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Research Article

Integral Effect of Seed Treatments and Production Systems for Sustainability of Rice Production under Acid Soil

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Abstract

Background and Objective: The establishment of healthy vigorous plant is the first step to attainment of high yield. The study was aimed to evaluate seed priming techniques and rice production systems to reduce the effect of acid soil on rice seed germination, growth, development and yield productivity. **Methodology:** The experiment was conducted by Complete Randomized Design (CRD) with four replications. Rice seeds (*Oryza sativa* L. var. *indica* cv. Pathumthani 1) was primed by three priming materials, polyethylene glycol (PEG) 6000 at the concentration of 10% and 2% potassium nitrate (KNO_3) for 48 h, hydro priming (deionized water) for 24 h, where as non-primed seeds were used as a control treatment. After that, the treated rice seed was grown organically by conventional (CN) and the system of rice intensification (SRI) methods in greenhouse condition using acid soil as growth media. The result showed that primed seed had a significant effect ($p<0.05$) on germination percentage, speed of germination, seedling growth rate and mean emergence time (t50) over control (non-primed seeds). Moreover, the integral of priming techniques and the production systems, SRI result indicate there was significantly different affected on number of leaves, leaf area, leaf and plant dry weight, number of tillers per plant, number filled grains per panicle and total crop yield in kilogram per hectare over CN ($p<0.05$). **Results:** Among the treatments, the hydropriming technique provided the best result of seed germination performance, seedling development parameters and total rice yield per hectare followed by the osmopriming technique using polyethylene glycol (PEG 6000). **Conclusion:** Finally, the promising results were recorded on SRI for Water Use Efficiency (WUE) that the little amount of water used during production was able to double the yield output compered with conventional methods.

Key words: Seed priming, system of rice intensification, osmopriming, acid soil

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

High yield and good quality rice is the most desired end for every rice producer and rice breeders as well. The good end is normally having high consistence with good start in production. Good start in rice production stars with the good quality seeds, which will ensure rapid, uniform and high percentage germination[1]. Rice is a staple food in Thailand, about 91% of people of Thailand eat rice two or three times every day[2]. Central area of Thailand is among the important area for production of Thai rice used for food and export purpose, but large part of central area where irrigated rice are produced were affected by acid soil[3]. Acid soil cause serious problem on the sustainability of irrigated rice production as it delay seed onset, reduce the rate of seed germination and even leading to poor crop health and finally low crop yield[4]. Due to its importance and high demand of rice production in central Thailand, Phatumthani Research Institute has develop a hybrid rice variety which can tolerate acid soils[5]. But use hybrid seeds require again the application lime plus inorganic fertilizer frequently to enhance germination, promoting better growth and development of plant[3]. This process, not only contribute to the increment of acidity in the soil[6] due to acidification, but also raise the costs of rice production, while farm gate price of rice remain unchanged and so the sustainability of rice production became questionable.

As the demand for rice increases, the chances for expanding areas for rice cultivation in the future become limited due to scarcity of land and water for agriculture[7]. Where, as most of the available land especially for irrigation rice production are mostly affected by salinity, alkalinity and acidity, which reduce rice yield[8] and making the land less productive.

Therefore, this study was aimed to determine alternative ways of growing rice by integrating the seed priming technologies and production system using organic farming to reduce the effect of acid soil on seed germination, growth and yield for sustainability of rice production.

MATERIALS AND METHODS

The experiment was conducted in seed laboratory and green house of Agronomy Department, Kasetsart University. Rice seed (*Oryza sativa* L. var. *indica* cv Pathumthani 1 (PT1)) was primed using three osmoticant namely: Polyethylene glycol (PEG) 6000 at the concentration of 10% w/v giving the osmotic potential around -0.85 MPa[9], 2% potassium nitrate KNO_3 (giving the osmotic potential around -0.97 MPa[10] and deionized water (Hydropriming and osmotic potential around 0.0 MPa). Non-primed seeds were used as a control. Before start priming seed initial moisture content (SMC) was determined using high constant temperature oven method at 130°C[11] and found to be 12%, then the moisture were equilibrated to 20% by adding water. The quantity of adding water, in milliliter was calculated by using the following equation:

$$\text{Weight of subsample at 20\% MC} = [\text{initial weight}]\times [(100\text{-initial SMC})/(100\text{-desired SMC})]$$

Then 60 g of rice seeds at ~ 20% SMC were soaked in 600 mL of deionized water for 24 h. Another 60 g rice seeds were soaked in (PEG) 6000 and KNO_3 for 48 h, respectively. The soaked seeds were performed in the germinator, Seed buro Achieva Precision Table Top Germinator, SEEDBURO Equipment Company, Illinois, USA, with oxygen provider at 25°C in darkness. After stop soaking primed seeds were dried to initial SMC then stored for six days before exposure to germination and growth experiment.

The soil, 200 kg of acid soil was collected from Pathumthani province. The site for soil sampling was planted rice for many years and several time lime was applied. The sample was taken soon after rice harvesting season, where the area was flooded to about 1-4 cm of water. There were total of five plots each of 0.5 ha and the sample was taken randomly from each plot, placed in plastic bags and sent to green house of Kasetsart university, for sun dry then grinded, mixed together to ensure uniformity. The acid soil were mixed with organic (cow dung) at the rate of 12 t ha^{-1} and the soil sample was filled into pots arranged in Complete Randomized Design (CRD).

Then water was added into the pots up to (800 mL) 5 cm and the mixture left to stand for 17 days before planting allowing for release of nutrient.

The laboratory soil analysis was done before starting experiment, after addition of OM and after crop harvest. The interesting thing was the increase of soil pH after mixing with cow dung and the result of soil pH after harvesting in both production systems were similar. Previous reports indicate that when acid soil exposed to oxygen the oxidation of FeS_2 in the presence of H_2O result into sulphuric acid so increase acidity in the soil[3], but through this experiment the result of soil after experiment (Table 1) shows no different in soil pH between SRI (saturated and dry) and continuously flooding or conventional practice (CN) experiment result agreed with the study of Shamshuddin *et al.*[12] (Table 1).

Field emergence test: The field emergence test was carried out in green house with CRD, 100 seeds were used per

Table 1: Soil properties of samples collected before and after mixed with organic and after crop harvest labeled S11-2, S11-1, S270-1 and S269-1 respectively

Soil properties	Before mixed with organic matter S11-2	After mixed with organic matter S11-1	After harvesting SRI (S270-1)	CN (269-1)
pH	06.10	7.30	6.70	6.70
Clay (%)	65.00	65.00	60.00	60.00
Organic matter (OM)	5.94	7.47	6.43	6.60
Phosphorus (mg kg^{-1})	85.00	109.00	57.00	54.00
Extractable Fe (mg kg^{-1})	18.19	94.10	127.87	119.06
Extractable Al (mg kg^{-1})	1.60	1.80	nd	nd

nd: Not detected

treatment and four replications each. Temperature and relative humidity of the field was collected 24 h intervals. Radicle emergence (about 2 mm in length) and germination (normal seedling) were determined at 24 h intervals for 28 days and seedling quality was evaluated.

Growth and yield experiment: About 14 and 28 days old seedling were transplanted into the pots filled with acid soil for SRI and CN methods respectively to study the growth and yield parameters. Single seedling was transplanted per pot for SRI, where the soil was just saturated at the spacing of 25×25 cm^2 and four seedlings were transplanted into CN pots flooded at the distance of 10×10 cm^3.

WUE: Seven days after transplanting on SRI, the soil was dried by natural evaporation, until makes the soil crakes around 0.5-1.5 cm depth and then water added again up 800 mL (5 cm). Therefore, makes the soil saturated at interval of 7 days wet and 7 days drying, then at flowering stage 400 mL of water were continuously maintained until harvesting. Continuous flooding of 800 mL was maintained for 110 days from the day one until harvesting time for CN methods.

Data collection: Radical emergence, about 2 mm in length and germination (normal seedling) were determined at 24 h intervals for 24 days. Normal seedling was evaluated in accordance with the ISTA rules for seed testing[13]. Germination indices, both of radical emergence and normal seedling, including maximum radical emergence or normal seedling (%), mean radical emergence or normal seedling, time (hours) and speed of radical emergence or normal seedling (t50, hours) were calculated using GERMINATOR software (curve-fitting program designed for the analysis of germination data)[14]. Germination energy was taken as total percentage of seeds germinated at 72 h according to Stanhill[15]. Shoot and root of 100 representative seedlings were randomly recorded in centimeter. Plant heights, number of leaf and number of tillers were countedat the 39, 49 and 69 Days After Planting (DAP). Number of panicles, filled and unfilled grains per panicle was determined by counting then percentage of filled grain was computed to obtain total yield per treatment and per hectare. Estimated yield and yield component among treatment and production system were done by following equations[16-18]:

$$\text{Harvesting index} = \frac{\text{Economical yield}}{\text{Biological yield}}$$

$$\text{Relative grain yield} = \frac{\text{Yield of treatment}}{\text{Yield of control}}\times100$$

$$\text{Water use efficiency} = \frac{\text{Grain yield (t)}}{\text{Total water used}}$$

Statistical analysis: The experiment was designed as a factorial arrangement in Completely Randomized Design (CRD). Data was presented as mean values of four and three replication where analysis of variance (ANOVA) method was used to compare mean among treatments. Statistix 8.0 computer software was used to carry out statistical analysis. The significance of differences among means was compared by using Less Significant Difference (LSD) *post hoc* tests.

RESULTS AND DISCUSSION

The result from the study suggests that growing rice organically under acid soil by integrating the seed treatment technology and production system (SRI and CN) may improve seed germination, seedling growth rate and total rice yield for both production systems. Treated seeds had a significantly ($p<0.05$) affected on germination percentage (maximum germination), the speed of seed germination, seedling growth rate (germination energy), mean emergence time (t50), number of leaves per plant, Leaf Area Index (LAI), Leaf Dry Weight (LDW), Plant Dry Weight (PDW), number of tillers, number of seeds per panicle, filled grain percentage and total rice yield per hectare over control (non-primed seeds) and between production system.

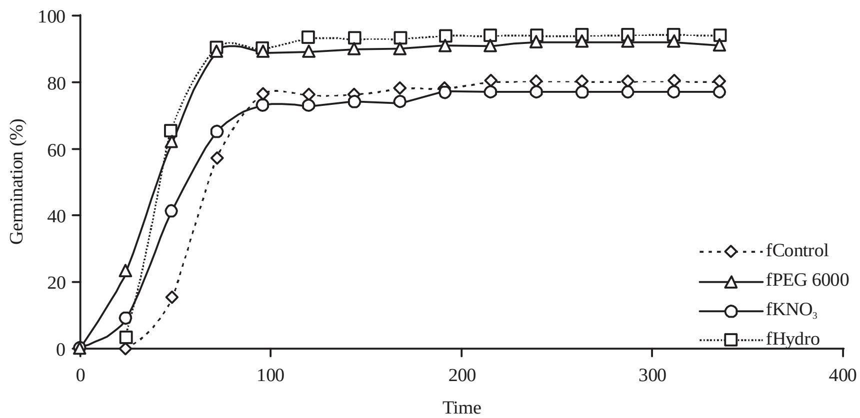

Fig. 1: Cumulative germination percentage in the field of different seed priming processes

Table 2: Effect of different priming methods on germination percentage, germination speed and mean germination time

Treatments	Germination (%)	T50 (days)	Germination energy	Germination speed (%)
Control	77[c]	2.69[a]	61[c]	71[c]
PEG 6000	91[ab]	1.81[b]	92[a]	94[ab]
KNO_3	80[bc]	2.08[b]	79[b]	87[b]
Hydro priming	94[a]	1.93[b]	96[a]	98[a]
CV (%)	4.9**	9.3*	8.4**	6.6**

*Significant, **Highly significant values for the certain parameter marked with the same letter are not significantly different at p<0.05 (LSD test)

The maximum germination was noted in hydropriming, which was 94% followed by osmopriming using PEG 6000, which was 91% (Fig. 1). Primed seeds indicate good germination parameters compare to non-primed seed the results was in accord with the study finding by Khorshidi *et al.*[19].

The result from Table 2 indicated that there is no significant different between hydro priming and osmopriming with PEG 6000 on maximum germination germination energy and germination speed, the two priming technique perform similar. However, these two techniques shows similar performance but hydropriming seems to be the best sustainable technique due to the practice require only water when compared[20] to PEG 6000 and KNO_3. Furthermore, the technique consume less time for preparation. It needs only 24 h where as the other two methods require 48 h to complete treatment process. Likewise in term of environmental safely and cost of processing, the technique is environmental friendly as no chemical used during treatment. Hydropriming is therefore might the best and suitable technique.

Table 2 showed that soaking rice seeds for 24 h using water and 48 h using PEG 6000 at the concertation of 10% reduced MGT from 2.69 days of non-primed seeds to 1.81 and 1.93 days for primed seeds, respectively. The short germination time in the primed seed expresses more uniformity of seedling and fast germination. So, rice seed might be able to escape the problem of late seed onset due to acidity condition of the soil, which agreed with[21].

Results of Table 3 showed highly significantly differenton number of tillers, number of leaf per plant, leaf area and total plant dry weight between primed seeds and non-primed seed (p<0.5). Primed seed from the hydropriming technique were the best of average of 11.8 tillers per plant followed by PEG 6000 with 10.3 tillers per plant. The primed seeds show fast growth with highest plant height and large leaf area. The large leaf area maximizes light intensity-absorption capacity (canopy photosynthesis) hence stimulates formation of carbohydrate which results into high yield capacity of crops[22]. High LAI of 3.36 was obtained from hydroprimingcompare with 3.08 of control. According to Beer-Lambert, high LAI reflects low extinction coefficient (k). Low value of extinction coefficient will provide more yields (Table 3). High dry matter content was obtained in primed seeds compare to control. The high content of biomass in primed seed as the byproduct of rice (Rice straw/rice hulls) can be the best source for renewable energy feed stuff[23,24] and feed to livestock[25].

Greater number of seeds per panicle was observed in the hydropriming with SRI-that gives 134 seed and (PEG) 6000 with SRI that gives 126.9 seeds followed by KNO_3 and hydropriming together with CN that were 121 and 119 seeds, respectively (Table 4). Hydropriming technique indicate best performance in both production systems for total filled grains per plant and final crop yield followed by PEG 6000 and KNO_3, where as the control was the list. Hydropriming showed high yield of 5,425 kg ha^{-1} followed by PEG6000+SRI (4,906 kg ha^{-1}) and KNO_3+SRI (4128 kg ha^{-1}) where least was non primed seed+CN (3065 kg ha^{-1}). Yield differences between treated and non treated seeds were accounted about 34% (Table 5).

Table 3: Effect of different priming methods on plant growth and development parameters

Treatments	No. of tillers	Leaf area (cm)	leaf dry weight (g)	Plant dry weight (g)	LAI	LWR
Control	7.5^{c}	1491.2^{b}	9.8^{c}	18.1^{c}	3.08^{b}	0.544^{b}
PEG 6000	10.3^{b}	1500.2^{b}	11.9^{a}	24.8^{a}	3.10^{b}	0.513^{c}
KNO_3	09.5^{b}	1367.9^{c}	10.1^{d}	21.5^{b}	2.86^{b}	0.574^{ab}
Hydro	11.8^{a}	1627.1^{a}	14.2^{a}	24.7^{a}	3.36^{a}	0.570^{a}
CV (%)	7.8**	4.0**	3.2**	1.2**	3.7**	4.1**

**Highly significant values for the certain parameter marked with the same letter are not significantly different at p<0.05 (LSD test), LAI: Leaf area index and LWR: Leaf weight ratio

Table 4: Integral effect seeds treatments and production systems on plant growth characteristic and final yield for Pathunthani 1 rice variety

Production systems	Treatments	Panicle length (cm)	No. of seed/ panicle	No. of filled grain/panicle	Filled grain (%)	Total yield (kg ha^{-1})	Biological yield/plant (g)	Economic yield/plant (g)	Harvest index
SRI	Control	28.2^{abc}	116.3^{bc}	090.47^{b}	78.7^{a}	3595.8^{cd}	47.8^{c}	27.8^{c}	0.58^{a}
	PEG 6000	28.7^{ab}	126.9^{ab}	101.30^{a}	77.7^{a}	4906.8^{a}	73.5^{a}	39.5^{a}	0.54^{bc}
	KNO_3	27.4^{bcd}	115.3^{c}	097.39^{a}	76.4^{ab}	4128.9^{b}	59.9^{b}	33.8^{b}	0.56^{ab}
	Hydro	29.2^{a}	134.8^{a}	102.73^{a}	81.2^{a}	5425.8^{a}	70.9^{a}	41.7^{a}	0.59^{a}
CN	Control	27.1^{cd}	117.4^{bc}	82.6^{b}	70.7^{b}	3065.9^{c}	27.7^{f}	11.4^{f}	0.41^{e}
	PEG 6000	26.5^{d}	111.3^{c}	84.7^{a}	71.1^{b}	3595.0^{bcd}	31.0^{e}	15.5^{e}	0.49^{cd}
	KNO_3	26.9^{cd}	121.8^{bc}	100.1^{a}	82.8^{a}	3946.5^{bc}	32.5^{e}	15.6^{e}	0.47^{d}
	Hydro	27.0^{cd}	119.8^{bc}	098.2^{a}	81.9^{a}	3765.8^{a}	39.6^{e}	19.3^{d}	0.48^{d}
CV (%)		3.3^{ns}	5.7 *	007.2 **	4.49^{ns}	7.6*	3.55**	6.87*	4.42*

*Significant, **Highly significant values for the certain parameter marked with the same letter are not significantly different at p<0.05 (LSD test)

Table 5: Integral effect seeds treatments with production systems on plant growth characteristics and final yield for Pathunthani 1 rice variety

Production systems	Panicle length	No. of seeds/panicle	No. of filled grain/panicle	Filled grain (%)	Yield (kg ha^{-1})	Total water used (Gallons)	WUE	Harvest index
SRI	28^{a}	123.3^{a}	97.7^{a}	78.5^{a}	5425.8^{a}	13.74	0.32^{a}	0.57^{a}
CN	26^{b}	117.6^{a}	91.6^{b}	76.6^{a}	3560.1^{b}	23.25	0.13^{b}	0.46^{b}
CV	3.3**	5.7^{ns}	7.2*	4.9^{ns}	0009.5**	-	13.60**	13.60**

ns: Not significant, *Significant, **Highly significant, values for the certain parameter marked with the same letter are not significantly different at p<0.05 (LSD test)

The better yield in organic SRI was contributed with higher tillering capacity of treated seeds and the management practice of soil, water and nutrient. The practice promotes the root and tiller to grow faster and healthier as the competition to nutrient was reduced due to wider spacing used during transplanting. Unlike other primed, the seeds treated with KNO_3 under convention system showed high filled grain percentage of 82.8% followed by hydropriming in both CN and SRI by 81.9 and 81.2% respectively (Table 4). The high filled grain percentage in CN method may be an effect of sufficient water availability during growth period. However, osmopriming and hydropriming together with CN shows high filled grain percentage (Table 4) the crop of CN method shows low tillering capacity of 6 and 7.6 tillers per plant respectively, compared to SRI which was 13 and16 tiller per plant (Fig. 2a). The difference of about 65% of tillering capability for primed seed in SRI methods may be from wider spacing used during planting which makes the plant to have good access of light, water and nutrient. Therefore, there was less plant competition. Beside light, water and nutrient, the alternative process of making soil in dry and saturated condition increase availability oxygen to soil and soil biota. The soil biota is important factor that makes organic SRI system study better in this experiment as it speed up decomposition of OM. The process which makes the nutrients to be readily available for plant and due to the created environment of different water potential between the root and the soil the root can go more deep and absorb more nutrients.

In the CN method flooding reduces oxygen and also results in increased ethylene production or lack of ethylene diffusion away from the root due to water logged condition. The poor aeration condition result into straight and shorter roots with more lateral there fore reduce nutrient absorption in deep soil[26].

Moreover according to Van der Kavie and Yenmanas[27], under normal conventional practice in acid soil the application of lime (3-6 t ha^{-1}) and fertilizer (about 30-45 kg of N and 37 kg of P_2O_2), the maximum rice yield is about 1.2-2.2 t ha^{-1}. But the integration of seeds treatment with SRI organic surprisingly the yield show to be high up to 5.4 t ha^{-1} compared to yield of 3.5 t ha^{-1} in the integrated CN organic this increment is equivalent to 34% ha^{-1} (Table 5). The integral of organic SRI approximately save the amount of water use over 41% compare to CN methods.

Furthermore, Hay[16] noticed that increase of HI has parallel consequence increase of WUE. Results of Table 6 showed high

Table 6: Integral effect of different seed priming techniqueson water use efficiency, yield and yield attribute

Treatments	Yield (kg ha^{-1})	1000 grain (g)	Biological yield/plant (g)	Economic yield/plant (g)	Relative grain yield	Harvest index	WUE
Control	3369.8^{b}	22.6^{a}	37.7^{d}	19.6^{d}	100.0^{b}	0.5^{b}	0.19^{b}
PEG 6000	4179.5^{a}	22.8^{a}	52.3^{b}	27.5^{b}	123.62^{a}	0.52^{ab}	0.25^{a}
KNO_3	3993.0^{a}	22.9^{a}	46.2^{c}	24.7^{c}	120.27^{a}	0.52^{ab}	0.23^{a}
Hydro	4300.2^{a}	22.7^{a}	55.3^{a}	30.5^{a}	127.84^{a}	0.54^{a}	0.26^{a}
CV (%)	10.6**	3.4^{ns}	3.55**	6.87**	10.4**	4.42*	10.67**

ns: Not significant, *Significant, **Highly significant values for the certain parameter marked with the same letter are not significantly different at p<0.05 (LSD test)

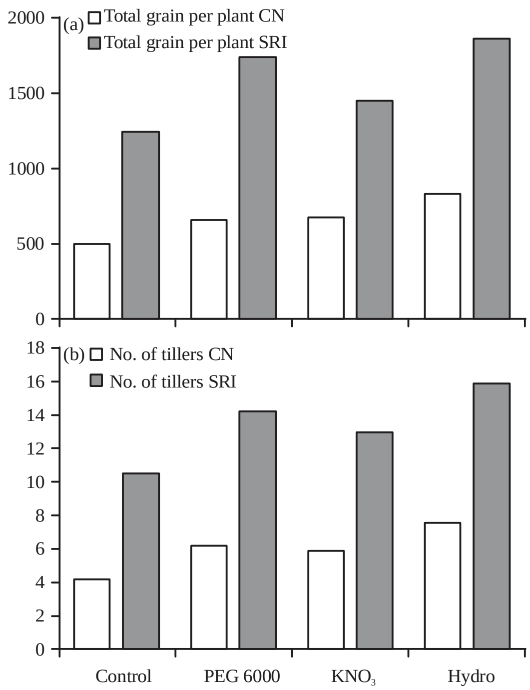

Fig. 2: Effects of different priming methods on number of tillers and number of grain per plant for rice production system after seed treatment

HI and WUE inprimed seeds compered to non-primed seed. Hydropriming has high HI and WUE of 0.54 and 0.26 followed by PEG 6000, which was 0.52 and 0.25 respectively. Higher HI in hydropriming was an expression of increasing ability of spike to compete for assimilation[16]. On the other hand, high WEU was noted in hydropriming followed by PEG 6000 (Table 6). High WUE indicate less amount of water used during production, this is termed as reduced water use (reduced-WU)[28]. Improved WUE on the basis of reduce-WU is explained as an indicator of improved yield under water limited condition. These phenomenon agreed with our result where less water was used in SRI (less by 41%) over CN method but the yield was higher (by 34%) over that of CN (Table 7).

The highly significant differences (p<0.5) observed on yield between production system (Table 5) and within the

Table 7: Comparison of the water use efficiency and yield of each production system DAP = days after planting

Treatment	Watering (DAP)	Drainage (DAP)	Amount of water SRI	CN
Hydro priming	18-24	25-31	800 mL	800 mL for
and control	001-7	008-14	800 mL	110 days
	15-21	22-28	800 mL	
	001-7	008-14	800 mL	
	15-21	xxxxx	800 mL	
	March 22-April 21	xxxxx	400 mL daily for 30 days	
Water (%)		52,000 mL		88,000 mL
used efficiency		(41)		(100)
Harvesting date		Yield	5,425.8 kg ha^{-1}	3,560.1
30/04/2015		(Field)*	(34%)	(kg ha^{-1})

DAP: Days after planting, *Yield was computed on actual filed bases in kilogram per hectare and expressed in percentage

treatments (Table 6) might be the best indicator for alternative sustainable method for integral organic rice production under acid soils conditions.

CONCLUSION AND FUTURE RECOMMENDATIONS

This study determined an alternative way for growing rice under acid soil by integrating the seed treatment technology and production system to improve soil quality, eliminate the effect of acids soil on growth, development and rice yield. Results of the study suggest that treated seeds can escape acidity stress by reducing germination time, increasing germination percentage and germination speed, while enhance rice yield significantly compared to non-treated seeds. Results also revealed that addition of organic matter into acid soil, increase OM content availability of P and raise soil pH. Among the four seeds priming techniques that was applied in this study, the hydropriming (soaking seeds in water for 24 h) and osmopring with PEG 6000 (soaking rice seeds in a solution of polyethylene glycol 6000 for 48 h at the concentration of 100 g kg^{-1} of water) the two method performed similarly. This implies that for the selected variety (phatumthani 1), hydropriming and osmopriming gave better germination performance, growth and final crop yield under acid soil.

The hydropriming is the recommended practice for the selected rice variety as the best alternative methods for ensuring good seeds germination, germination speed and final yield when integrated with SRI when economically sound is considered. One thing to keep in mind is that this study, however was conducted in green house where all factors were controlled. Further study is required to be done in actual field to determine the integral effect of primed seeds and SRI organic under acid soil before a general conclusion is drawn.

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