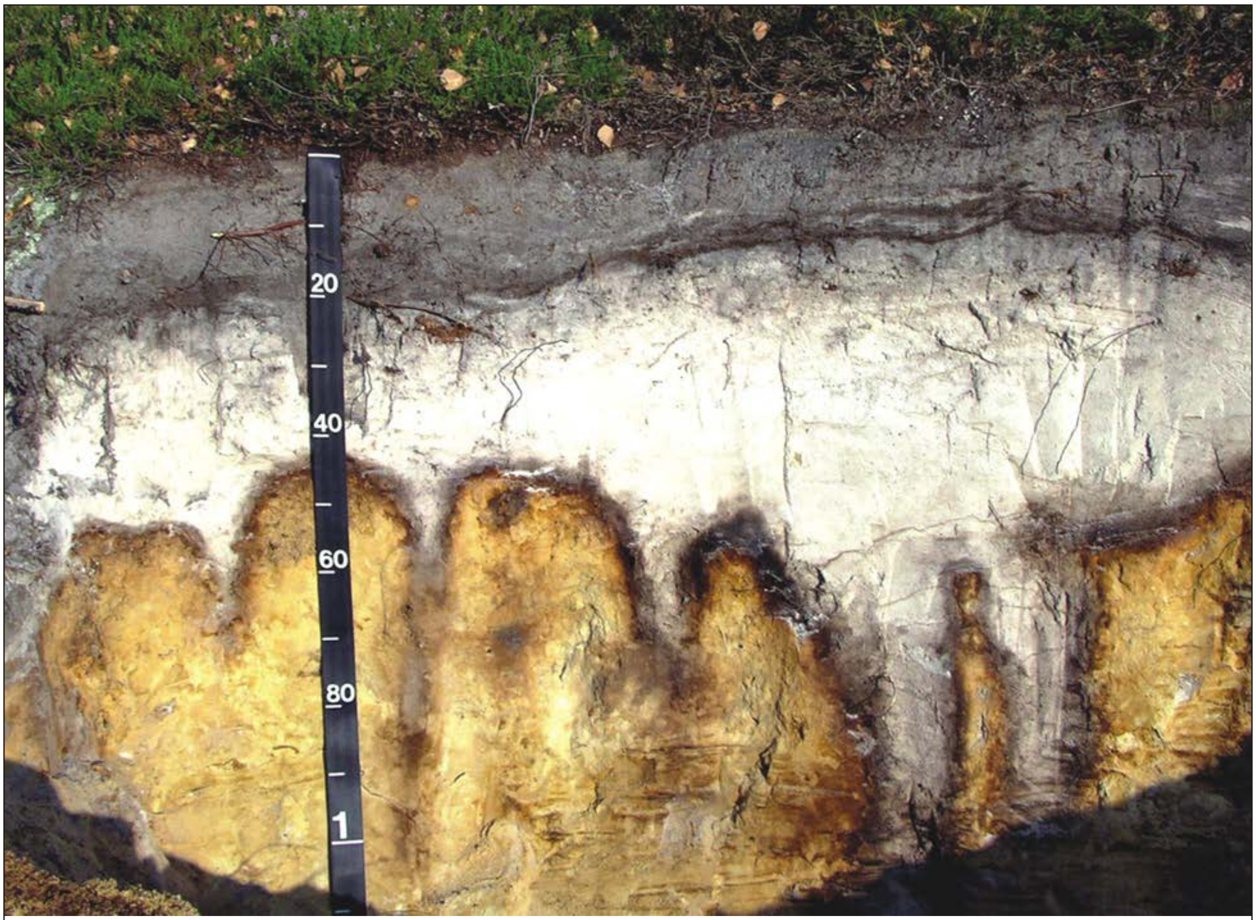

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Soil Amendments Effect on Yield and Quality of Jasmine Rice Grown on Typic Natraqualfs, Northeast Thailand

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ABSTRACT

Response of jasmine rice, KDML 105 cultivar, to different soil amendments; gypsum (0.08 t ha^{-1}), ground limestone (0.03 t ha^{-1}), rice husk (0.16 t ha^{-1}), rice husk biochar (0.08 t ha^{-1}), acacia leaf (0.16 t rai^{-1}), was experimented in saline sodic and sodic soils. Soil amendments applied slightly increased yield and quality of jasmine rice; acacia leaf and gypsum gave, with no statistical difference, the highest grain yield of 1.01 and 1.18 t rai^{-1} when grown on saline sodic and sodic soils, respectively. Rice husk stimulated the highest aromatic 2-AP contents of 3.50 and 3.97 mg kg^{-1} when rice grown on respective sodic and saline sodic soils. This coincided with the highest S concentration in grain, the lowest soil moisture content at the depth between 10-20 cm, the poorest quality of cooked rice, especially in the case of its taste. Aromatic 2-AP in grain statistically correlated with N concentration in grain (r = 0.85**), whereas Na, Zn, Mn and Cu concentrations had significantly negative correlation with rice yield. Soil amendments, gypsum in particular, improved topsoil properties and reduced salinity and sodium adsorption ratio of logging water throughout growth stages when compared to no soil amendment.. In the case of saline sodic soil, gypsum, however, induced the highest ECe, causing rice to produce significantly lowest percentage of filled grain. Rice husk decreased salinity level the most. Incorporated acacia leaf released the highest nitrogen which was consistent with height and grain yield of rice grown on the saline sodic soil.

Key words: Paddy soils, coarse-textured soils, salt affected soils, KDML105 cultivar, milled rice quality

INTRODUCTION

In northeastern region of Thailand, salt affected soils cover approximately 11.5 million hectare and are extensively found in Nakhon Ratchasima province where salt bearing rocks are found underneath (Arunin, 1992). These soils mainly contain the large amount of neutral soluble salts, predominately sodium chloride which result in a high sodium adsorption ratio in a soil solution. The high amount of soluble salts in soils is a serious problem for plant growth (Clermont-Dauphin *et al.*, 2010; Ghassemi *et al.*, 1995). A sodicity problem commonly comprises the loss of soil structure, formation of crusting surface and dispersion of both clay and organic matter (Cha-Um and Kirdmanee, 2011).

Jasmine rice cultivar (*Oryza sativa* L.), namely Khao Dawk Mali 105 (KDML105), are a premium quality and widely cultivated in the Northeast, particularly in the area of salt affected soils. An average reported yield of jasmine rice in the current year was low, 2.01 t ha^{-1} (Office of Agricultural Economics, 2011). This is because of drought problem as mainly affected by substantial soluble salts in these soils which increasingly induce high osmotic potential within the soils in addition with low soil fertility level. Rice often has the same appearance as plants grown under moisture stress conditions (Clermont-Dauphin *et al*., 2010). Moreover, excessive concentration of individual ions e.g., Na, Cl and B, are normally toxic to rice and/or may retard the absorption of other essential plant nutrients (Ghassemi *et al*., 1995; Suwanarit, 1982). Salt also affects photosynthetic components such as enzymes, chlorophylls, carotenoids, depending upon the severity and duration of stress (Ghassemi *et al*., 1995; Clermont-Dauphin *et al*., 2010). Additionally, high salinity level of which the ECe of greater than 8.0 dS m^{-1} reduced grain yield and rice qualities including softness, stickiness, whiteness and glassiness of boiled rice, but increased the aromatic substance contents (Suwanarit *et al*., 1991; Wanichananan *et al*., 2003). There are many researchers who reported that the incorporation of soil amendments could successfully reclaim salt affected soils in the area where water resource was limited. Calcium-rich soil amendments such as gypsum can reduce the sodicity problem (Qadir *et al*., 1996; Ilyas *et al*., 1997), whereas the incorporation of plant residues and the use of green manure can preserve soil moisture during rice growing period and consequently decrease the salinity effect on rice growth (Suwanarit, 1982; Brady and Weil, 2008). Nevertheless, the attempt to increase the yield by increasing the amount of fertilizers applied such as nitrogen, phosphorus and potassium has been unsuccessful due to a negative relationship between grain yield and aromatic substances (Suwanarit *et al*., 1991). Therefore, the reclamation of soil affected soils by using soil amendments objectively to improve soil moisture availability for jasmine rice production in the northeast Thailand is probably more practical.

MATERIALS AND METHOD

Study area and soil characteristics: Field trials under rainfed condition were set up during July, 2012 and November, 2012. Regarding to ECe and SAR values, chosen areas were saline sodic- and sodic soils (Table 3), located in farmer fields at Kamtalesor district, Nakhon Ratchasima province, northeast Thailand. The saline Sodic Site (SS) was located on 47P 0810600^{E}, 1668647^{N} which was approximately of 500 m northerly aspect away from the sodic site (Sod) (47P 08105563^{E}, 1668387^{N}) (Fig. 1). Both areas were nearly flat terrain with slope gradient of 1%. The areas are under tropical savanna climate with average annual rainfall and temperature of 1,054 mm/yr and 28.0°C, respectively.

According to soil taxonomy (2010), the representative soils of both experimental sites were classified as Typic Natraqualfs (Table 2). The soils had sandy loam to sandy clay loam texture as influenced by their parent material, sandstone derived alluvium. Soil pH was moderately alkaline to very strongly alkaline (pH 7.5-10.0) which was consistent with the high sodium adsorption ratio (19.64-77.87) as normally found in saline sodic- and sodic soils. They had non to moderately salinity level (0.58-7.71 dS m^{-1}), very low to very high contents of extractable bases ofwhich Na was dominant. Additionally, they had poor fertility status (Table 3).

Experimental design and land preparation: Six treatments in Randomized Complete Block Design with four replications were employed in each site. The treatments were composed of three

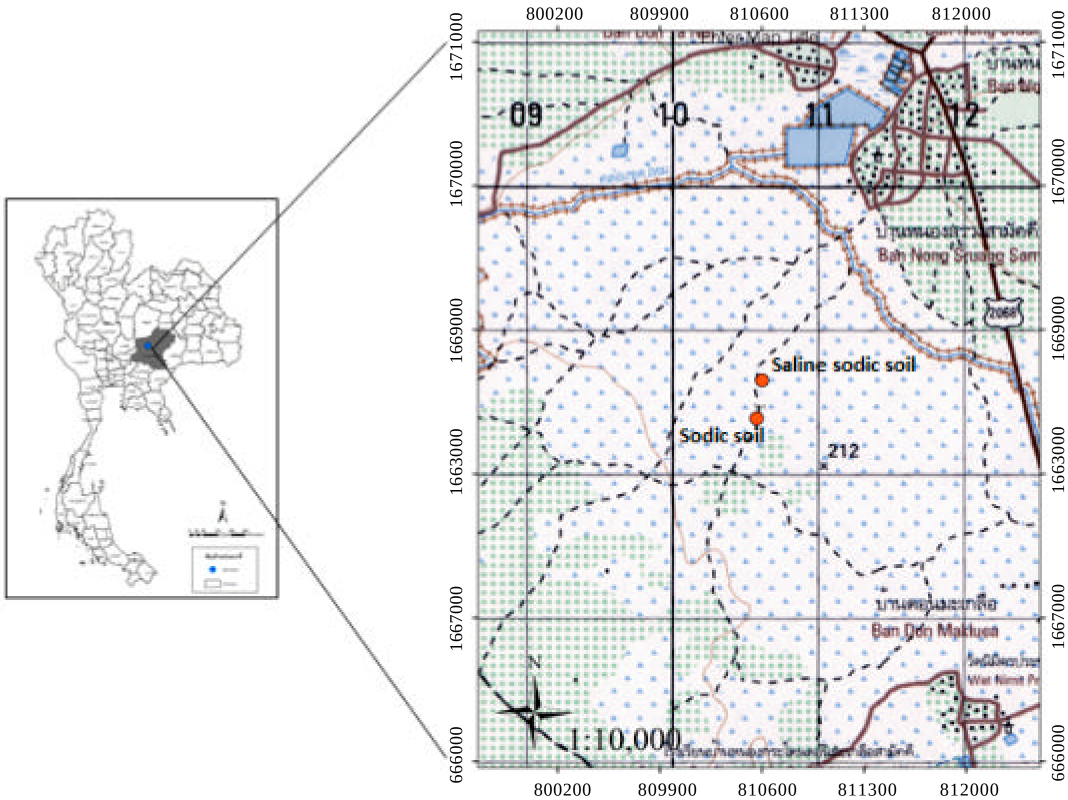

Fig. 1: Locations of salt affected soil chosen for set up the experiment in Kamtalesor district, Nakhon Ratchasima province Northeast Thailand

types of soil amendments such as gypsum (0.08 t ha^{-1}), ground limestone (0.03 t ha^{-1}), rice husk (0.16 t ha^{-1}), rice husk biochar (0.08 t ha^{-1}), fresh acacia leaf (0.16 t rai^{-1}) and no application of soil amendment as a control. Properties and plant nutrient compositions of soil amendments used in this experiment were given in Table 1.

Soil in the experimental areas was ploughed twice using harrowing before building up bunds surrounding each plot. Plot with 3×3 m size was completely separated from each other by these bunds. Soil amendments were applied and incorporated into soils by hoe to approximate depth of 15 cm from the surface. All plots were left follow for three weeks before transplanting jasmine rice, KDML105 cultivar, using 35 days old seedling with plant spacing of 25×25 cm.

Fertilization for all treatments was performed based on recommended rate, 0.125 t ha^{-1} of 16-16-8 at 10 days after transplanting and topdressing with 16-16-8 and urea (46-0-0) at the rates of 0.063 and 0.044 t ha^{-1} at tillering and booting stages, respectively. Pest and weed controls and all other necessary operations were performed uniformly for all treatments according to general local practices and recommendations.

Soil sampling and laboratory analyses: Composite soil samples of topsoil (0-15 cm) and subsoil (15-60 cm) layers were collected prior to conducting the experiment for soil property analyses. Topsoil samples from each plot were collected at two following times, 3 weeks after the incorporation of soil amendments and 1 week after harvesting rice for the analyses of soil property changes.

Table 1: Property of soil amendments used in this experiment

Property	Rice husk	Rice husk biochar	Acacia leaves	Ground limestone	Gypsum
pH (1:5 H_2O)	6.4	7.5	6.6	9.2	8.1
EC (1:5 H_2O) (dS m^{-1})	2.08	2.48	12.48	0.06	2.49
Organic matter (%)	131.3	39.6	145.0	-	-
C/N ratio	264:1	132:1	98:1	-	-
Dry matter (%)	84.4	99.0	54.6	99.9	94.2
N (g kg^{-1})	2.88	1.74	8.56	nd	0.01
P (g kg^{-1})	1.33	1.51	2.23	nd	nd
K (g kg^{-1})	3.64	7.55	14.36	0.05	0.03
Ca (g kg^{-1})	2.40	2.14	31.38	265.44	75.14
Mg (g kg^{-1})	0.44	0.93	3.61	21.92	0.20
Na (g kg^{-1})	0.26	0.57	0.36	0.04	0.02
S (g kg^{-1})	0.74	0.48	1.18	0.22	2.22
Si (g kg^{-1})	13.46	23.01	0.96	1.63	1.14
Zn (mg kg^{-1})	21.1	109.4	8.9	24.0	-
Fe (mg kg^{-1})	844	954	268	717	239
Mn (mg kg^{-1})	269	463	137	43	15

nd: Not detectable, -: Not determined

Table 2: Site characterization of the salt affected soils used in the experiment

Horizon	Depth (cm)	Sand	Silt	Clay	Texture[1/]	pH (1:1 H_2O)	ECe (dS m^{-1})	SAR	Extractable ($cmol_c$ kg^{-1}) Ca	Mg	Na	K	BS (%)
		------------g kg^{-1}	------------										
Saline sodic soil: Typic Natraqualf													
Apg	0-25	655	253	92	SL	7.5	3.82	35	0.78	0.32	3.36	0.02	69
Btng1	25-40	604	260	136	SL	9.4	6.69	58	0.53	0.34	8.74	0.02	76
Btng2	40-64	616	252	132	SL	9.7	5.71	69	0.48	0.27	7.82	0.02	81
Btng3	64-90	608	236	156	SL	9.7	7.71	59	0.38	0.15	6.99	0.02	79
Btng4	90-115	619	233	148	SL	9.4	5.93	73	0.45	0.24	8.16	0.03	75
Btng5	115-140	595	221	184	SL	9.6	5.12	78	0.38	0.19	7.04	0.02	72
Btng6	140-170	585	191	224	SCL	9.5	2.39	61	0.85	0.44	9.85	0.05	85
Btng7	170-200	616	180	204	SCL	9.7	2.30	74	0.77	0.37	7.84	0.04	82
Sodic soil: Typic natraqualf													
Apg	0-20	747	145	108	SL	8.6	2.43	26	1.39	0.54	2.23	0.02	68
Btng1	20-40	725	179	96	SL	9.2	2.24	25	1.80	0.97	5.20	0.02	89
Btng2	40-58	729	143	128	SL	9.4	1.54	23	1.22	0.63	3.48	0.05	73
Btng3	58-79	723	153	124	SL	9.6	0.97	35	2.01	0.78	3.82	0.02	77
Btng4	79-103	715	125	160	SL	9.6	0.89	33	1.87	0.79	4.02	0.02	87
Btng5	103-132	692	136	172	SL	9.7	0.86	31	2.10	0.92	3.96	0.02	78
Btng6	132-158	670	114	216	SCL	10.0	0.72	20	1.47	1.15	6.78	0.03	83
Btng7	158-175	636	88	276	SCL	9.7	0.58	23	1.01	1.15	6.98	0.05	79
Btng8	175-200	601	91	308	SCL	9.4	0.58	48	2.08	1.39	10.47	0.04	85

[1/]USDA system, SL: Sandy loam, SCL: Sandy clay loam

Soil samples were air-dried, crushed and passed through 2 mm sieve. Then soil samples were used for laboratory analyses basing on the standard procedure, consisting of total N (Jackson, 1956), extractable NH_4^+ and NO_3^--N (Keeney, 1982), organic carbon content (Nelson and Sommers,

Table 3: Properties of the soil prior to conducting the experiment

	Saline sodic soil (SS)		Sodic soil (Sod)	
Soil property	Topsoil (0-15 cm)	Subsoil (15-60 cm)	Topsoil (0-15 cm)	Subsoil (15-60 cm)
pH (1:1 H_2O)	7.3	9.9	7.4	9.9
ECe (dS m^{-1})	3.9	6.7	1.4	1.8
SAR	52.4	175.9	24.4	86.3
Organic matter (g kg^{-1})	4.8	1.4	6.7	2.4
Available P (mg kg^{-1})	2.4	1.0	2.4	1.5
Extractable Ca ($cmol_c$ kg^{-1})	0.76	1.01	1.40	1.51
Extractable Mg ($cmol_c$ kg^{-1})	0.34	0.04	0.51	0.80
Extractable K ($cmol_c$ kg^{-1})	0.02	0.02	0.03	0.04
Extractable Na ($cmol_c$ kg^{-1})	3.36	8.28	2.26	4.34
CEC ($cmol_c$ kg^{-1})	2.88	1.38	3.25	5.63
BS (%)	69	78	67	81
Soil texture	Loamy sand	Sandy loam	Loamy sand	Sandy loam

1996), available phosphorus (Bray and Kurtz, 1945), available potassium (Thomas, 1982) electrical conductivity of the soil extract (EC_e) (Richards, 1954) and Sodium Adsorption Ratio (SAR) (USDA, 1954).

Plant sampling and laboratory analyses

Yield components: Grain yield adjusting to 14% moisture content and rice components such as weight of 100 grains, % filled grain and weight of dried straw were harvested within the harvesting area of 4 m^2 and measured when the rice was 132 days old.

Plant nutrient concentrations: Plant parts (rice grain and straw) of rice samples were collected at the harvesting time for determining plant nutrient concentration and uptake in harvested plant parts. All plant part samples were oven dried at 60°C, ground and used for plant nutrient measurement. Plant samples were digested with H_2SO_4-Na_2SO_4-Se mixture and then total N was analyzed by using Kjeldahl method (Jackson, 1956). For other total plant nutrient compositions except for Si, plant samples were digested with HNO_3-H_2SO_4-$HClO_4$ mixture (Johnson and Ulrich, 1959), then P content was determined by using UV-Vis., Spectrophotometer (Murphy and Riley, 1962) and K, Ca, Mg, Na, Zn, Fe, Mn and Cu contents were determined by using Atomic Absorption Spectrophotometry (Westerman, 1990). Total Si content was determined by colorimetric method (Nayar *et al.*, 1975) after plant samples were digested with conc. HNO_3.

Quality of jasmine rice, KDML 105: Milled rice was prepared by removing all bran and germ from the rough rice after hand milling. Milled rice grains were placed in plastic, airtight bags and stored at 10°C for approximately one month before conducting the analysis. A content of 2-acetyl-l-pyrroline (2-AP) was determined by using gas chromatography (Petrov *et al.*, 1995). Amylase content was determined according to the modified method of Juliano (1971).

Milled rice was cooked for 20 min in automatic rice cooker at a 1:1.6 (v/v) rice to water ratio for determining the aroma, softness, stickiness, whiteness and glassiness of cooked milled rice by using sensory methodology (Amerine *et al.*, 1965). These qualitative scores were rated by 20 testers. Scoring was ranging from (5) Extremely satisfied, (4) Very satisfied, (3) Satisfied, (2) Not satisfied, (1) Not identified.

Water sampling and laboratory analyses: Logging water in each plot was sampled every two weeks, starting from 1-9 weeks after transplanting. Water samplings were stopped at the stage of ripening when water was drained out from the plot. The depth of waterlogging in plots was also recorded at the same time of sampling by using a ruler. The samples were used for determining pH, electrical conductivity and sodium adsorption ratio (Richards, 1954; USDA, 1954)

Time domained refectrometry installation: The Time Domained Refectrometry (TDR) probes were installed in the center of representative plots in both salt affected soils to determine the soil moisture content at the following depths; 10, 20, 40 and 80 cm. The installations were set up at three weeks after planting jasmine rice. The weekly measurement was undertaken after logging water having been drained out from the plot at the ripening stage until the harvesting time. In the case of saline sodic soil, moisture content cannot be read because of the rise of water table to soil surface throughout rice growing period.

Statistical analyses: All parameters as an indication of the reclamation efficiency of soil amendments were analyzed for statistical significance. The analysis of variance (ANOVA) was done by using SPSS program ver.16.0 and Duncan's Multiple Range Test (DMRT) used to analyze mean separation at a significant level at least $p<0.05$. Plant nutrient concentrations in rice grain and straw and their relationships to yield and aromatic 2-AP substance of jasmine rice were determined by using Statistica program version 6.0.

RESULTS AND DISCUSSION

Yield components of jasmine rice, KDML 105: There was significant difference on plant height only when KDML 105 rice grown on a saline sodic soil amended with different soil conditioners. Gypsum as well as acacia leaves significantly induced the greatest height of rice whereas the other soil conditioners gave plant height statistically lower than did the control plot (Table 4). However, organic soil amendments tended to increase rice grain yield better than did inorganic soil amendments, especially the application of acacia leaves which, no statistical difference, gave the highest amount of 1.01 t ha^{-1} (Fig. 2). These result indicated that organic amendments may have been more efficient in preserving soil moisture in a saline sodic soil during a period of growth when compared to inorganic amendments. The result agrees with Cha-Um and Kirdmanee (2011) that the application of green manure and farmyard manure (ratio 1:1 by wt.) at the rate 12.5 kg m^{-2} gave the highest rice yield (55% increase).

When grown on the sodic soil, there was only filled grain percentage that showed statistical difference (Table 4). The addition of gypsum to a sodic soil with no statistical difference gave the lowest filled grain percentage (86.3%) which in contrast to the the highest grain yield of 1.18 t ha^{-1} obtained (Fig. 2). This is because gypsum diminished the problem of Na^{+} by replacing it in the rooting zone with Ca^{2+} (Ilyas *et al.*, 1997). Calcium in ground limestone may have played a similar fashion, hence this application gave the highest filled grain percentage of 93.0 and 93.5% when grown on sodic and saline sodic soils, respectively (Table 4).

Table 4: Effect of soil amendments on yield components of Jasmine rice grown on salt affected soils

	Filled grain (%)		100-grain weight (g)		Straw weight (t ha^{-1})	
Treatment[1/]	SS[1/]	Sod[2/]	SS[1/]	Sod[2/]	SS[1/]	Sod[2/]
No soil amendment	89.3	92.0[a]	3.7	3.8	0.92	1.51
Gypsum 0.08 t ha^{-1}	87.5	86.3[b]	3.8	3.8	1.12	2.01
Ground limestone 0.03 t ha^{-1}	93.5	93.0[a]	3.7	3.8	1.33	1.51
Rice husk 0.16 t ha^{-1}	90.5	88.8[ab]	3.7	3.8	1.20	1.66
Rice husk biochar 0.08 t ha^{-1}	90.0	92.0[a]	3.7	3.7	1.21	1.12
Acacia 0.16 t ha^{-1}	90.3	91.5[a]	3.4	3.7	1.61	1.58
F-test [3/]	ns	*	ns	ns	ns	ns
	Height (cm)		Plant (No./tiller)		Panicle (No./tiller)	
Treatment[1/]	SS[1/]	Sod[2/]	SS[1/]	Sod[2/]	SS[1/]	Sod[2/]
No soil amendment	103[ab]	106	3.1[bc]	3.3[b]	3.5[ab]	3.6[bc]
Gypsum 0.08 t ha^{-1}	107[a]	103	3.3[ab]	3.6[a]	3.2[c]	3.7[ab]
Ground limestone 0.03 t ha^{-1}	101[b]	104	3.1[bc]	3.3[b]	3.4[abc]	3.9[a]
Rice husk 0.16 t ha^{-1}	99[b]	110	3.0[c]	3.3[b]	3.3[bc]	3.6[b]
Rice husk biochar 0.08 t ha^{-1}	101[b]	106	2.9[c]	3.3[b]	3.2[bc]	3.9[a]
Acacia 0.16 t ha^{-1}	106[a]	102	3.5[a]	3.2[b]	3.6[a]	3.3[c]
F-test [3/]	*	ns	**	**	**	**

[1/]SS: Saline sodic soil, [2/]Sod: Sodic soil, [3/]ns: Non significant, *,**Significant at 0.05 and 0.01 probability levels, respectively. Means in the same column followed by the same lowercase letter are not significantly different using Duncan's multiple range test at p<0.05

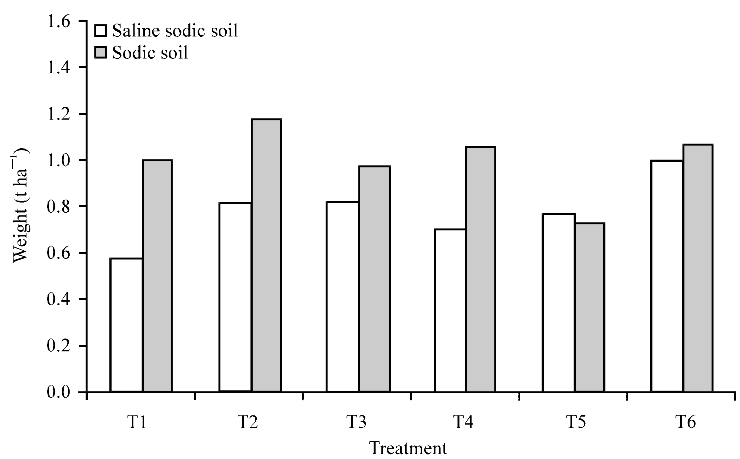

Fig. 2: Effect of soil amendments on yield of jasmine rice grown on saline sodic and sodic soils T1: No soil amendment (control), T2: Gypsum 0.08 t ha^{-1}, T3: Ground limestone 0.03 t ha^{-1}, T4: Rice husk 0.16 t ha^{-1}, T5: Rice husk biochar 0.08 t ha^{-1} and T6: Acacia 0.16 t ha^{-1}

Jasmine rice quality: Soil amendments had slight effect on a content of aromatic 2-AP substance in rice grain which was clearly observed in the case of sodic soil (Fig. 3). Rice husk was likely to effectively stimulate the synthesis of aromatic 2-AP with the highest content obtained from both sodic and saline sodic soils (Fig. 3). Rice husk application in sodic soil significantly gave the highest content of 2-AP substance of 3.97 mg kg^{-1} in rice grain, followed by the applications of ground limestone (3.52 mg kg^{-1}), rice husk biochar (3.22 mg kg^{-1}), gypsum (3.19 mg kg^{-1}) and acacia leaves

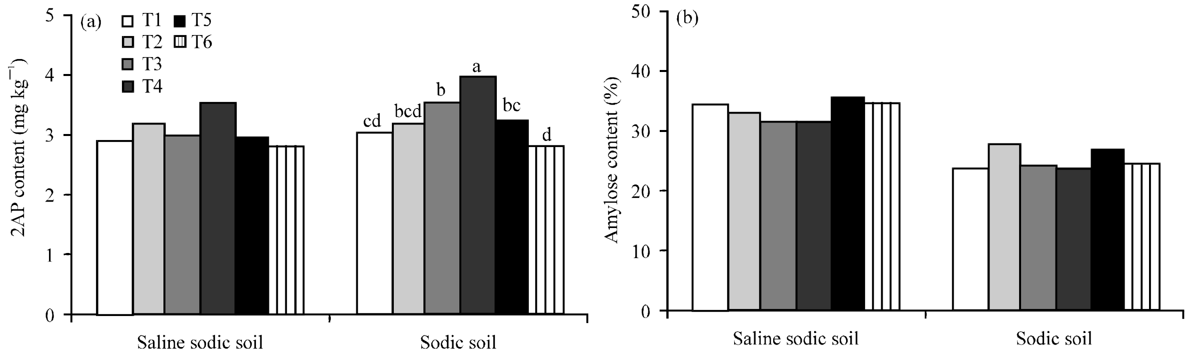

Fig. 3(a-b): Effect of soil amendments on aromatic 2AP substance and amylose contents in rice grain of jasmine rice grown on salt affected soils. T1: No soil amendment (control), T2: Gypsum 0.08 t ha^{-1}, T3: Ground limestone 0.03 t ha^{-1}, T4: Rice husk 0.16 t ha^{-1}, T5: Rice husk biochar 0.08 t ha^{-1} and T6: Acacia 0.16 t ha^{-1}, Remark: Different letters (a, b, c or d) in graph differ significantly according to Duncan's multiple range test at $p<0.05$

Table 5: Sensory scores for qualities of cooked milled rice as affected by different soil amendments

	Scores of qualities									
	Aroma		Solfness		Whiteness		Stickiness		Glassiness	
Treatment[1/]	SS[2/]	Sod[3/]	SS[2/]	Sod[3/]	SS[2/]	Sod[3/]	SS[2/]	Sod[3/]	SS[2/]	Sod[3/]
T1	2.8	3.2^{ab}	3.1^{bc}	3.3^{b}	3.5^{ab}	3.6^{bc}	3.1	3.4	3.3	3.4^{ab}
T2	2.9	3.0^{b}	3.3^{ab}	3.6^{a}	3.2^{c}	3.7^{ab}	3.2	3.6	3.2	3.4^{ab}
T3	2.9	3.0^{b}	3.1^{bc}	3.3^{b}	3.4^{abc}	3.9^{a}	3.1	3.4	3.1	3.6^{a}
T4	2.8	3.0^{b}	3.0^{c}	3.3^{b}	3.3^{bc}	3.6^{b}	3.3	3.4	3.2	3.2^{b}
T5	2.6	3.2^{ab}	2.9^{c}	3.3^{b}	3.2^{bc}	3.9^{a}	3.0	3.5	3.2	3.6^{a}
T6	3.0	3.3^{a}	3.5^{a}	3.2^{b}	3.6^{a}	3.3^{c}	3.3	3.4	3.2	3.2^{b}
F-test[4/]	ns	*	**	**	**	**	ns	ns	ns	**

[1/]T1: No soil amendment, T2: Gypsum 0.08 t ha^{-1}, T3: Ground limestone 0.03 t ha^{-1}, T4: Rice husk 0.16 t ha^{-1}, T5: Rice husk biochar 0.08 t ha^{-1}, T6: Acacia 0.16 t ha^{-1}, [2/]SS: Saline sodic soil, [3/]Sod: Sodic soil, [4/]ns: non significant, *,**Significant at 0.05 and 0.01 probability levels, respectively. Means in the same column followed by the same lowercase letter are not significantly different using Duncan's multiple range test at $p<0.05$

which the later gave lowest content of 2.81 mg kg^{-1}. This can be interpreted as the result of high nitrogen content released to the soil during the decomposition of the acacia leaf. As a result, high nitrogen content rather enhanced vegetative plant growth than increased aromatic substance production as agreed with previous reports (Suwanarit *et al*., 1991; Kanchanaprasert, 1988). However, 2-AP content in rice grain was not statistically different in the case of jasmine rice grown on the saline sodic soil but the amount obtained was similar to that gained from the sodic soil. Additions of rice husk and acacia leaves gave the highest and lowest contents of aromatic 2-AP substance with the respective values of 3.50 and 2.82 mg kg^{-1}. This was in contrast to the qualities of cooked mill rice which rice husk and acacia leaves gave the lowest and the highest qualities such as aroma, softness and whiteness (Table 5). Moreover, the concentration of aromatic substance in jasmine rice grown on the sodic soil was higher than of those grown on the saline sodic, 2.81-3.97

compared to 2.82-3.50 mg kg^{-1}. This is due to the higher amount of sodium contained in the sodic soil which results in inducing more stress on rice growth. Consequently, carbohydrates in grains change to differentiation product, therefore, the aroma increased (Kanchanaprasert, 1988; Buttery *et al.*, 1982).

The use of rice husk biochar and gypsum was likely to induce the highest amylose content of 35.7 and 28.1% when grown on saline sodic and sodic soils, respectively, but without a statistical difference. Moreover, the amylose contents retrieved from this study were 31.4-35.7% and 23.8-28.1% for rice grown on saline sodic and sodic soils, respectively which were higher than the normal value (14-18%) produced by jasmine rice as reported elsewhere (Wongpiyachon *et al.*, 1998); therefore the stickiness of cooked rice in this case was poorer.

Plant nutrient concentrations: There was no significant effect of soil amendments on plant nutrient concentration in grain of jasmine rice grown on both salt affected soils except for N and Cu concentrations in the case of saline sodic soil (Table 6 and 7). It was found that the highest concentrations of N (15.5 mg kg^{-1}) and Cu (1.17 mg kg^{-1}) in rice grain were found in the plot without applying soil amendment but grain yields obtained from this control treatment were lowest (Table 6). Rice husk, without statistical difference, tended to give the higher S concentration in rice grain than did other soil amendments (Table 6). This result was consistent with the highest 2-AP content in rice grain (Fig. 3); because S is known as promoter to simulate fragrant in plant (Wongpiyachon *et al.*, 1998; Suwanarit *et al.*, 1991). Na accumulation in grain of jasmine rice grown on the saline sodic soil was higher than that on the sodic soil (Table 6 and 7); consequently, it caused the lower grain yield. Result also revealed that the application of soil amendments in this saline sodic soil was likely to reduce the toxicity of Na, especially in the case of gypsum that induced

Table 6: Effect of soil amendments on plant nutrients concentrations in rice grain of jasmine rice grown on salt affected soils

	Plant nutrients concentrations in rice grain											
	N	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu	Si	Na
Treatment[1/]	g kg^{-1}			mg kg^{-1}							g kg^{-1}	
Saline sodic soil												
T1	15.5^{a}	3.32	1.31	59	219	1028	18.8	8.1	7.8	1.17^{a}	1.56	0.08
T2	13.8^{b}	1.43	1.31	119	248	694	16.9	12.2	7.3	0.90^{ab}	1.91	0.06
T3	13.5^{b}	1.34	1.29	96	245	616	17.4	23.7	7.2	0.52^{b}	1.35	0.07
T4	13.7^{b}	1.57	1.42	67	277	935	17.6	6.1	8.2	0.61^{b}	1.41	0.07
T5	13.1^{b}	1.43	1.30	88	249	664	17.0	35.8	8.0	0.82^{ab}	1.61	0.08
T6	13.5^{b}	1.24	1.34	63	259	688	18.2	7.1	7.8	0.72^{b}	2.15	0.07
F-test[2/]	**	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
Sodic soil												
T1	15.38	1.3	1.18	92	203	844	18.3	5.8	6.1	0.91	1.76	0.05
T2	15.57	1.39	1.25	83	218	792	14.4	5.1	5.4	1.02	1.75	0.06
T3	15.49	1.36	1.22	91	233	739	15.9	6.0	5.8	0.91	1.82	0.06
T4	16.98	1.31	1.21	61	226	927	16.4	5.3	5.9	1.24	1.65	0.06
T5	15.53	1.38	1.27	82	243	947	17.5	8.3	6.0	0.84	1.44	0.06
T6	14.94	1.45	1.27	84	218	958	16.5	3.5	5.7	0.88	1.20	0.06
F-test[2/]	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1/]T1: No soil amendment, T2: Gypsum 0.08 t ha^{-1}, T3: Ground limestone 0.03 t ha^{-1}, T4: Rice husk 0.16 t ha^{-1}, T5: Rice husk biochar 0.08 t ha^{-1}, T6: Acacia 0.16 t ha^{-1}, [2/]ns: Non significant, *,**Significant at 0.05 and 0.01 probability levels, respectively. Means in the same column followed by the same lowercase letter are not significantly different using Duncan's multiple range test at $p<0.05$

Table 7: Effect of soil amendments on plant nutrients concentration in straw of jasmine rice grown on salt affected soils

	Plant nutrients concentration in rice straw											
	N	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu	Si	Na
Treatment[1/]	g kg^{-1}			mg kg^{-1}							g kg^{-1}	
Saline sodic soil												
T1	8.25	1.58	6.30	829^{b}	957	674^{b}	25.4^{a}	315	1.17^{a}	1.1^{b}	7.86	5.06
T2	8.31	1.69	7.76	1069^{a}	893	1537^{a}	15.0^{b}	309	0.90^{ab}	1.9^{a}	5.92	4.99
T3	9.03	1.69	6.70	788^{b}	899	708^{b}	20.5^{ab}	187	0.52^{b}	1.8^{a}	8.28	4.48
T4	9.78	1.98	7.97	650^{b}	811	590^{b}	25.5^{a}	218	0.61^{b}	1.2^{b}	9.04	4.69
T5	9.10	2.07	6.16	692^{b}	810	650^{b}	26.9^{a}	228	0.82^{ab}	1.3^{ab}	7.53	6.81
T6	6.34	1.74	5.82	700^{b}	897	617^{b}	18.5^{ab}	336	0.72b	1.4^{ab}	6.40	4.23
F-test[2/]	ns	ns	ns	**	ns	**	*	ns	*	*	ns	ns
Sodic soil												
T1	7.18	0.98	8.80	761	965	675	14.9	269	756	1.0	7.47	5.50
T2	7.68	1.01	8.31	699	1053	783	12.6	232	706	1.4	7.25	4.68
T3	7.57	1.21	8.05	725	1027	1085	12	228	670	1.0	6.12	6.11
T4	9.33	1.17	7.57	738	1056	885	12.9	266	772	1.4	7.40	5.32
T5	8.09	1.5	7.66	739	903	904	19.1	230	763	1.1	8.05	3.97
T6	7.39	1.14	6.83	741	1069	845	14.7	279	824	1.2	8.14	6.39
F-test[2/]	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1/]T1: No soil amendment, T2: Gypsum 0.08 t ha^{-1}, T3: Ground limestone 0.03 t ha^{-1}, T4: Rice husk 0.16 t ha^{-1}, T5: Rice husk biochar 0.08 t ha^{-1}, T6: Acacia 0.16 t ha^{-1}, [2/]ns: Non significant, *,**Significant at 0.05 and 0.01 probability levels, respectively. Means in the same column followed by the same lowercase letter are not significantly different using Duncan's multiple range test at $p<0.05$

the lowest Na concentration in rice grain. Regarding plant nutrient concentration in straw, the addition of gypsum in the saline sodic soil statistically induced the highest concentrations of Ca, S and Cu (1,069, 1,537 and 1.9 mg kg^{-1}, respectively) which were consistent with the highest plant height and the greatest numbers of tiller and spikelet. The application of organic soil amendments tended to increase Zn concentration, especially when applied rice husk biochar (26.9 mg kg^{-1}) (Table 6). The highest Mn concentration of 1.17 mg kg^{-1} was found in rice grown with no application of soil amendment. With no statistical difference, soil amendments tended to reduce Na concentration in straw which the lowest Na concentration (4.23 g kg^{-1}) that coincided with the highest grain yield was obtained when applied acacia leaves. The concentrations of plant nutrient in straw of jasmine rice grown on the sodic soil were not significantly different (Table 7), however, soil amendments gavelower Na concentration, especially in the case of rice husk biochar (3.97 g kg^{-1}).

In the context of correlation between plant nutrient concentrations in rice grain and straw and 2AP content and grain yield, there was only N concentration in rice grain that had highly statistically correlated with the aromatic 2AP content with r = 0.85** (Table 8). This result was not consistent with previous studies reported by Kanchanaprasert (1988) and Suwanarit *et al.* (1991) who found that the unfavorable conditions for growing crops such as water stress, high salinity and sodium levels, low contents of nitrogen and phosphorus, promoted the simulation of the aromatic 2-AP substances. Additionally, concentrations of sodium (r = -0.63*), zinc (r = -0.64*) manganese (r = -0.71*) and copper (r = -0.62*) in rice grain had negative correlations with rice grain yield (Table 8). This interpreted that the yield of jasmine rice grown on these salt affected soils would be low when the plant took up more of Na, Zn, Mn and Cu to store in the rice grains.

Table 8: Correlation coefficients of plant nutrient concentrations and 2-acetyl-1-pyrroline and yield of jasmine rice grown on salt affected soils

Plant nutrient concentration in grain	2AP	Yield	Plant nutrient concentration in straw	2AP	Yield
N	0.85**	-0.14	N	0.24	-0.01
P	-0.49	0.38	P	-0.12	0.03
K	-0.29	0.22	K	0.27	0.24
Ca	-0.17	0.07	Ca	-0.07	-0.18
Mg	0.13	-0.41	Mg	0.15	0.25
Na	-0.45	-0.63*	Na	-0.02	-0.28
Si	0.03	0.28	Si	-0.02	-0.02
Fe	-0.28	-0.38	Fe	-0.12	0.18
Mn	-0.29	-0.71*	Mn	-0.14	-0.06
Cu	-0.35	-0.62*	Cu	-0.01	-0.08
Zn	-0.38	-0.64*	Zn	-0.25	-0.06
S	0.20	-0.19	S	0.18	0.04

*,**Correlations are significant at 0.05 and 0.01 probability levels, respectively, n = 48

Soil properties: Properties of the topsoils in both studied areas as affected by soil amendments were not clear (Table 9). However, soil amendment applications had a potential to improve topsoil property. The incorporation of organic soil amendments tended to reduce the salinity level more than did inorganic soil amendments. Significant reduction in salinity in saline sodic soils with the value of 1.74 and 0.84 dS m^{-1} for both collected before transplanting and after harvesting, respectively, after treated with rice husk (Table 9). This result indicated that rice husk could preserve soil moisture during the rice growing period better than other soil amendments, consequently decreasing the salinity effect on rice as consistent with numerous reports (Puttaswamygowda and Pratt, 1973; Brady and Weil, 2008). Therefore, the rice yield increased possibly because of the efficiency of this organic soil amendment.

Gypsum was the best soil amendment that can reduce SAR in both soils studied, giving the lowest SAR valuesof the soils after the incorporation of soil amendments and after harvesting rice of 10.4 and 2.3, respectively (Table 9). This result agrees with some previous studies (Qadir *et al.*, 1996; Ilyas *et al.*, 1997) because exchangeable Na^+ in soils was replaced by Ca^{2+} that was released from gypsum applied. However, gypsum statistically increased highest acidity (pH 6.13) and electrical conductivity (5.61 dS m^{-1}) of the saline sodic soil (Table 9), resulting in the lowest percentage of filled grain (Table 4) of rice which was adversely affected by the high salinity level (Cha-Um and Kirdmanee, 2011). The highest available phosphorus content stored in soil after harvesting rice (4.18 mg kg^{-1}) in the plot applied with gypsum, nevertheless, played no part in enhancing the increase of grain yield.

Rice husk biochar significantly released the highest content of NO_3-N of 16.1 mg kg^{-1} in the sodic soil after it was incorporated which was similar to the amount of 10.3 mg kg^{-1} obtained from the plot amended with acacia leaves). Rice husk released the lowest NO_3-N content of 4.0 mg kg^{-1} because of its greatest C:N ratio. The incorporation of acacia leaf gave the highest NO_3-N contents of = 2.98 and 5.25 mg kg^{-1} stored in both saline sodic and sodic soils after harvesting rice (Table 9). This result was consistent with height and grain yield of rice grown on this soil (Table 4 and Fig. 2). Besides, the application of rice husk, rice husk biochar and acacia leaf tended to retain

Table 9: Effects of soil amendments on topsoils property of salt affected soils at 3 weeks after the incorporation of soil amendments and 1 week after harvesting rice

	Topsoils (0-15 cm)							
	Incorporation of soil amendments		After harvesting rice		Incorporation of soil amendments		After harvesting rice	
	SS[1/]	Sod[2/]	SS[1/]	Sod[2/]	SS[1/]	Sod[2/]	SS[1/]	Sod[2/]
Treatment	ECe ($dS\ m^{-1}$)				SAR			
No soil amendment	2.20^{bc}	3.50	1.08^{b}	1.53	49.4^{ab}	26.9	9.0^{bc}	30.0
Gypsum 0.08 $t\ ha^{-1}$	5.61^{a}	4.68	2.05^{a}	1.16	10.4^{d}	82.5	2.3c	34.8
Ground limestone 0.03 $t\ ha^{-1}$	2.6^{bc}	4.72	1.17^{b}	1.54	30.9^{bc}	34.4	4.5^{bc}	26.2
Rice husk 0.16 $t\ ha^{-1}$	1.74^{c}	3.41	0.84^{b}	1.33	47.8^{ab}	47.6	10.3^{ab}	29.5
Rice husk biochar 0.08 $t\ ha^{-1}$	3.23^{bc}	3.87	0.99^{b}	1.04	56.1^{a}	27.2	17.1a	35.8
Acacia 0.16 $t\ ha^{-1}$	3.73b	3.98	1.09^{b}	1.49	23.7^{cd}	43.7	10.5^{ab}	35.3
F-test [3/]	**	ns	**	ns	**	ns	**	ns
	Soil pH (1:1 H_2O)				**OM ($g\ kg^{-1}$)**			
No soil amendment	7.08	8.49	6.19^{b}	7.93	7.6	8.1	6.7^{ab}	4.6
Gypsum 0.08 $t\ ha^{-1}$	6.13	8.65	6.29^{b}	8.24	9.4	5.4	7.8a	3.2
Ground limestone 0.03 $t\ ha^{-1}$	7.25	7.94	6.71^{ab}	8.34	9.1	6.3	5.0^{b}	3.2
Rice husk 0.16 $t\ ha^{-1}$	6.78	8.34	6.20^{b}	7.79	9.9	6.8	8.2^{a}	4.7
Rice husk biochar 0.08 $t\ ha^{-1}$	7.03	7.64	6.28^{b}	7.70	8.1	8.5	6.3^{ab}	4.3
Acacia 0.16 $t\ ha^{-1}$	6.93	8.56	6.84^{a}	8.59	7.9	7.4	6.8^{ab}	3.4
F-test [3/]	ns	ns	*	ns	ns	ns	ns	ns
	$N\text{-}NH_4^+$ ($mg\ kg^{-1}$)				**$N\text{-}NO_3^-$ ($mg\ kg^{-1}$)**			
No soil amendment	6.3	6.1	17.2	1.230	2.6	4.9^{b}	1.050	0.88
Gypsum 0.08 $t\ ha^{-1}$	12.6	2.1	16.8	1.051	2.6	4.7^{b}	0.001	1.58
Ground limestone 0.03 $t\ ha^{-1}$	10.2	3.2	11.2	0.700	3.0	4.4^{b}	0.350	0.88
Rice husk 0.16 $t\ ha^{-1}$	12.1	2.6	10.5	1.582	2.8	4.0^{b}	0.001	1.40
Rice husk biochar 0.08 $t\ ha^{-1}$	14.2	1.9	17.5	0.702	4.2	16.1^{a}	2.470	1.75
Acacia 0.16 $t\ ha^{-1}$	10.2	4.9	9.1	0.001	1.9	10.3^{ab}	2.980	5.25
F-test [3/]	ns	ns	ns	ns	ns	*	ns	ns
	Available P ($mg\ kg^{-1}$)				**Available K ($mg\ kg^{-1}$)**			
No soil amendment	5.1^{c}	6.4	2.8^{b}	3.4	20.1	20.3	27.0	11.5
Gypsum 0.08 $t\ ha^{-1}$	5.4^{bc}	6.0	4.2^{a}	3.0	23.8	31.4	18.5	10.7
Ground limestone 0.03 $t\ ha^{-1}$	6.2^{abc}	4.0	2.5^{b}	2.7	48.8	14.3	21.9	10.2
Rice husk 0.16 $t\ ha^{-1}$	8.9a	5.7	3.4^{ab}	4.1	32.4	16.1	21.5	11.9
Rice husk biochar 0.08 $t\ ha^{-1}$	8.1^{ab}	4.8	3.3^{ab}	2.6	24.8	13.5	21.3	8.6
Acacia 0.16 $t\ ha^{-1}$	5.9^{bc}	4.8	3.3^{ab}	2.4	22.7	19.2	19.1	11.1
F-test [3/]	*	ns	*	ns	ns	ns	ns	ns

[1/]SS: Saline sodic soil, [2/]Sod: Sodic soil, [3/]ns: Non significant, *,**Significant at 0.05 and 0.01 probability levels, respectively. Means in the same column followed by the same lowercase letter are not significantly different using Duncan's multiple range test at $p<0.05$

higher amounts of soil organic matter and nutrients in both salt affected soils after harvesting rice than did the applications of gypsum and ground limestone (Table 9). The incorporation of soil amendments showed different effect on the form of N released when compared between saline sodic- and saline soils. The former soil had more of NH_4^+-N while NO_3^--N was detected more in the latter soil (Table 9). The amount of N clearly reduced in soils after harvesting rice especially

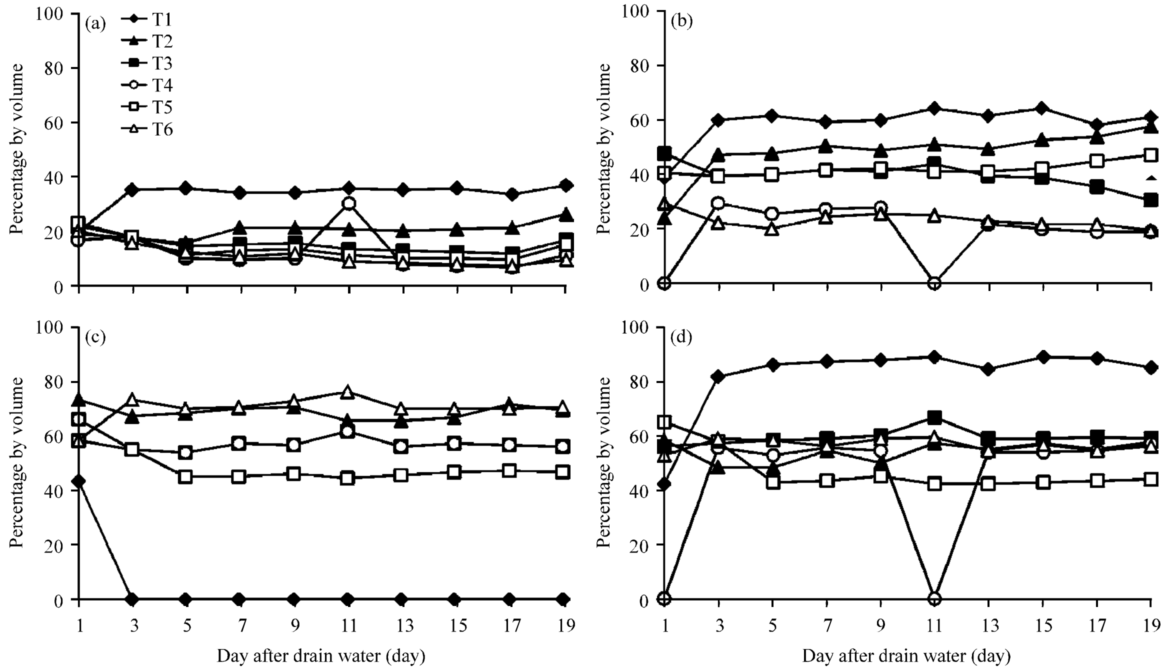

Fig. 4(a-d): Effects of soil amendments on soil moisture content of sodic soil at percentage by volume. T1: No soil amendment (control), T2: Gypsum 0.08 t ha^{-1}, T3: Ground limestone 0.03 t ha^{-1}, T4: Rice husk 0.16 t ha^{-1}, T5: Rice husk biochar 0.08 t ha^{-1} and T6 = Acacia 0.16 t ha^{-1} (a) 10, (b) 20, (c) 40 and (d) 80 cm depth

NH_4^+-N. This is because rice mostly consumed N in the form of NH_4^+-N (Suwanarit, 1982; Lipman and Conybeare, 1936) while NO_3^--N was easily leached by water. In addition, the application of rice husk, rice husk biochar and acacia leaf tended to maintain higher amounts of organic matter and plant nutrients in soil after harvesting rice than did the application of gypsum and ground limestone (Table 9).

Time Domained Refectrometry was installed in representative plots in sodic soil to determine soil moisture content changes during ripening and harvesting periods. The content was measured at the following depths; 10, 20, 40 and 80 cm (Fig. 4). Result revealed that a control plot had the highest soil moisture content for the longest periods except those measured at the depth of 40 cm that cannot be detected. Soil moisture content increased with depth in all treatments. The incorporation of rice husk gave the lowest soil moisture content for most periods of measurement with the values of 12.6-57.8% by vol., especially in between 0-20 cm depth (12.6-19.0%) which was consistent with the highest 2-AP content (Fig. 3). This indicated that water stress starting from ripening to harvesting periods favored jasmine rice to produce the aromatic substance (Jongkaewwattana *et al.*, 2005).

Property of flooded water during the rice growing period: Water-logging levels in the two studied sites during transplanting to rippenning periods ranged between 3.5-11.0 and 3.0-10.0 cm for saline sodic and sodic soils, respectively (Fig. 5 and 6). The pH of logged water in saline sodic

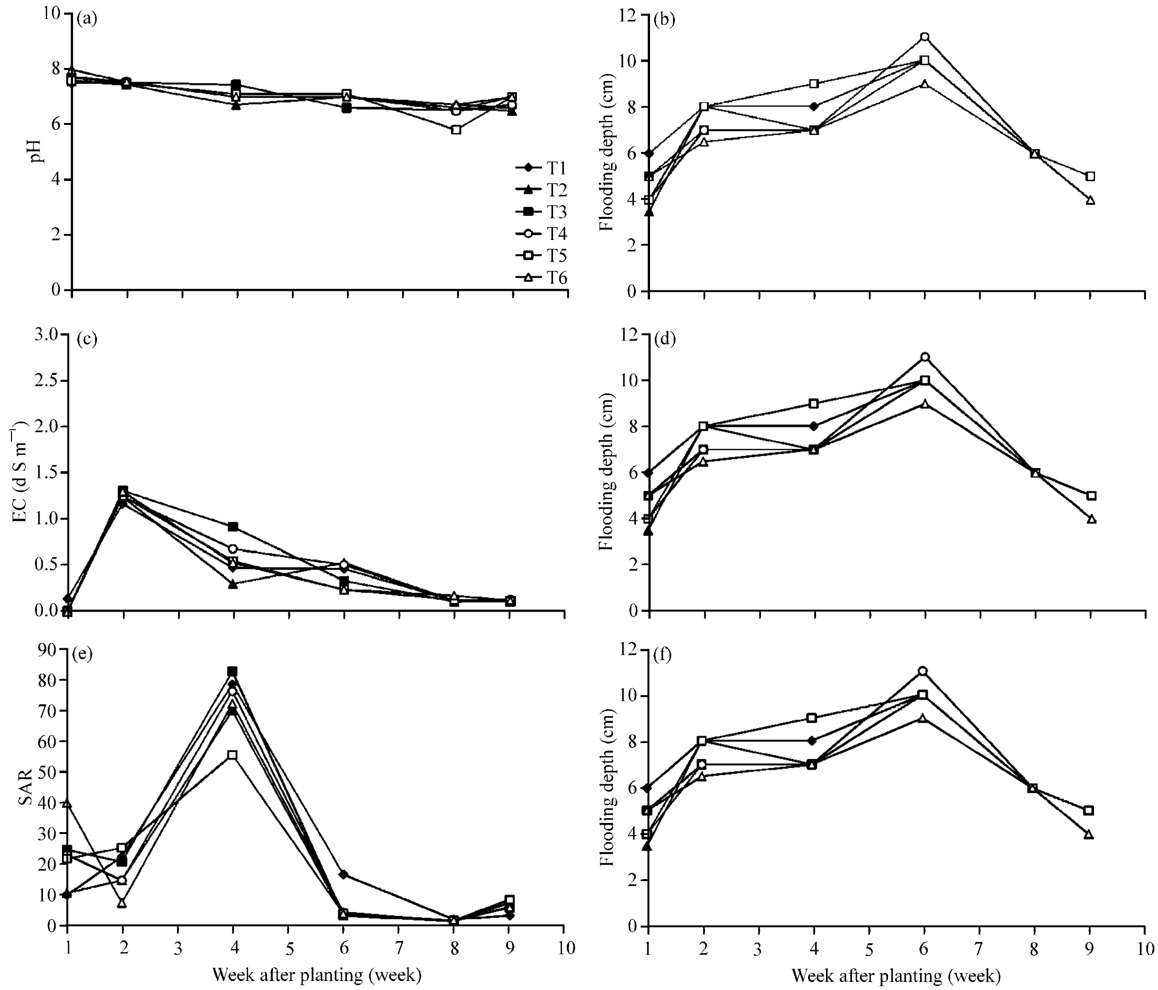

Fig. 5(a-f): Effects of soil amendments on property of logged water on saline sodic soil during transplanting to ripening periods of jasmine rice growing at different (a) pH, (c) Elective conclusion, (e) SAR and (b, d, f) Flooding depth. T1: No soil amendment (control), T2: Gypsum 0.08 t ha^{-1}, T3: Ground limestone 0.03 t ha^{-1}, T4: Rice husk 0.16 t ha^{-1}, T5: Rice husk biochar 0.08 t ha^{-1} and T6: Acacia 0.16 t ha^{-1}

and sodic soils amended by different soil amendments ranged from 5.85-7.94 and 6.65-8.85, respectively, but there was no difference compared to the control. This is due probably to flooding effect (Kyuma, 2004; Stumm and Morgan, 1970) (Fig. 5 and 6). Logged water on these saline sodic and sodic soils were at non salinity level with the value of 0.014-1.29 and 0.13-2.74 dS m^{-1}, respectively (Fig. 5 and 6). Soil amendments showed no different impact on the salinity levels of logged water, however, the level was slightly decreased in the periods of grain setting and rippenning stages. The control plot with no soil amendment application induced the highest salinity level logged water, especially at 1 and 2 weeks after transplanting rice in sodic- and saline sodic soils, repectively (Fig. 5 and 6). This resulted in the lowest grain yield obtained (Fig. 2). SAR values of waterlog in the sodic soil applied with different soil amendments were highest at 1 week after transplanting and the highest value of 60.8 was detected from the control plot. After that, the value

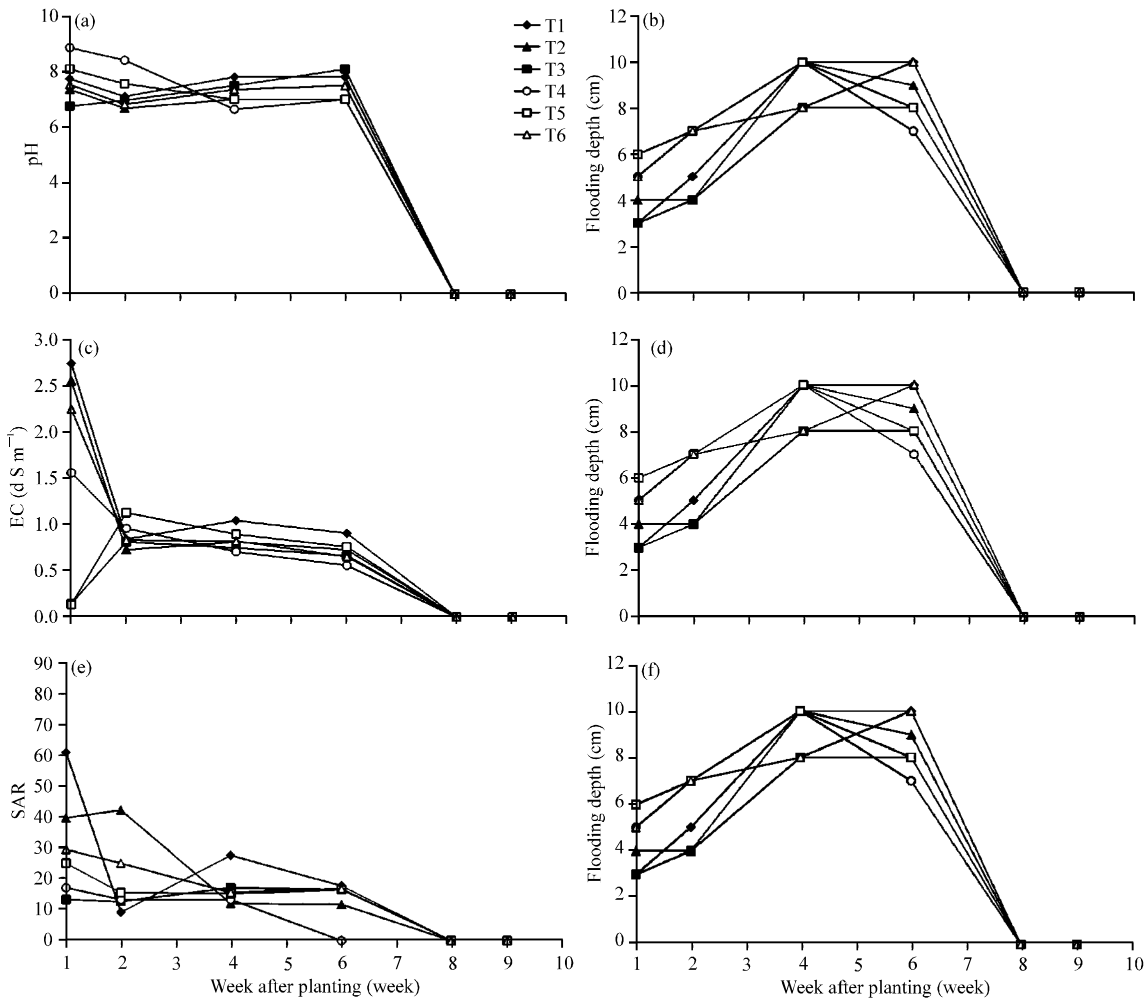

Fig. 6(a-f): Effects of soil amendments on property of logged water on sodic soil during transplanting to ripening periods of jasmine rice growing at different (a) pH, (c) Elective conclusion, (e) SAR and (b, d, f) Flooding depth. T1: No soil amendment (control), T2: Gypsum 0.08 t ha^{-1}, T3: Ground limestone 0.03 t ha^{-1}, T4: Rice husk 0.16 t ha^{-1}, T5: Rice husk biochar 0.08 t ha^{-1}, T6: Acacia 0.16 t ha^{-1}

slightly decreased and was clearly down to lower than 13 at the flowering stage except for the control plot. The same trend was found in saline sodic soil. SAR values of logged water in the saline sodic soil slightly increased as the plant grown and the maximum values of 55.8-82.7 were found at 4 weeks after transplanting and then decreased to below 13 at flowering stage. Gypsum tended to have more effect on the reduction of sodium adsorption ratio than the other soil amendments in both soils. This is because Ca that was released from gypsum reduced the effect of Na in the solutions (Brady and Weil, 2008; Qadir *et al.*, 1996; Ilyas *et al.*, 1997).

CONCLUSION

The incorporation of soil amendments had slightly effects on yield and quality of jasmine rice grown on saline sodic and sodic soils, Typic Natraqualfs. The organic soil amendments, especially acacia leaf applied at the rate of 0.16 t ha^{-1}, were the most suitable for the reclamation of saline sodic soil for growing jasmine rice, considering the highest yield obtained and the increased available nitrogen contents in this soil. Applying gypsum to the sodic soil gave the highest yield, whereas the greatest percentage of filled grain was found in the plot amended with ground limestone in both salt affected soils. Rice husk applied at the same rate as acacia leaf was the most effective soil amendment in terms of decreasing soil salinity, increasing available phosphorus and organic matter contents in the soils and tended to induce the greatest synthesis of aromatic 2-AP substance in rice grain.

In the contrary, the inorganic soil amendments diminished the problem of sodium more efficiently than did the organic soil amendments. Gypsum was the most effective soil amendment used to reduce sodium adsorption ratio but tended to increase the highest acidity and electrical conductivity in the saline sodic soil which the latter effects resulted in the lowest percentage of filled grain. Organic matter and plant nutrient contents stored in soil after harvesting rice were lower compared to the amounts in the soil after the incorporation of soil amendments. This included salinity level and SAR which were reduced to the level that were harmless to plant growth at the time before transplanting jasmine rice. Soil amendments tended to reduce salinity and sodium adsorption ratio of logged water in sodic and saline sodic soils during all stages of growth better when compared to no soil amendment application.

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REFERENCES

Amerine, M.A., R.M. Panghon and E.B. Roessler, 1965. Principle of Sensory Evaluation of Food. Academic Press, New York, ISBN-13: 978-0120561506, Pages: 602.

Arunin, S., 1992. Strategies for utilizing salt-affected lands in Thailand. Proceedings of the International Symposium on Strategies for Utilizing Salt Affected Lands, February 17-25, 1992, Bangkok, Thailand.

Brady, N.C. and R.R. Weil, 2008. The Nature and Properties of Soils. 14th Edn., Prentice Hall, Inc., New Jersey, ISBN: 13-978-0-13-227938-3.

Bray, R.H. and L.T. Kurtz, 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci., 59: 39-45.

Buttery, R.G., L.C. Ling and B.O. Juliano, 1982. 2-Acetyl-1-Pyrroline an important aroma component of cooked rice. Chem. Ind., 13: 958-959.

Cha-Um, S. and C. Kirdmanee, 2011. Remediation of salt-affected soil by the addition of organic matter: An investigation into improving glutinous rice productivity. Scientia Agricola, 68: 406-410.

Clermont-Dauphin, C., N. Suwannang, O. Grunberger, C. Hammecker, C. Hammecker and J.L. Maeght, 2010. Yield of rice under and soil salinity rash in farmers fields in Thailand. Field Crop Res., 118: 289-296.

Ghassemi, F., A.J. Jakeman and H.A. Nix, 1995. Salinisation of Land and Water Resources: Human Causes, Extent, Management and Case Studies. UNSW Press, Wallingford, UK.

Ilyas, M., R.H. Qureshi and M.A. Qadir, 1997. Chemical changes in a saline-sodic soil after gypsum application and cropping. Soil Technol., 10: 247-260.

Jackson, M.L., 1956. Soil Chemical Analysis-Advanced Course. Department of Soils, University of Wisconsin, Madison, WI.

Johnson, C.M. and A. Ulrich, 1959. Analytical methods for use in plant analysis. Calif. Agri. Exp. Stat. Bull., 767: 26-78.

Jongkaewwattana, S., S. Meechoui, V. Tulyathan, S. Wongpornchai, A. Pontanee and A. Polvatana, 2005. The effects of environmental factors and management strategies on grain quality of rice cv. Khao Dok Mali 105: System approach study. Department of Agriculture, Bangkok. http://mis.agri.cmu.ac.th/research/view_research_detail.asp?TRes_id=04-052-B-46.

Juliano, B.O., 1971. A simplified assay for milled rice amylose. Cereal Sci. Today, 16: 334-338.

Kanchanaprasert, N., 1988. A study on vital diagnostic features in soil development and land potential evaluation of alfisols and inceptisols in Mae Klong drainage basin. Ph.D. Thesis, Kasetsart University, Bangkok, Thailand.

Keeney, D.R., 1982. Nitrogen-Availability Indices. In: Methods of Soil Analysis, Physical and Mineralogical Methods, Part 1, Klute, A. and Page, A.L. (Ed.). 2nd Edn., American Society Agronomy Inc., Madison, Wisconsin, USA.

Kyuma, K., 2004. Paddy Soil Science. Kyoto University Press, Kyoto, Japan, ISBN: 9781920901004, Pages: 280.

Lipman, J.G. and A.B. Conybeare, 1936. Preliminary note on the inventory and balance sheet of plant nutrients in the United States. Bulletin New Jersey Agricultural Experiment Station 607, pp: 1-23.

Murphy, J. and H.P. Riley, 1962. Phosphorus Analysis Procedure. In: Method of Soil Analysis, Part 2. Chemical and Microbiological Properties, Page, A.L., R.H. Miller and D.R. Keeney (Eds.). 2nd Edn., America Society of Agronomy Inc., Madison, Wisconsin, pp: 413-414.

Nayar, P.K., A.K. Misra and S. Patnaik, 1975. Rapid microdetermination of silicon in rice plant. Plant Soil, 42: 491-494.

Nelson, D.W. and L.E. Sommers, 1996. Total Carbon, Total Organic Carbon and Organic Matter. In: Methods of Soil Analysis, Part 3: Chemical Methods, Sparks, D.L. (Eds.). American Society of Agronomy, Madison, Wisconsin, pp: 961-1010.

Office of Agricultural Economics, 2011. The key economic forecasting crop production, crop year 2556/57. Journal of Agricultural Productivity Forecasting. http://www2.oae.go.th/mis/Forecast/page3_th.html

Petrov, M., M. Danzart, P. Giampaoli, J. Faure and H. Richard, 1995. Rice aroma analysis: Discrimination between a scented and a non-scented rice. Sci. Aliments, 16: 339-352.

Puttaswamygowda, B.S. and P.F. Pratt, 1973. Effects of straw, calcium chloride and submergence on a sodic soil. Soil Sci. Soc. Amer. Proc., 37: 208-212.

Qadir, M., R.H. Qureshi and N. Ahmad, 1996. Reclamation of a saline-sodic soil by gypsum and *Leptochloa fusca*. Geoderma, 74: 207-217.

Richards, L.A., 1954. Diagnosis and Improvement of Saline and Alkali Soils. U.S. Salinity Laboratory Handbook No 60. USDA, Washington, DC.

Stumm, W. and J.J. Morgan, 1970. Aquatic Chemistry an Introduction Emphasizing Chemical Equilibrium in Natural Waters. Wiley-Inter Sci. Inc., New York.

Suwanarit, A., 1982. Soil and Plant Relationship. Kasetsart University, Bangkok.

Suwanarit, A., K. Somchai, V. Warunee, T. Patcharee and S. Sirichai *et al*., 1991. Effects of the fertilizer elements, sulphur, soium and salinity on yield and quality of rice. Kasetsart University Annual Report, Bangkok.

Thomas, G.W., 1982. Exchangeable Cations. In: Methods of Soil Analysis, Page, A.L., R.H. Miller and D.R. Keeney (Eds.). ASA and SSSA, Madison, WI., pp: 159-165.

USDA, 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA, Washington, DC.

Wanichananan, P., C. Kirdamanee and C. Vutiyano, 2003. Effect of salinity on biochemical and physiological characteristics in correlation to selection of salt-tolerance in aromatic rice (*Oryza sativa* L.). Sci. Asia, 29: 333-339.

Westerman, R.L., 1990. Soil Testing and Plant Analysis. 3rd Edn., American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin.

Wongpiyachon, S., P. Sawangjit and N. Kongseri, 1998. Rice cooking quality from difference mixed ratio between KDML105 with Chainat 1 or RD23 varieties. Department of Agriculture, Bangkok.