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EFFECT OF IRRIGATION REGIME AND FERTILIZERS TO RICE UPTAKE OF FE AND MN IN RED RIVER DELTA, VIETNAM

Nguyen Xuan Hai[1], Nguyen Thi Bich Nguyet[1] and Nguyen Viet Anh[2]
[1]Faculty of Environmental Sciences, VNU University of Science, Vietnam
[2]Water Resources University, Hanoi, Vietnam
E-Mail: nguyenxuanhai@hus.edu.vn

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 grain 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.

Keywords: 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]; Ottgw *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.

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;
- **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

a) 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 back 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.

b) 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.

c) 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 DISCUSSIONS

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.

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 Silt Clay	 % % %	 20.5 62.4 17.1	 18.8 66.5 14.7	 12 70.5 17.5	 21.2 63.7 15.1

Fe content in paddy soils

Fe-H_2O content in soil

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
$\overline{X}$	65.89	61.86	61.36	60.76		61.34	

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 [6].

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 treatment with organic fertilizer (CT2), the Fe-H_2O content is lower than no-fertilizer treatment.

Fe- NH_2OH/HCl content in soil

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

Time after transplanting (days)	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	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
$\overline{X}$	288.9	273.1	243.2	261.4		240.4	

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

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

Time after transplanting (days)	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	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
$\overline{X}$	799.55	783.97	759.03	846.34		760.1	

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

Brinkman *et al*., [7] 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] 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 [8].

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
$\overline{X}$	48.53	59.99	50.11	51.78	46.02

In this experiment, Fe content in all formulas are lower than obtained by Brinkman *et al*., [7] because alluvial soil has neutral pH, so Fe precipitated in hydroxyl form.

The uptake of rice in shooting stage is highest, except the shallow and exposure irrigation formula - CT4) [9]), in the next stages, Fe content in rice decreases, this can be explained by dilution effect when rice increasing biomass.

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).

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
$\overline{X}$	1747.83	1849.58	1894.52	1798.36	1656.04

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.

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.

Table-7. Fe content (ppm) in rice grain.

Stages	CT1	CT2	CT3	CT4	CT5
Middle of flowering period	28.83	23.63	75.33	32.7	25.7
Milk-dough hardening stage	10.4	10.1	12.3	9.9	8.7
$\overline{X}$	19.61	16.86	43.81	21.3	17.2

Fe contents in grain are much lower than in stem, leaf and root of rice. Their contents in 2 stages (middle of flowering period and milk-dough hardening stage) ranges from 10.1 to 32.7 ppm, except control - CT3 (regular shallow irrigation).

The content of Fe in grain at milk-dough hardening stage is always less than flowering period in all treatments because of Fe accumulation mainly in grain husk and the rate of husk/grain higher in flowering period. And on other hand, Fe content in grain also affected by the dilution.

Irrigation regimes and fertilizers do not lead to difference in Fe rice grain because of low content of Fe in rice grain.

Effect of irrigation regime to Mn uptake into rice

Mn content in rice in the published literature ranged widely from 66 ppm to 750 ppm (Pins, 1980) [10]. Phillis (1963) [11] reported, that Mn in young leaf is 280 ppm and 490 ppm in old rice leaves and in dried old leaves is 1600 ppm. The higher value is also a published by other authors; for example, Vlamis and Williams (1965) [12] found Mn content in old leaf up to 7000 ppm. Similar to the case of Fe, the study of Mn in rice plants at different stages of growth is not sufficient.

Mn content in rice leaf and stem are shown in Table-8.

Table-8. Mn content (ppm) in rice leaf and stem.

Stages	CT1	CT2	CT3	CT4	CT5
Middle of shooting stage	64.8	71.2	73.9	84.4	81.53
Middle of phase to ear	62.57	60.6	74.33	78.43	68.83
Middle of flowering period	75.6	74	67.9	58.6	64.5
$\overline{X}$	67.65	68.6	72.04	73.81	71.62

Rice plant part (above ground) in all treatments and growth stages with Mn content ranged from 58.6 ppm (CT4, flowering period) to 84.4 ppm (CT4, at shooting stage). Compared to reports of Pins (1980) and a number of authors mentioned above, it can be said: although in irrigated conditions and different fertilizer regimes, in this soil Mn is very low. To explain this phenomenon may be related to soil pH (neutral reaction). When dry or wet pH fluctuated around 7, in such conditions Mn^{2+} easily converted into $MnCO_3$, Mn_3O_4 or $Mn(OH)_2$ forms, and rice hardly can uptake Mn. Thus, the phenomenon of Mn deficiency in plants in soil with neutral and alkaline reaction was discovered many authors.

According Ottow *et al.* (1982) [3], if the Mn content in the leaf is less than 20 ppm: the deficiency; and higher than 2500 ppm - the toxicity can occur for rice. In this study, Mn content in rice soil ranging from 58.6 to 84.4 ppm and can be confirmed at a low level, maybe lead to manganese deficiency. However, by observing the rice in the experiment did not detect this phenomenon.

Assessment of irrigation and fertilizer regimes to Mn in rice leaf and stem as follows:

- Compared Mn content in rice leaf and stem of different irrigation regimes (CT3, CT4 and CT5), there were no significant difference (CT3 - 72.043 ppm; CT4 - 73.81 ppm; CT5 - 71.62 ppm). This result suggests that irrigation regimes were conducted not significantly change Mn content in rice leaf and stem.
- Mn content in rice leaf and stem of different fertilizers (inorganic and organic - CD3 (72.043 ppm), no fertilizer - CD1 (67.6567 ppm) and organic fertilizer - CD2 (68.6 ppm) also did not differ significantly.

Mn content in rice leaf and stem in the growing periods makes a clear difference, especially between shooting stage and phase to ear. Mn content in rice leaf and stem is highest at shooting stage and reduces in 2 next stages (clearly shown in formula CT3, CT4 and CT5). This phenomenon is explained similarly in case of Fe, is due to the law of dilution effects (a concept in plant nutrition). However, this effect is not so clearly as iron nutritional elements have been presented above.

Table-9. Mn content (ppm) in rice root.

Stages	CT1	CT2	CT3	CT4	CT5
Middle of shooting stage	196.1	176.7	203.1	193.9	188.2
Middle of phase to ear	133.5	150	170.8	160	176.6
Middle of flowering period	123.4	111.9	105.9	124.3	106.3
$\overline{X}$	151.01	146.19	159.92	159.39	157.03

Mn content in rice roots in the treatments are presented in the above table and can draw the following important observations:

- Mn content in roots in all treatments and in different growth stages in the study ranged from 105.9 (CT3, flowering period) to 203.1 ppm (CT3-shooting stage). Thus, the Mn content in roots is higher than in stems and leaves. This phenomenon is quite different from some previous studies.
- Comparison of Mn content on regular shallow irrigation (CT3-159.92 ppm) with shallow and exposure irrigation (CT4 - 159.39 ppm) and moisture keeping irrigation (CT5 - 157.03 ppm) found no significant difference.

Since it can be observed that shallow and exposure irrigation and moisture keeping irrigation does not significantly influence to the concentration of Mn in rice roots.

- When comparing the Mn content of rice roots in the fertilizer formula inorganic and organic (CT3 - 159.92 ppm) with no fertilizer formula (CT1 - 151.01 ppm) and organic fertilizer treatments (CT2 - 146.19 ppm) did not detect significant differences. Since it can also commented fertilizer regimes did not significantly change Mn content in rice roots.
- Differ from the case of Fe, the Mn content in roots decreases with the growing periods significantly in all formulas (in the opposite case Fe). Mn content in roots decreased from shooting stage to next studying stages. The phenomenon of decreasing Mn in rice roots can be explained by the development of the root system as the dilution effect like in rice leaf and stem. This result is consistent with the results of a number of published authors (Van Huy Hai, 1986) [9].

As mentioned above, while the amount of Fe in rice root growth increased over time, in contrast, the amount of Mn in roots decreased gradually. This is a special phenomenon can be explained by no accumulation of manganese oxide in rice roots. In soil with a neutral reaction and prolonged flooding, Mn^{2+} can be converted to $MnCO_3$, Mn_2O_3, Mn_3O_4 or $Mn(OH)_2$. These compounds are difficult to penetrate into the roots. Root uptake Mn^{2+} and involved in the metabolism of matter in the stems, leaves and roots. When the roots, as well as stems and leaves develop, the Mn content is under the dilution effect as mentioned in the section above.
Mn contents in rice grain are presented in Table-10.

Table-10. Mn content (ppm) in rice grain.

Stages	CT1	CT2	CT3	CT4	CT5
Middle of flowering period	44.87	44.77	45.53	43.87	36.87
Milk-dough hardening stage	29.7	19.5	24.9	19.8	27.2
$\overline{X}$	3728	32.13	35.21	31.83	32.03

From this table following important remarks are drawn:

- Mn content in rice grain in different treatments and periods of growth ranged from 19.8 (CT4, milk-dough hardening stage) to 45.53 ppm (CT3 - flowering period). Mn content in the grain is much lower than in the leaves and roots.
- Comparison of Mn in the grain of regular shallow irrigation (CT3) with shallow and exposure irrigation (CT4) and moisture keeping irrigation (CT5) can be observed: Shallow and exposure irrigation and moisture keeping irrigation reduces Mn content in grain, however, the level of reduction is not clear. This phenomenon may be related to these irrigation measures increases Eh than regular shallow irrigation and thereby limiting the release of Mn^{2+} in the soil, limiting the absorption of manganese by rice. But this is a manifestation and hard to come to correct conclusions. Because, as noted above, found no significant impact of shallow and exposure irrigation

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and moisture keeping irrigation to Mn content in leaves and roots.

- Comparison of Mn in the grain in treatments of inorganic and organic fertilizer (CT3) with no fertilizer (CT1) and organic fertilizer (CT2) did not detect significant differences. From these it can be remarked that fertilize measures does not change the concentration of Mn in the rice grain.
- The comparison of grain Mn content in all treatments and growth stages (between flowering and milk-dough hardening stage) can go to the remark: Mn content in rice grain in flowering stage higher significantly than in milk-dough hardening stage. The cause of this phenomenon is the same as explained in the case of iron nutrients. The first reason is the dilution effect. In addition, the rate of husk and grains in the period of growth is also different. In the flowering period rate was higher in the milk-dough hardening stage. The accumulation of Mn and Fe is higher in the husk. This is to explain the cause of grain Mn content in flowering period was higher in the milk-dough hardening stage.

CONCLUSIONS

a) Fe content in rice (stems and leaves) was low, the highest value at the shooting stage, then decreased gradually in the period to flowering. The law of the dilution effect explains the cause of this phenomenon. This phenomenon does not occur in rice roots, on the contrary, by growing periods, Fe content in roots increases by surrounding and absorption of FeOOH. In submerging process and growth period of rice, the available Fe increases in soil. However, it is difficult to find the relationship of Fe dynamics in the soil and plants.

b) Among the irrigation measures, the shallow and exposure irrigation to reduce Fe content in rice, markedly in rice shooting stage. This phenomenon is related to an increase of Eh, limiting the release of Fe^{2+}. Limiting the formation of Fe^{2+} - a toxic to roots - as a basis for increasing the growth of rice plants and thus can assert the superiority of shallow and exposure irrigation measures.

c) Mn in rice was at low level. The highest Mn content in rice is at shooting stage and reduced in flowering period. Unlike the case of Fe, Mn in roots decreases with the growth stage and is also interpreted as Mn in stems and leaves is due to the dilution effect. In environmental conditions neutral soil reaction and actual Mn content in rice low, the ability of Mn deficiency for plants in soil are likely to occur.

d) Shallow - exposure irrigation measures and moisture keeping irrigation, and also fertilization measures does not significantly affect the concentration of Mn in stems, leaves and roots.

e) For assessing Fe and Mn nutrition in rice, it’s better to determine the content of these elements in the stems and leaves at shooting stage, because at this stage Fe and Mn concentrations in rice is the highest. After shooting stage, Fe content in the stems, leaves and roots (compared with Mn) decrease due to the dilution effect. However, this effect does not occur with Fe in the roots, on the contrary, by growing periods, Fe content in roots increased. This phenomenon is explained by the penetration and surrounding of FeOOH in rice roots.

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