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Effect of Irrigation Regime and Fertilizers to Iron (Fe) Dynamic in Paddy Soil and Rice Yield

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Abstract: This paper presents the effects of different irrigation regimes and fertilizers to Fe available in paddy soil and rice yield in Red River Delta, Vietnam. Results show that shallow and exposure irrigation method by withdrawing water during shooting stage decreased Fe^{2+} in soil, rice uptake and increased rice yield compared to the traditional method. Organic fertilizer reduced Eh soil and increased Fe^{2+}, while cultivation method can limit Fe toxicity for rice easily by FeOOH precipitation. In shallow and exposure irrigation formula by withdrawing water, the Fe-H_2O content was decreased shapely compared to the regular shallow irrigation (traditional method). Organic fertilizer also decreased Fe available compare to control formula. Irrigation with withdrawing water at shooting stage decreased Fe^{2+} in soil, limited Fe^{2+} uptake (toxic form for rice) due to Fe precipitation. As a result, rice yield was increased by 1.6-9.27% in comparison to the traditional method, while moisture keeping irrigation reduced the yield by 4.74-24.19%. On neutral alluvial soil, Fe content in rice stem and leaf at shooting stage ranged from 47.6 to 76.3 ppm is determined as medium level. Fe-H_2O form in soil at shooting stage of rice is suitable for monitoring dynamic of this nutritional element for paddy soil.

Key words: Irrigation regime · Fertilizer · Fe forms · Rice yield · Red River Delta

INTRODUCTION

In Vietnam tropical soils, the toxicity of Fe, Al and Mn is a problem. It's always true in acid soils, but in neutral soil like in Red River Delta it is still left open. According to Tanado and Yoschida [1]; Benckiser *et al*. [2]; Ottow *et al*. [3] Fe toxicity observed in soil rich with iron, but the deficit of this element also reported by Okajima *et al.* [4]. Analyzing data of Fe in soil cannot let us know exactly the nutritional deficiency of Fe. Fe^{2+} form in soil is considered as toxic element. Monitoring of soil Fe^{2+} content in stages of rice growing under cultivation technique is necessary for science and practice.

On the other hand, Vietnam is a traditional agricultural country with rice cultivation, big amount of water proportion should be used for rice production. Submerge irrigation regime and not rational fertilization do not only waste natural resources but also change the soil oxidation-reduction potential [5-8] and create toxicants in soil such as methane [9], Fe and Mn [10].

Within the scope of this paper, the irrigation regime has been studied in order to examine the effect to Fe^{2+} content in soil, rice uptake by stages of growing and rice yield in Red River Delta, Vietnam.

MATERIALS AND METHODS

Materials:

- Rice varieties: DT - 28.
- Red River alluvial soils with slight acidic - neutral reaction in Hoai Duc district, Ha Noi (Eutric Fluvisols)
- Irrigation regime
- Fe forms in paddy soil, extracted by H_2O, NH_2OH/HCl and acetate ammonia (Hac).

Methods:
The Field Experimental Treatments:

Treatment 1 (CT1): Regular shallow irrigation, no fertilizer;

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Treatment 2 (CT2): Regular shallow irrigation, organic fertilizer;

Treatment 3 (CT3): Regular shallow irrigation, inorganic + organic fertilizers

Treatment 4 (CT4): Shallow and exposure irrigation, inorganic + organic fertilizers;

Treatment 5 (CT5): Moisture keeping irrigation, inorganic + organic fertilizers;

Description of Treatments with Experimental Watering Regimes: The regular shallow irrigation: Surface water layer in the fields of rice growing period is maintained as follows: green recovery phase cultures to maintain 20-30 mm deep layer of surface water, if raining- remove the water to 20-30 mm in 01 days. From shooting to ripening, maintaining 30-60 mm layer of water, having increased rainfall depth 60-90 mm, to dry naturally for 30-60 mm depth. 10-15 days before harvest water drained.

The formula shallow-exposure irrigation: Field of surface layers at different stages of growth is maintained as follows:

- Phase transplanted to green recovery: maintaining surface water layer 20-30 mm, having rain - draining back to 20-30 mm in one day.
- Shooting stage: from 30-60 mm field of surface layer, to dry naturally to reveal the ground 1-2 days, irrigation to 30-60 mm (if raining - also have to drain in 1 day), irrigation to 30-60 mm. The end of shooting: surface water draining 10-day field exposure.
- Panicle formation stage: 30-60 mm layer of surface water field, to drain a natural ground 1-2 days to 30-60 mm irrigation, rain having similar shooting.
- Flowering period: 30-60 mm layer of surface water field, to drain naturally, exposing the ground, irrigate immediately to 30-60 mm of rain have increased 60-90 mm depth to drain naturally, exposing ground, irrigate immediately to 30-60 mm.
- The milk-dough - hardening (of the grains) stage: 30-60 mm layer of the field, to drain naturally, exposing the ground 1-3 days, 30-60 mm irrigation on rain having similar shooting. 10-15 days before harvest draining fields.

The moisture keeping: Maintain soil moisture in the growing period as follows:

- Phase transplanted to green recovery: maintaining surface water layer 20-30 mm field, having returned to remove rain water from 20 to 30 mm in one day.
- The phases shooting, Panicle formation stage and The milk-dough - hardening (of the grains) stage, when soil moisture is reduced to the lower 60%, 70% and 80% of saturation, irrigate to increase soil moisture reached moisture saturation.
- Flowering period: maintain class 30-60 mm field of surface water to drain naturally then irrigate right to 30-60 mm (if rain having similar treatment of other formulas). Prior to harvest 10-15 days do not irrigate.

Experimental Conditions: The experimental formulas differ only in water regime (water level and soil exposure time) and fertilizers, the following factors such as rice variety, crop and cultivation techniques are the same. Execution time was in 2010-2011. The experiment repeated 3 times to get average values.

RESULTS AND DISCUSSION

Research Results of Experimental Soil: Experimental zone located at agricultural meteorology station of Institute of meteorological science and the environment on Kim Chung commune, Hoai Duc district, 13 km West of Hanoi. This soil has large area and typical for the Red River Delta. Soil has a neutral reaction (pH = 6.8), humus content of 2.6% and 0.11% total nitrogen (Table 1). Soil cultivated 3 seasons in year: spring rice - summer rice - winter crops.

Quantitative analysis results showed that soil typically for the Red River alluvial with medium mechanical composition; neutral reaction; cation adsorption capacity and calcium, magnesium exchange high. The amounts of macronutrients (N, P, K) were from moderate to high, suitable for growth and development of rice plant.

Fe content in paddy soils:

Fe-H_2O Content in Soil: Fe-H_2O content decreased by the time of submerged can be explained by precipitation of Fe in $Fe(OH)_2$ or $Fe_3(OH)_8$ the same results were reported by Ponnamperuma [5]. In the initial period, analyzing value increased but not obviously because the soil was drowned before rice transplanting, on the contrary to in laboratory experiment [3].

Table 1: The agricultural chemical properties of experimental soil

N	Parameters	Unit	Layer 1 (0-20cm)	Layer 2 (21-30cm)	Layer 3(31-90cm)	Layer 4(91-125cm)
1	Bulk density	g/cm^3	1.05	1.17	1.38	1.50
2	Soil density	-	2.46	2.47	2.55	2.68
3	Porosity	%	57.48	51.38	45.88	44.50
4	Humus	%	2.6	1.68	1.04	0.86
5	N	%	0.10	0.06	0.04	0.04
6	P_2O_5	%	0.11	0.09	0.08	0.08
7	K_20	%	1.8	1.47	1.55	1.60
8	pH_{KCl}	-	6.81	6.95	6.62	6.55
9	CEC	me/100g	19.8	18.2	18.5	18.5
10	Fe_2O_3	%	6.12	6.30	6.38	6.45
11	MnO	%	0.18	0.22	0.26	0.25
12	Al^{3+}	me/100g	0.3	0.2	0.62	0.74
13	Ca^{++}	me/100g	12.5	13.4	11.8	12.2
14	Mg^{++}	me/100g	4.2	3.8	3.6	3.4
15	H^+	me/100g	0.15	0.05	0.20	0.30
16	Base saturation	%	84.34	94.51	83.24	84.32
17	Composition:					
	- Sand	%	20.5	18.8	12	21.2
	- Silt	%	62.4	66.5	70.5	63.7
	- Clay	%	17.1	14.7	17.5	15.1

Table 2: Dynamic of $Fe-H_2O$ (mean value) in formulas with different irrigation regimes and fertilizers

Days after transplanting	CT1	CT2	CT3	CT4		CT5	
	h= 5cm (Regular shallow irrigation)			Shallow and exposure irrigation		Moisture keeping irrigation	
	ppm	ppm	ppm	ppm	h (cm)	ppm	h (cm)
4	95.0	81.2	66.2	105.3	5	65.5	0
11	89.6	99.7	91.4	92.1	5	90.3	0
25	80.1	87.5	85.6	55.8	0	82.6	0
46	69.7	69.1	67.0	66.6	5	68.4	0
60	54.57	29.72	51.6	39.02	5	55.66	0
81	6.4	3.94	6.36	5.76	5	5.59	0
$\bar{x}$	65.89	61.86	61.36	60.76		61.34	

Effect of Irrigation Regime: In shallow and exposure irrigation formula (CT4) by withdrawing water, the $Fe-H_2O$ content falls off to 55.8 ppm, after water supplying increases the $Fe-H_2O$ content again, that shows the effect of this irrigation regime in lowering the $Fe-H_2O$ content obviously (toxicity). In moisture keeping formula (CT5), the $Fe-H_2O$ content maintains more stable than other irrigation regime.

Effect of Fertilizers: In the CT1 (no fertilizer, regular shallow irrigation), $Fe-H_2O$ fluctuated from 6.4 ppm to 89.6 ppm that shows the big difference of $Fe-H_2O$ by the submerging. Minimum value at 81th day caused by lowering water level in the ripening period of rice. In formula with organic (CT2), the $Fe-H_2O$ content is lower than no-fertilizer formula.

$Fe-NH_2OH/HCl$ Content in Soil: $Fe-NH_2OH/HCl$ content in all formulas increase from the first to the thirst time sample analyzing and then decrease to the fifth and sixth times. The irrigation regime also doesn't affect the dynamic of Fe- NH_2OH/HCl.

Fe-Hac Content in Soil: Fe-Hac content in all formulas increase from the first to the thirst time sample analyzing and then decrease to the sixth times. The irrigation regime doesn't affect the dynamic of Fe-Hac.

The Uptake of Fe by Rice

The Fe Content in Rice Stem and Leaf: Brinkman *et al.* [11] found that Fe content in rice stem and leaf depends on environmental condition and ranges from 50 to 500 ppm. In rice leaf with toxic symptom, Ottow *et al.* [3]

Table 3: Dynamic of *Fe- NH_2OH/HCl* (mean value) in formulas with different irrigation regimes and fertilizers

	CT1	CT2	CT3	CT4		CT5	
	h= 5cm (regular shallow irrigation)			Shallow and exposure irrigation		Moisture keeping irrigation	
Time after transplanting (days)	ppm	ppm	ppm	ppm	h (cm)	ppm	h (cm)
4	170.2	125.1	123.7	131.2	5	115.3	0
11	206.5	245.1	243.1	220.8	5	211.1	0
25	500.6	497.8	396.8	568.4	0	401.9	0
46	490	471.9	344	390.09	5	379.7	0
60	128.7	92.77	145.5	96.47	5	123.7	0
81	237.6	206.2	206.6	161.83	5	210.9	0
$\bar{x}$	288.9	273.1	243.2	261.4		240.4	

Table 4: Dynamic of *Fe- Hac* (mean value) in formulas with different irrigation regimes and fertilizers

	CT1	CT2	CT3	CT4		CT5	
	h= 5cm (regular shallow irrigation)			Shallow and exposure irrigation		Moisture keeping irrigation	
Time after transplanting (days)	ppm	ppm	ppm	ppm	h (cm)	ppm	h (cm)
4	685.4	591	477.5	900.7	5	471.1	0
11	997.2	1116	1023	1030.7	5	1007	0
25	897.8	920.7	956.5	1042.6	0	926.4	0
46	834.6	808	765.4	762.62	5	798.3	0
60	706.4	617.4	675.2	706.61	5	699.2	0
81	675.9	650.7	656.6	634.8	5	658.6	0
$\bar{x}$	799.55	783.97	759.03	846.34		760.1	

Table 5: Fe content (ppm) in stem and leaf of rice

Stages	CT1	CT2	CT3	CT4	CT5
Middle of shooting stage	59.73	76.3	60.2	47.63	56.73
Middle of panicle formation stage	52.27	72.77	54.13	50.83	47.63
Middle of flowering period	33.6	30.9	36	56.9	33.7
$\bar{x}$	48.53	59.99	50.11	51.78	46.02

founded very high content at 2217 ppm and affirmed that toxicity of Fe begin from 300 ppm. In rice leaf Fe content at 63-80 ppm recognized as low or deficit for rice [12].

In this experiment, Fe content in all formulas are lower than obtained by Brinkman *et al.* [11] because alluvial soil has neutral pH, so Fe precipitated in hydroxyl form.

The uptake of rice in shooting stage is highest, excepts the shallow and exposure irrigation formula – CT4) [6]), in the next stages, Fe content in rice decreases, this can be explained by dilution effect when rice increasing biomass.

Effect of Irrigation Regime to Fe Uptake into Rice: According to above table, the shallow and exposure irrigation formula (CT4) in the shooting stage has the lowest Fe content (47.63 ppm) to compare to CT3 (60.2 ppm) and CT5 (56.73 ppm). As above-mentioned, from shooting stage to panicle formation stage and flowering period, soil Eh stable in all formulas. By withdrawing water level till crackle of soil surface in shooting stage (CT4), soil Eh increases so Fe^{2+} was oxidized to Fe^{3+} and precipitated in $Fe(OH)_3$. On the other hand, withdrawing increases air exchange and oxygen penetrates into soil and oxidizes Fe^{2+}. In other words, shallow and exposure irrigation at shooting stage decreases Fe^{2+} in soil, limits Fe^{2+} uptake (toxic form for rice). Precipitation of Fe can reduce FeOOH membrane surrounding rice root, help them well developed. This is scientific basic explains advantages of shallow and exposure irrigation regime for rice cultivation (beside limitation of no-effect shooting).

Fe Content in Rice Root and Grain: Fe contents in root are higher many times than in stem and leaf, ranged from 1656.04 to 1894.52 ppm, similar to other authors, so effect of FeOOH surrounding rice root can be omitted in this study.

Table 6: Fe content (ppm) in rice root

Stages	CT1	CT2	CT3	CT4	CT5	
Middle of shooting stage		1074.3	1218.83	1185	1175.8	976.2
Middle of phase to ear		1882.2	1975.9	2151	1908.3	1994
Middle of flowering period		2287	2354	2348	2311	1998
$\bar{x}$	1747.83	1849.58	1894.52	1798.36	1656.04	

Table 7: Rice yield in different irrigation regimes compare to traditional method (CT3)

	CT3		CT4		CT5	
Season/year	ton/ha	%	ton/ha	% to CT3	ton/ha	% to CT3
Spring/2009	5.60	100	5.80	103.45	5.00	88.00
Summer/2009	6.85	100	7.55	109.27	6.54	95.26
Spring/2010	5.20	100	5.40	103.70	4.90	93.88
Summer/2010	6.80	100	6.95	102.16	5.80	82.76
Spring/2011	6.00	100	6.10	101.64	5.30	86.79
Summer/2011	8.01	100	8.61	106.97	6.45	75.81

Differ from Fe in stem and leaf, Fe concentration in rice root increases from middle stage of shooting to milk-dough – hardening stage in all formulas, so dilution effect occurs for stem and leaf, but not for root. Moisture keeping irrigation (CT5) has the lowest Fe content in root, then the shallow and exposure irrigation (CT4) and highest at regular shallow irrigation (CT3).

Fertilizers organic and inorganic do not lead to significant difference in Fe content in rice root.

Effect of Irrigation Regime to Rice Yield: Rice yield in spring 2009 of CT4 is 5.8 ton/ha higher 3.45% compared to CT3 5.6 ton/ha, similar in summer season 7.55 ton/ha to 6.85 ton/ha at CT3.

In spring season: CT4 rice yield higher than CT3 3.70%, in summer season 2010 higher than CT3 2.16%, due to the arid climate so rice yield decreases than spring season.

In 2011: CT4 has increasing to 6.97% than CT3. CT4 has the highest rice yield (1.6-9.27% higher than CT3) and CT5 has the lower rice yield 4.74-24.19% than CT3.

Results show that shallow and exposure irrigation regime (CT4) meets the criteria of water economic and increase rice yield to compare to traditional irrigation method (CT3).

CONCLUSION

- In shallow and exposure irrigation formula by withdrawing water, the Fe-H_2O content decreases shapely than regular shallow irrigation (traditional method). Organic fertilizer also decreases Fe available than control formula.
- Shallow and exposure irrigation by withdrawing water at shooting stage decreases Fe^{2+} in soil and limits Fe^{2+} uptake (toxic form for rice). As a result, rice yield increases 1.6-9.27% than traditional method, while moisture keeping irrigation lowers the yield 4.74-24.19%.
- On neutral alluvial soil, Fe content in rice stem and leaf at shooting stage ranges from 47.6 to 76.3 ppm is determined as medium level. Fe-H_2O form is suitable for monitoring dynamic of this nutritional element for paddy soil.

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