves. In a quick way, higher chlorophyll content is indicated by higher values of the chlorophyll meter reading or higher value of the green color of the rice leaves detected using leaf color chart (LCC) produced by the International Rice Research Insitute (IRRI), which is normally used to determine if additional nitrogen fertilization is needed during anthesis or panicle initiation stage (Singh et al., 2002, 2010; Yang et al., 2014). Based on the results of green color measurement of the flag leaves of the rice plants using the four panels IRRI LCC in this study, it was evident that leaves of the rice plants intercropped with peanuts were greener in their color than those in the monocropped rice plants. The LCC value in the measurement was mostly 2 or between 2 and 3 in monocropped rice plants, while for rice leaves in the peanut-rice intercropping, it was mostly between 3 and 4, but on some beds it was 3 and on some beds it was 4 (Fig. 1), indicating higher levels of N in the leaves of the intercropped than in those of the monocropped rice plants.

Significantly higher clump size or stem number per clump at anthesis (Table 2) with greener leaves of the red rice plants in intercropping than those in monocropping system (Fig. 1) could also mean higher number of green leaves of the rice plants in intercropping than in monocropping system at anthesis. Greener leaves of the intercropped rice plants measured using the IRRI LCC (Fig.1) indicate higher N content of the leaves of the intercropped than monocropped rice plants (Singh et al., 2002, 2010; Yang et al., 2014). Many have reported that higher N content of the rice leaves is related to higher leaf photosynthetic rates (Hirasawa et al., 2010; Taylaran et al., 2011). Therefore, it is logical that filled grain number and harvest index were higher, while percentage of unfilled grain number was lower on rice plants in intercropping with peanut than on those in monocrop. These would support higher grain yield of the rice plants in intercropping than in monocropping system, i.e. 69.48 *versus* 36.77 g/clump (Table 3). Chu et al. (2004) also reported that rice plants grown in intercropping with peanuts showed higher leaf N concentration and values of SPAD-(Soil Plant Analysis Development)-chlorophyll meter reading compared with those grown in monocrop,

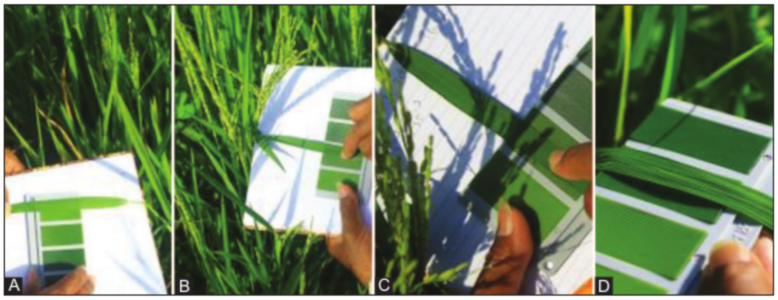



**Fig 1.** Measurement of the rice leaf color using the IRRI leaf color chart (A. level 2 of the rice leaf color in monocropped rice; B. level 3, C. level between 3 and 4, D. level 4 of the rice leaf color in rice intercropped with peanuts).

and they found higher grain yield of rice in intercropping with peanuts than in monocrop. Intercropping with soybean was also found to increase grain yield of upland red rice under aerobic irrigation systems (Wangiyana et al., 2021a).

The higher leaf N content of rice leaves in intercropping with peanuts compared with in monocropped rice, according to experimental results reported by Chu et al. (2004), was resulted from transfer of N from peanut rhizosphere to rice. In relation to transfer of fixed N from legume to non-legume crops growing in intercropping, Fujita et al. (1990) also reported that there was N transfer from rhizosphere of soybean to sorghum grown in soybean-sorghum mixed cropping, which resulted in higher dry matter production of the intercropped sorghum plants, and the rates of N transfer was higher as the planting distance between soybean and sorghum was closer. Similarly, the higher N content of the rice plants in the intercropping due to greener leaf color (Fig. 1) compared with those in the monocrop in this research, could also be resulted from some transfer of fixed N from peanut rhizosphere to adjacent rice plants, especially under the single row pattern, in which the distance between the peanut and rice plants in the intercropping in this study was only 12.5 cm. In addition, Wang and Wang (2012) reported that exudation of N compounds (in the forms of $NO_3^-$ and $NH_2^+$ ions and N total) was much higher in the rhizosphere of rice-peanut intercropping than in that of monocropped rice or peanut in all growth stages of both crops, and the highest amount of N compounds exuded was during the flowering stage. Thus, higher level of leaf green color of the rice plants in intercropping than in monocroping system measured using the IRRI LCC in this study, could be due to transfer of N from rhizosphere of peanut to rice.

In relation to higher filled grain number per plant in rice plants intercropped with peanut than in the monocropped rice, Chu et al. (2004) also reported that spikelet weight per plant and 1000-grain weight were significantly higher on rice in intercropping with peanut than in monocropped rice. They also showed a higher chlorophyll content in leaves of rice plants intercropped with peanut than in the monocropped rice. Higher filled grain number or lower percentage of unfilled grain number per clump in Table 3 could also mean higher assimilate partition to developing spikelets in the rice plants intercropped with peanut than in monocropped rice, as can also be seen from Table 3 that harvest index was also higher in intercropped than monocropped rice.

Based on the results of correlation analysis between grain yield per clump and yield components of the rice plants in this study (Table 4), the strongest correlation in which the $R^2$ were higher than 80% is between grain yield per clump and filled grain number per clump ($R^2$= 97.8%) or percentage of unfilled grain number ($R^2$= 85.0%) or harvest index ($R^2$= 84.5%). Thus, in addition to higher panicle number and percentage of panicle number per clump, grain yield per clump was stronger related to higher filled grain number per clump and higher harvest index, but lower percentage of unfilled grain number in the rice plants intercropped with peanut compared with those in the monocropped rice plants (Table 3).

These mean that increases in grain yield per clump was mainly due to better partition of assimilate to the developing seeds of the red rice plants, which resulted in higher filled grain number per clump and lower percentage of unfilled grain number (Table 3). These all must have also been due to higher photosynthetic rates per clump resulted from higher N content in the leaves of the red rice plants in intercropping with peanuts than in monocropped rice, indicated by greener leaves of the rice plants in intercropping measured using the IRRI LCC (Fig. 1). According to previous studies, higher N content of the rice leaves at anthesis supports higher leaf photosynthetic rates during seed-filling stage (Hirasawa et al., 2010; Taylaran et al., 2011).

In relation to the effects of the patterns of rice rows, most variables showed non-significant effects except on the dry straw weight, percentage of panicle number (Table 2), and weight of 100 filled grains (Table 3), which were the lowest on rice plants in the single row pattern and highest on those in triple row pattern. However, there are significant interaction effects between both factors on dry straw weight and percentage of panicle number (Table 1). When the mean values are plotted over the treatment factors, it can be seen from Fig. 2 and Fig. 3 that the lowest averages of dry straw weight and percentage of panicle number are on the red rice plants under single row pattern, but only in monocropped rice, while in the intercropped rice, they were non-significantly different between patterns of rice rows. These mean that the single-row rice plants in intercropping with peanut had higher rates of dry matter production than those in the monocropping system.

When the mean values of grain yield and the above-ground biomass weight per clump are also plotted over the treatment factors, although the interaction effects were not significant on these variables, it can be seen from Fig. 4 and Fig. 5 that grain yield and total biomass per clump of the rice plants under single and double row patterns are significantly lower than those under triple row pattern, but these differences are significant only in the monocropped rice plants, while those in intercropping with peanut, there are no significant differences between patterns of rice rows. Therefore, it is clear that the red rice plants in the single row pattern get the highest benefits from intercropping with peanut compared with those in the double or triple row patterns. This could be due to the distances between rice and peanut rows were the closest in the single row than in the double or triple row patterns, which is similar to the results of the study reported by Fujita et al. (1990) in relation to the nitrogen contribution from soybean to sorghum, which was highest in the closest planting distance between soybean and sorghum plants in the intercropping systems.

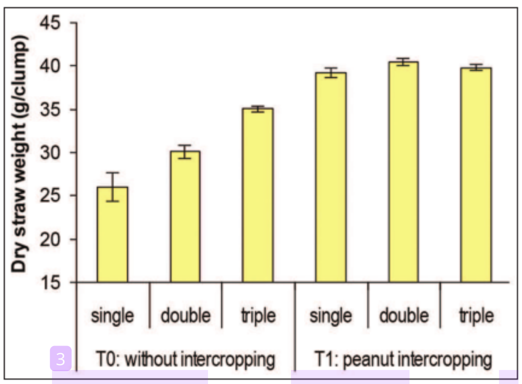



Fig 2. Average (Mean ± SE) dry straw weight (g/clump) of red rice for each combination of intercropping and patterns of rice rows.

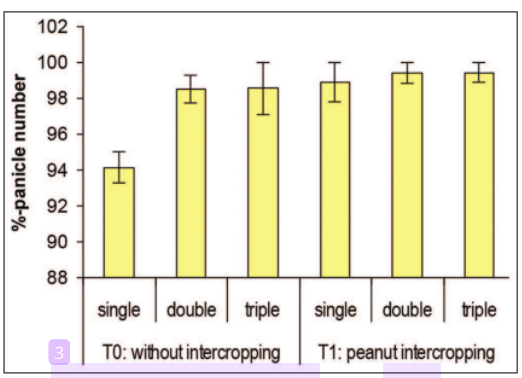



Fig 3. Average (Mean ± SE) percentage of panicle number (%) of red rice for each combination of intercropping and patterns of rice rows.

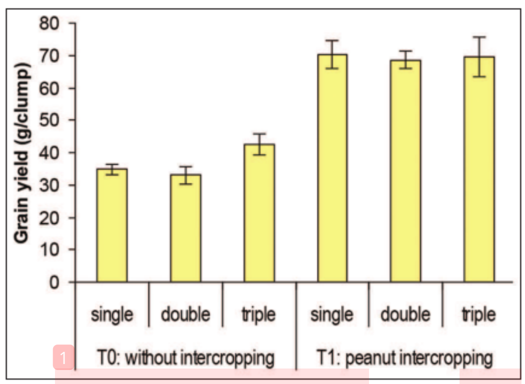



Fig 4. Average (Mean ± SE) grain yield (g/clump) of red rice for each combination of intercropping and patterns of rice rows.

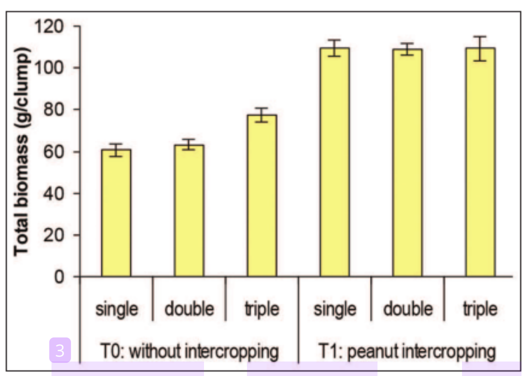



Fig 5. Average (Mean ± SE) total biomass (g/clump) or red rice for each combination of intercropping and patterns of rice rows.

Thus if we are not too concerned on the pod yield of the peanut plants relay-planted between rows of red rice plants but are concerned more on the harvest of atmospheric $N_2$ using peanut plants for better growth and higher yield of the red rice plants additive-intercropped with peanut or for better nitrogen contribution of peanut plants to the soil for better N nutrition of the subsequent crops, then additive intercropping with peanut plants inserted between single rows of rice plants would be the best of all row patterns. Alternatively, other species of crops or weeds having high potentials of harvesting the atmospheric $N_2$ through biological nitrogen fixation need to be found and studied for better nitrogen contribution to the soil or adjacent crops in intercropping systems in order to improve soil fertility or to reduce the use of commercial N fertilizers.

## CONCLUSION

It can be concluded that additive-intercropping with peanut plants significantly increased grain yield of red rice plants per clump under aerobic irrigation system on raised-beds, while reducing the percentage of unfilled grain number, especially under single row pattern. However, when the red rice plants were grown under monocropping system, triple row was the best row pattern.

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### Authors' contributions

All authors had participated in running the field experiment, field measurement, data compilation, and preparation of the manuscript. Author #3 and Author #4 did the field plant measurements and data tabulation, Author #2 was the main contact person with the funding agency and presentation of research results and prepared initial draft using Indonesia language; Author #1 designed the entire research project including the field experiment and layout, ran statistical data analyses, translated and wrote the English manuscript, submitted the manuscript, and completed the revisions.

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