The use of ^{32}P Method to Evaluate the Growth of Lowland Rice Cultivated in a System of Rice Intensification (SRI)

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ABSTRACT

A pot experiment has been conducted to evaluate the growth of the Dyah Suci, a lowland rice variety, in an SRI (System of Rice Intensification) planting system. The phosphorus-32 (^{32}P) isotope technique was used to evaluate the growth of plants in relation with their phosphorus uptake. The uptake was assumed to vary in the same direction as the growth of the plant. The ^{32}P uptake is assumed to vary in the opposite direction to the plant's total phosphorus uptake. Here the ^{32}P uptake is expressed in count per minutes (cpm) which is then transformed to disintegration per minute (dpm). The results show that, in terms of promoting the plant's uptake of phosphorus, the SRI planting system is superior to the conventional planting system, and it is manifested in the higher dry weight of straw and grain. From this experiment it is concluded that the ^{32}P method can be used satisfactorily as a tool for explaining the relation between P-uptake and plant growth.

INTRODUCTION

The diminishing lowland rice area is the main factor inhibiting Indonesia from reaching self-sufficiency in rice production. Rice is the main staple food of the Indonesian population, and it is considered as a highly strategic commodity. The consumption of rice here is around 139.15 kg/capita. This could hardly be met by the lowland rice area left, especially in Java. The harvest area of lowland rice is presently around 11–12 million ha, and this area is rapidly decreasing due to the conversion of land use to housing and industrial areas. The production of rice is now around 4–6 t/ha (the national average is 4.54 t/ha in 2004). However, to maintain food security, the rice production should be increased to 6–8 t/ha. To reach this productivity on limited areas, new technologies should be developed [1].

One of the promising technologies is SRI (System of Rice Intensification) which has boosted rice production in several infertile lowland areas nearly all over Jawa. Various research works shown that the static, even declining, rice production at national level is due to the saturated soil state, caused by the overuse of chemical fertilizers for several decades since the 1960's. The overflow of chemical fertilizers for such a long time has worsened the chemical, physical and biological properties of the soil. The soil's organic carbon (C-organic) content then became less than 2%, indicating a decrease in soil fertility [2]. The C-organic content is a key to evaluate the organic matter in soil, as an entry point of energy flow into the soil which then be used to support various processes in the soil [3]. Those processes would then improve soil fertility, meaning that it could support more plant production, in this particular case rice production.

The SRI system is based on the production potential of the rice variety itself. Hypotetically when the microenvironment of the rice plant is made favourable, then it is expected that the plant will show its production potential. In the SRI method, one relatively-young rice seedling is planted per hole. The transplanted young seedlings, of under 21 days of age, could stimulate high tiller number and earlier panicle and grain forming. The high yield components formed is expected to produce high yield [3].

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Anugerah *et al*. [4] forwarded that the SRI method practice is stressed on the management of soil, plant and water, utilized the local wisdom based on environment friendly conditions. The SRI technology is carried out based on six important components, i.e. (1) young seedlings transplantation; (2) use of one seedling per planting hole; (3) wide planting distances; (4) intermittent irrigation; (5) regular weed control; and (6) use of organic matter and organic fertilizers only. The experiences gained from the adoption of SRI technology in Garut and Ciamis regencies show that : (1) SRI planting practices increase rice production over conventional planting; (2) higher yield production increase farmer's income; (3) SRI was more efficient in the production process and financially; and (4) organic rice production has brought an impact in form of the high price of branded organic rice.

Intensification of rice production by the SRI technology has been conducted in several areas in Indonesia. The investigation done by Simarmata [2] showed that this technology could boost rice production to 8–12 t/ha. On fertile lowland soil the production could increase by 50–100% to 6–8 t/ha, while on less fertile soils the increase was 100–200% to 3–5 t/ha. The increase in plant production has a direct corellation with the enlargement of the rooting zone. The rooting zone enlarged up to 4–10 times, resulting in the incrase of panicles to 60–80 tillers. The length of those panicles could reach to 25–35 cm and grain could reach up to 150–250 per panicle. The key to this superior rice production when using SRI technology is the increase of the rooting systems, making them able to take up more nutrients, allowing the plants to grow more tillers. The higher number of tillers will boost the plant production.

The formation of roots and tillers is highly dependent on the absorbtion of nutrients, especially phosphorus. The optimal development of the root systems must be supported by the availability of nutrients and the diversity of the soil's biological condition. It could be speculated that, theoretically, if all the requirements of the rice plant as mentioned are fullfiled by SRI, then the potential yield will triple [1]. As mentioned before, phosphorus plays an important role in increasing the potential yield of rice. This is due to the role of phosphorus in promoting the cell-deviation process, which makes the plants grow much better compared with when phosphorus deficiency occurs. Hardjowigeno [5] established that phosphorus functions, among others: as a cell-dividing factor; in formation of flower, fruit and seed; accelerating maturity; strengthening plant stem; and increasing root development. Prassad and Power [6] also says that phosphorus is a very important part of cell nucleus and plays a great role in cell division and the development of meristematic tissues. It could be concluded that the SRI-technology is able to optimize the phosphorus absorbtion by plant and support phosphorus availability for plants.

The availability of phosphorus to plants, in the use of SRI technology, is surmised to be due to the application of organic matter (OM) which is one of the main rules of SRI. There are several techniques of soil management which can make the phosphorus absorbed by the soil mineral structure available to plants. These techniques are addition of OM, liming, application of fertilizer, and biotechnology [7]. Research done by Adiningsih and Rochyati [8] show that there is a positive correlation between the OM content of the soil and lowland rice productivity. The decline in soil organic matter content causes a decrease in soil productivity.

The decomposition process of OM produces organic acids which could help to increase P availability. The availability of adsorbed phosphorus (adsorp-P) in the soil mineral structure occurs through chelation process by OM. Besides that OM itself is a source of P and other plant nutrients. Its availability to plants is a slow process, and this could make them available through the whole plant life up to maturity. It is expected that the SRI technology will increase available phosphorus and therefore reducing the need for phosphorus derived from chemical fertilizers by replacing it with organic phosphorus.

This paper will describe the use of phosphorus-32 (^{32}P) to evaluate the growth of lowland rice cultivated in an SRI system.

EXPERIMENTAL METHODS

Plant material and soil

The rice variety used was a lowland rice variety, var. Dyah Suci, one of BATAN's mutants. Seeds were planted in plastic trays and transplanted at the ages of 8, 16 and 21 days (seedlings age = SA).

The soil used was an Inceptisols type from Sukamandi, West Java Province. The soil was air-dried before placed in the plant pot at a rate of 10 kg/pot. The pots are 20 L plastic baskets. The main physical and chemical properties of the soil are : The soil consisted of 40% clay, 55% silt, and 5% sand. Its had a nitrogen content of 0.09%, phosphorus (in the form of P_2O_5) of 24 mg 100/g, and potassium (K_2O) of 5 mg 100/g. It had a pH (H_2O) of 5.3, and (HCl) 4.3.

The soil in the plastic pots were submerged for 14 days before seed transplanting to create a muddy condition. In the first 7 days animal manure were added as a source of OM.

Treatments

The treatments conducted in this experiments were : (1) conventional planting system (PS), where each pot was planted with 2 seedlings. Transplantations were performed when the seedlings were 8, 16 and 21 days respectively. The fertilizers applied were inorganic fertilizer, urea = 250 kg/ha, SP-36 and KCl each 100 kg/ha. The code for this treatment is PS_1; (2) the SRI-inorganic PS, where seedlings were planted at the density of 1 seedling/pot. The rate of N, P and K were the same rate as in PS_1. The soil in the SRI-PS was not submerged. Watering was done until the soil is muddy but not flooded or covered with water. This condition was preserved until the plants were harvested. The code for this treatment is PS_2; (3) the SRI-organic PS, where the planting of seeds and watering were carried out as in PS_2, but without adding inorganic fertilizers. The fertilizer used was 100% organic in the form of compos at a rate of 5 t/ha and was further added with local microorganism (MOL). The addition of MOL is for enhancing the dissolution of OM. The code for this treatment is PS_3; and (4) the SRI-semi organic PS, which was carried out by adding 50% as much inorganic fertilizer as used in PS_1, and applying "Fertismart" bioorganic fertilizer at a rate of 300 kg/ha. The code for this treatment is PS_4.

When using the SRI-PS, the seedlings were planted at a depth of 2 cm, and the roots were place horizontally. It is important to consider that planting time has to be very short, less than 3 minutes/seedling. The seedling age when tranplanted were 8 (SA_1), 16 (SA_2), and 21 (SA_3) days respectively. Table 1 contains the codes of all the treatments applied in this experiment.

Table 1. Codes of treatments.

Planting system (PS)	Seedlings age (SA) days		
	SA_1 – 8 days	SA_2 – 16 days	SA_3 – 21 days
PS_1 : conventional inorganic	PS_1 SA_1	PS_1 SA_2	PS_1 SA_3
PS_2 : SRI-inorganic	PS_2 SA_1	PS_2 SA_2	PS_2 SA_3
PS_3 : SRI-organic	PS_3 SA_1	PS_3 SA_2	PS_3 SA_3
PS_4 : SRI-semi organic	PS_4 SA_1	PS_4 SA_2	PS_4 SA_3

^{32}P application and analysis

One day before seeds were transplanted, a carrier free solution of $KH_2{}^{32}PO_4$ was added to each pot. The $KH_2{}^{32}PO_4$ solution had a specific activity (s.a) of 300 μCi/20 ml. To each pot, 10 ml of the solution was added. The ^{32}P solution was mixed thoroughly to allow as homogeneous a spread of ^{32}P as possible. After harvesting, the plant samples were separated to panicles, straw and grain. Afterwards, ashing and further steps were undertaken to create a clear solution. This solution was then counted by liquid scintillation counter (LSC) which used Cherenkov counting [9] since ^{32}P is a strong β emitter.

Data collected

The data presented in Tables 2 to 4 is a mean collected from 2 replications. The data obtained from LSC is in cpm (counts per minute). The cpm data was then transformed to dpm (disintegration per minute) by dividing the cpm with the efficiency of LSC; dpm = cpm/efficiency.

The efficiency of LSC with Cherenkov counting is 40% = 0.4. The cpm and dpm data are presented in Table 2.

The dpm is transformed to dpm* at ^{32}P application by dividing the original dpm by the decay factor as shown by L'Annunziata [9]; dpm* = dpm/decay factor. Decay factor for panicle is 60 days and for grain and straw is about 120 days. The purpose of transforming dpm to dpm* is to determine the initial ^{32}P uptake by the plants, which is quite large. This values better shows the differences in nutrient uptake paths among treatments.

RESULTS AND DISCUSSION

Interrelation between ^{32}P content and phosphorus uptake

The ^{32}P content in the plant parts could be perused in Table 2, expressed in cpm (count per minute) and dpm (disintegration per minute).

All the data presented in Table 2 is a mean of two replications. The values of cpm and dpm in Table 2 are transformed from the original values to values which are emitted by the ^{32}P applied, as shown by L'Annunziata [9]. The calculation is as follows :

$$A_o = \frac{original\ cpm}{LSC\ efficiency} = x\ dpm \quad (1)$$

$$A_p = \frac{x}{decay\ factor} = y\ dpm \quad (2)$$

A_o = original A = sample activity
A_p = A at ^{32}P application

The values of y is the data presented in Table 2 as dpm. This done with the purpose to obtain larger values of dpm, so the difference among values become more prominent.

The dpm* of all plant parts, panicle, straw and grain decrease from PS_1 to PS_4. This means that the lower the dpm*, the higher the phosphorus uptake (P-uptake). Here P-uptake meant P-uptake soil + fertilizer either inorganic or organic. According to Zapata and Axmann [10] lower ^{32}P values, which in this experiment is expressed in dpm*, express a higher activity of P uptake. This is due to the plant's higher phosphorus content which dilutes the ^{32}P in the plant body, causing its concentration to decrease, while the P content increases. Contrarily, higher ^{32}P values is expressing a lower P content in the plant due to the lower activity of P uptake to dilute ^{32}P in the plant body.

After the data was evaluated, it become clear that PS_2, PS_3 and PS_4 took up more phosphorus than PS_1 did, or in other words SRI-PS is superior in P-uptake compared to the conventional PS. It is assumed that the better P-uptake by plants in SRI-PS promoted better plant growth and resulted in better production. Among the SRI-PS treatments, it is apparent that PS_4 resulted in the highest P-uptake followed by PS_3 and PS_2. As previously mentioned, PS_3 is SRI-inorganic PS, PS_3 = SRI organic PS, and PS_4 = SRI-semi organic PS. The highest P uptake by SRI-semi organic PS is believed to be caused by the soil condition which does not contain sufficient available phosphorus to support the earlier growth of the plants. As well known that the inorganic phosphorus from fertilizers are readily available for only a short time for plants. This is the assumption to support the PS_4 (SRI-semi organic PS) data with the highest P-uptake. It is expected that after several seasons using SRI-PS, especially SRI-organic PS, the physical and chemical properties and quality of the soil will be improved. This soil properties

Table 2. Cpm (count per minute) and dpm (disintegration per minute) of several plant parts.

Age of seeds	Cpm				dpm				dpm*			
	AS (age of seedling, days)				AS (age of seedling, days)				AS (age of seedling, days)			
Planting system	SA_1	SA_2	SA_3	Ro-PS	SA_1	SA_2	SA_3	Ro-PS	SA_1	SA_2	SA_3	Ro-PS
Panicle												
PS_1	105	111	116	111	262	277	290	276	6118	6470	6792	6460
PS_2	88	93	99	93	221	233	234	234	5152	5445	5796	5464
PS_3	74	77	82	78	186	192	205	194	4347	4479	4801	4542
PS_4	65	67	70	67	162	167	175	168	3776	3896	4099	3924
Ro-SA	83	87	92	-	208	217	230	-	4848	5073	5372	-
Straw												
PS_1	64	67	70	67	159	167	175	167	26008	26815	28266	27030
PS_2	54	59	60	58	135	144	149	143	21774	23186	23992	22984
PS_3	48	50	53	50	121	124	133	126	19355	19960	21371	20229
PS_4	40	44	46	43	101	109	114	108	16129	17541	18347	17309
Ro-SA	52	55	58	-	129	136	142	-	20817	21853	22994	-
Grain												
PS_1	66	67	69	67	166	168	172	169	26955	27280	27932	27389
PS_2	60	62	64	62	156	156	159	155	24267	25326	25896	25163
PS_3	55	56	58	56	140	146	146	141	22639	22801	22697	22712
PS_4	50	52	54	52	131	134	134	130	20359	21254	21824	21146
Ro-SA	58	66	61	-	144	153	153	-	23555	24165	24587	-

Notes : cpm readings are derived from LSC
dpm = cpm/efficiency, efficiency for the Cherenkov counting by LSC is around 40%
dpm* = dpm read at ^{32}P application dpm/decay factor
for panicle decay factor is arround 60 days = 0.05
for straw and grain decay factor is around 120 days = 0.007. the difference between the decay factor would make the difference in values of dpm**

improvement will further improve the availabitily of plant nutrients, including P.

All the dpm values in this experiment show a trend of diminishing values from PS_1 to PS_4 for all seedling ages (SA). For the SA treatment, it is shown that for all plant parts, the older the seedling age the higher the dpm become. This means that the younger the seedlings were when transplanted, the higher the possibility of P-uptake and this results higher plant production. This is in accordance with Anugerah [4] that the young age of seedling is important to guarantee high plant production when SRI-PS is applied.

Comparing P-uptake among treatments using dpm* values

In Table 2 the dpm* values is used to compare the assumed P-uptake using different PS and SA. The calculation of the comparison expressed in percentage (%) is done as follows, data in Table 2 shows that dpm* of $PS_1 \times SA_1 = 6118$ and for $PS_2 \times SA_1 = 5152$:

$$\frac{6118 - 5152}{6118} \times 100\% = 15.84\% \qquad (3)$$

Thus for SA_1, PS_2, as shown by $PS_2 \times SA_1$, absorbs 15.84% more P compared to PS_1, as shown by $PS_1 \times SA_1$. It follows that the P-uptake of PS_2 is 15.56% higher than PS_1, and the P-uptake of PS_3 is 29.77% higher than that of PS_1, and for PS_4 it is 37.67% higher than for PS_1 recpectively.

The data in Table 3 represents more clearly the use of dpm* values to show the trend of P-uptake and present them as percentages (%). Here it is shown that the PS_2-PS, PS_3-PS, and PS_4-PS are all able to take of P more than PS_1-PS which is the conventional PS, while PS_2, PS_3 and PS_4 are SRI method. The highest P-uptake capability is shown by PS_4, which has the highest percentage values. This is valid for all plant parts.

In rows 2 and 3 of the table there are comparisons among the SRI method, where PS_4 is compared to PS_2 and PS_3 (row 2) and PS_4 compared to PS_3 (row 3).

Thera are two important conclusion from this table. First, the SRI method enables the plant to take up more P than the conventional method. And second, among the SRI method PS_3 (SRI-organic) and PS_4 (SRI-semi-organic) are better in P-uptake compared to SRI-inorganic. It is assumed that organic matter in the fertilizer used for PS_3 and PS_4 has a role in P-uptake by plants.

Dry weight of several plant parts

The dry weight of several plant parts could be used to express the plant growth (Table 4). The harvest was collected at grain maturity, so the plant parts presented are straw and grain. The panicles were excluded because they were expected to have grown into grain.

The dry weight of straw and grain showed that there was an increase toward PS_4 from PS_1. This is in accordance to Tables 2 and 3, where the dpm values decrease from PS_1 to PS_4, with the

Table 3. Comparisson among treatments on assumed P-uptake using dpm*, expressed in percentage (%).

	PS_2, PS_3, PS_4 compared to PS_1 (%)				PS_3, PS_4 compared to PS_2 (%)				PS_4 compared to PS_3 (%)			
	SA_1	SA_2	SA_3	Ro-PS	SA_1	SA_2	SA_3	Ro-PS	SA_1	SA_2	SA_3	Ro-PS
Panicle												
PS_2	15,84	15,92	14,93	15,56	-	-	-	-	-	-	-	-
PS_3	29,05	30,82	29,4	29,77	15,66	17,78	17,28	16,91	-	-	-	-
PS_4	33,39	39,91	39,73	37,67	26,83	26,28	29,38	27,5	13,25	13,16	14,62	13,68
Ro-SA	26,09	28,89	28,02	-	21,25	22,03	23,33	-	13,25	13,16	14,62	-
Straw												
PS_2	15,57	13,54	14,95	14,69	-	-	-	-	-	-	-	-
PS_3	25,01	25,61	24,98	24,98	11,19	13,97	10,95	12,04	-	-	-	-
PS_4	37,64	35,07	35,95	35,96	26,34	24,92	23,6	24,53	17	12,89	14,43	14,77
Ro-SA	26,07	26,74	24,81	-	18,77	19,48	17,94	-	17	12,89	14,43	-
Grain												
PS_2	10,06	7,17	7,3	8,18	-	-	-	-	-	-	-	-
PS_3	17,49	16,46	15,17	16,37	8,38	9,76	16,6	11,58	-	-	-	-
PS_4	24,56	22,09	21,87	22,85	16,12	16,08	15,69	15,96	8,38	6,79	7,41	7,53
Ro-SA	17,37	15,24	14,78	-	12,25	15,89	16,15	-	8,38	6,79	7,41	-

Table 4. Straw and grain dry weight of lowland rice.

	Dry weight (g)							
	Straw				Grain			
	SA_1	SA_2	SA_3	Ro-PS	SA_1	SA_2	SA_3	Ro-PS
PS_1	37,03	37,39	36,66	37,03	48,52	41,35	39,00	42,96
PS_2	45,71	44,28	40,73	43,24	47,54	43,54	43,96	45,00
PS_3	46,98	48,73	49,05	48,25	56,54	51,78	45,25	52,10
PS_4	47,69	51,69	49,36	49,58	59,26	54,89	56,54	56,90
Ro-SA	44,10	45,42	43,95	-	52,97	47,89	46,19	-

assumption that the lower the dpm* values, the higher P-uptake by plants. It is expected that higher P-uptakes would increase plant growth, here expressed as straw and grain dry weights. For the SA it showed that the younger the seedlings age the better the growth expressed in dry weight of grain. However, this is not the case for straw. Apparently the nutrient in the straw, including P, has not been completely distributed to the grain, making the dry weight of straw high. For the interaction of PS × SA the trend of the SA treatment is not always consistent. For several PS × SA treatment as for straw (PS_3 × SA_1, SA_2, SA_3) showed the opposite of the statement above, the younger the seedling age the better the plant growth, here expressed in straw. Plant growth could be expressed as occuring in the dry weights of straw and grain, but it is more accurate to use the dry weight of the whole plant to express the plant's growth, as will be discussed next.

Lowland rice growth expressed in plant growth and P-uptake

In Table 5 the plant growth is expressed in terms of the dry weight of the whole plant, which is the dry weight of the straw plus the dry weight of the grain. The total P-uptake is also the total P-uptake of straw and grain.

A perusal of Table 5 shows that for the PS treatment, their total P-uptake is in line with their plant-dry weight and plant dpm. In other words, the P-total uptake and plant dry weight increase from PS_1 to PS_4, while their dpm decrease. As has previous been explained, the higher the P-total or the higher the dry weight, the lower the dpm. This appears to indicate that the SRI method is better then the conventional method; PS_2, PS_3, PS_4 are superior to PS_1 for their P-total uptake and dry weight. Other interesting data show that PS_3 has a slightly higher P-uptake compared to PS_4, but for the dpm it is reversed. The explanation could be that the dpm is not only decreased by higher P-total uptake but also by higher dry weight. According to Zapata and Axmann [10] the higher the dry weight by any nutrient the lower the dpm. In this experiment, the fertilizer added was compost (PS_3) and 50% inorganic + 50% biofertilizer (PS_4) are also sources of nitrogen. So it is assumed that the dry weight not only depended on P but also on N. It is possible that PS_4 is a better N source than PS_3 and this resulted in higher dry weight of PS_4 than PS_3. The higher dry weight of PS_4 also explains why its P-total uptake is lower than that of PS_3. This is speculated due to the P-total was more diluted in the higher dry weight of PS_4 compared to that of PS_3.

For the SA, for P-total and dry weight, a deeper investigation is still needed to determine which SA is the best. According to Ismachin [11], in practice, farmers tend to use older seedlings (> 7 days old) and still obtain good results for the production.

Table 5. Connection between rice growth and assumed P-uptake predicted by dpm.

	Plant-total P-uptake				Plant-dry weight				Plant-dpm			
	Mg				g				arbitrary units			
	SA_1	SA_2	SA_3	Ro-PS	SA_1	SA_2	SA_3	Ro-PS	SA_1	SA_2	SA_3	Ro-PS
PS_1	205,83	197,94	242,04	215,27	85,55	78,74	75,66	79,98	52963	54095	56198	54491
PS_2	203,72	218,73	221,66	214,70	93,25	87,82	84,69	88,59	46041	48512	49888	48147
PS_3	312,50	305,52	275,37	297,13	103,52	100,51	94,30	99,44	41994	42761	44068	42491
PS_4	288,24	248,51	340,93	292,56	106,95	101,58	95,55	103,03	36448	38795	40171	38471
Ro-SA	252,58	323,57	270,00	-	97,32	93,41	87,55	-	44362	46040	47581	-

CONCLUSION

From this experiment it could be forwarded that the ^{32}P method, expressed in dpm, could be satisfactorily used as a tool for indicating plant growth and P-uptake. The treatments carried out were varying planting systems (PS) and seedling ages (SA) which resulted in significant differences as expected.

The PS comparison clearly showed that the SRI technology is superior to the conventional method. This was shown by higher P-total uptake and dry weight by treatments using SRI compared to the conventional method. While for SA it could be that the seedling age has to be studied more thoroughly, to prove that the younger the seedlings the better the growth of the rice plants.

The lower dpm values which indicate high P-uptake and high dry weight of plants apparently not only depends on phosphorus itself but also by its dry weight. Further, the plant dry weight depends not only on P-uptake but also by N-uptake and this should be studied further, especially to develop SRI technology.

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