Kasetsart J. (Nat. Sci.) 41 : 28 - 33 (2007)

Effects of Vanadium on Rice Growth and Vanadium Accumulation in Rice Tissues

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ABSTRACT

The experiment on effects of vanadium on rice growth in hydroponic culture with the Mckeehen's nutrient solution formulae was conducted during September 5 to January 3, 2005 at the Department of Agricultural Technology, Thammasat University, Rangsit Campus, Thailand. Vanadium of 80 mg/l caused the lowest stem height, stem diameter, fresh and dried stem weights, and fresh and dried root weights of 84.21 cm., 1.98 cm., 24.44 and 9.61 g, and 20.59 and 1.47 g, respectively. Without Vanadium, a tendency to give the longest root of 48.85 cm, the highest number of panicles per hill of 11.00, the highest number of seeds per panicle of 222.18, the highest weight of seeds per hill of 58.55 g, and the highest 100-seed weight of 2.40 g were obtained. The two vanadium concentrations of 40 and 80 mg/l, however, caused death to the rice plant before the flowering stage. The vanadium concentrations were found in the root > leafy stem > seed, respectively.

Key words: vanadium, hydroponic culture, Mckeehen's nutrient solution, rice growth

INTRODUCTION

Thai farmers have been using a lot of chemical fertilizers for years. Phosphate rock, a source of phosphorus, which has been imported to Thailand for the production of chemical fertilizers, contains some toxic elements such as vanadium (NH_4VO_3). Using those chemical fertilizers may cause the vanadium to become widespread in soil, water and plants. Wang and Liu (1992) found that the stem tip and root of soybean became yellowish, wilted and less growing when planted in the soil treated with 30 ppm vanadium. There was also a report that vanadium absorbed by plant caused an obstruction of hydrogen ion function on plasma membrane which was necessary for the ATPase translocation within the plant. As the result, this led to the disability of plant in mineral absorption (Wuilloud *et al*., 2000). Distal renal tabular acidosis has been reported to be a common health problem in northeastern Thailand, with the population background of the low potassium intake, low urine citrate, and decreased red blood cell Na-K adenosine triphosphate (ATPase) activity and the environment of the high soil vanadium. The patients have higher urine vanadium than normal rural northeastern villagers. H-K ATPase is possibly inhibited by vanadium. Mutation of AE1 gene is noted in few patients. Both genetic and

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environmental factors could contribute to the pathogenesis of the disease (Tosukhowong *et al*., 1999). Vanadium is confirmed to be essential for a number of animal species such as chicken and rats whose deficiency symptoms are retarded growth, impairment of reproduction, disturbance of lipid metabolism and inhibition of Na/K-ATPase activity in the kidney, brain and heart (Frank *et al*., 1996; McCrindle *et al*., 2001). It is still poorly understood for the behavior and effects of vanadium pollution in most ecosystems. A number of researches indicated the ambient levels of vanadium in the air are associated with cardiovascular diseases, bronchitis and lung carcinoma in the general population (Jerome, 1998). In this experiment, a recommended Thai rice variety called RD7 was used to determine how vanadium affected the rice vegetative and reproductive growths and where it was proportionally accumulated within the rice plant. In order to make a solution of vanadium accumulation in soil, the hydroponic culture technique was used in the experiment (Chongkid and Saeton, 2005).

MATERIALS AND METHODS

Experimental design

The experiment was conducted using the Completely Randomized Design (CRD) with 4 replications and 6 vanadium concentration treatments: 0, 1, 10, 20, 40 and 80 mg/l vanadium. Each treatment consisted of ten plants.

Methods

Each 7-day rice seedling was grown in a slit of sponge piece which was fully dipped into the water comprising the half-strong Mckeehen's starter nutrient solution (used for the 7-75 day rice plant) within the plastic tray for 3 days and then the rice seedling was transferred into the closed plastic tray containing 25 l full-strong Mckeehen's starter nutrient solution. The 3,500-watt pump was connected to the plastic tray to add O_2 for the rice plant. When the rice plant became 45 days old, each of 6 vanadium concentrations was separately added into the Mckeehen's starter nutrient solution and the starter nutrient solution was changed every 2 weeks as well as vanadium was added whenever the starter nutrient solution was changed.

The Mckeehen's pre-anthesis and post-anthesis nutrient solutions were used instead of the Mckeehen's starter nutrient solution when the rice plants were 76-90 and 91-120 days old, respectively, based on the same method done with the Mckeehen's starter nutrient solution. The pH of all 3 Mckeehen's nutrient solutions was maintained at 5.8-6.0. The components of 3 Mckeehen's nutrient solution formulae were as follows (Mckeehan *et al*., 1996):

Chemical used (mg/l)	Starter	Pre-anthesis	Post-anthesis
KNO_3	212.00	262.60	207.05
$Ca(NO_3)_2.4H_2O$	182.00	182.00	91.00
Fe-EDTA	60.50	6.98	3.49
$MgSO_4.7H_2O$	63.00	31.50	31.50
KH_2PO_4	81.60	68.00	68.00
H_3BO_3	0.13	0.64	0.64
$MnSO_4.4H_2O$	0.53	5.32	5.32
$ZnSO_4.7H_2O$	0.89	0.29	0.29
$CuSO_4.5H_2O$	0.08	0.25	0.25
NH_4NO_3	4.80	-	-
$(NH_4)_6Mo_7O_{24}.5H_2O$	0.02	0.06	0.06
$NaSiO_3.5H_2O$	0.01	0.01	0.01

Data collection: the measurements of rice characteristics were done as follows:

Plant height and stem diameter were measured at the booting stage (90 days after planting). The number of tillers per hill was counted at the booting stage. The fresh and dry weights of rice stems and roots were weighed at the panicle stage (120 days after planting). The rice root length was measured at the panicle stage. The numbers of panicles per hill and seeds per

panicle were counted at the panicle stage. The seed weight per hill and 100-seed weight (at 14% seed moisture content) were weighed after seed harvesting. Five plants were taken for sample in each characteristic measurement.

Measurement of vanadium in plant tissues

An on-line preconcentration and sample clean-up chromatographic method (Vachirapatama *et al.,* 2005) was used for the determination of the vanadium levels in rice tissues. Screw-top Savillex® Teflon beakers (Savillex, Minnesota, USA) were used for rice sample digestion prior to analysis. Standard ammonium metavanadate (NH_4VO_3, 99.99% purity) was obtained from Aldrich (Milwaukee, WI, USA.) and a stock solution of 1.00 g/ℓ ammonium metavanadate (NH_4VO_3) was prepared in 1.0□M HNO. All water used in the chromatographic system was distilled and deionized. HPLC grade methanol was obtained from Merck (Darmstadt, Germany). All other chemicals used were AR grade unless otherwise specified.

RESULTS AND DISCUSSION

Vegetative growth

The rice plants treated with 80 mg/l vanadium had the shortest plant height and smallest stem diameter of 84.21 and 1.98 cm, respectively, which were significantly different from those of rice plants treated with each of the 5 concentrations (Table 1). Reductions in plant height and stem diameter caused by 80 mg/l vanadium can be explained by the report of Wuilloud *et al*. (2000) who found that vanadium was a barrier for an activity of plasma membrane hydrogen ion in transferring the ATPase which is necessary for essential mineral absorption of some plant tissues. As a result, such effect must bring about the retarded growth of the rice plant. It was found from the experiment that the rice plants treated with all concentrations of vanadium for 42 days gave insignificant number of tillers per hill from 7 to 10.25. The rice plants treated with 80 mg/l vanadium, however, had a tendency to give the lowest number of tillers per hill of 7.00 (Table 1).

The fresh stem weights of rice plants treated with 20 and 40 mg/l vanadium for 70 days were significantly less than those of the ones treated with 0, 1 and 10 mg/l vanadium, while 80 mg/l vanadium caused the lowest fresh stem weight of 24.44 g (Table 2). The reason for this effect may be due to the fact that vanadium at a low concentration such as 10 mg/l can help increase nitrogen in the form of ammonium compound activating the rice growth but when

Table 1 Plant height, stem diameter and number of tillers per hill of RD7 rice variety treated with 0, 1, 10, 20, 40 and 80 mg/l vanadium for 42 days.

Vanadium concentration (mg/l)	Plant height (cm)[1/]	Stem diameter (cm)	Number of tillers per hill
0	89.80[a]	2.44[a]	7.13
1	90.54[a]	2.35[a]	9.38
10	93.00[a]	2.37[a]	10.25
20	88.88[a]	2.45[a]	7.38
40	93.99[a]	2.47[a]	7.88
80	84.21[b]	1.98[b]	7.00
F-test	*	*	ns
% C.V.	6.69	6.25	32.84

[1/] Means followed by the same letter in a column are not significantly different at the 5% level of probability by DMRT. * Significantly different at the 5% level of probability. ns = Not significantly different at the 5% level of probability.

vanadium concentration increases, it may obstruct the mineral absorption of the rice tissue (Wang and Liu, 1992). Vanadium of 80 mg/l caused the significantly lowest dried stem weight of 9.61 g (Table 2). The reason for this effect is possibly due to the same attribution as in the fresh stem weight.

The root lengths of rice plants treated with all concentrations of vanadium for 70 days were found insignificantly different. The untreated rice plants had a tendency to have the longest root of 48.85 cm whereas the rice plants treated with 80 mg/l vanadium had thin blackish-brown roots with many small knots (Table2 and Figure 1) while their stems became yellow and soft (Figure 2). The rice plants treated with 80 mg/l vanadium had a tendency to have the lowest fresh and dried root weights of 20.59 and 1.47 grams, respectively. The reason for this effect is similar to that given in the fresh stem weight.

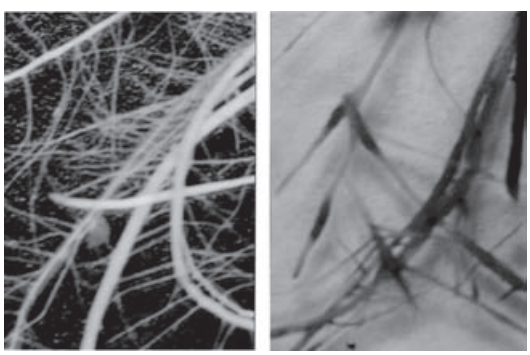
Reproductive growth

The results showed that the rice plants treated with 0 and 1 mg/l vanadium for 70 days gave the significant highest number of panicles per hill at 11.00 and 10.88, respectively. The ones treated with 40 and 80 mg/l vanadium were dead before the flowering stage at about 80 and 56 days,

Table 2 Fresh and dried stem weights, root length, fresh and dried root weights of rice plants with 0, 1, 10, 20, 40 and 80 mg/l vanadium for 70 days.

Vanadium concentration (mg/l)	Fresh stem weight (g)[1/]	Dried stem weight (g)	Root length (g)	Fresh root weight (g)	Dried root weight (g)
0	63.36^{ab}	18.84^{ab}	48.85	35.57^{ab}	3.08^{b}
1	73.34^{ab}	18.79^{ab}	44.34	47.05^{a}	3.40^{ab}
10	91.05^{a}	22.79^{a}	43.9	52.82^{a}	4.75^{a}
20	55.73^{b}	15.36^{ab}	45.96	23.24^{b}	2.18^{bc}
40	54.02^{b}	17.13^{ab}	42.39	25.12^{b}	2.02^{bc}
80	24.44^{c}	9.61^{b}	43.78	20.59^{b}	1.47^{c}
F-test	*	*	ns	*	*
% C.V.	30.76	30.47	12.59	37.21	35.13

[1/] Means followed by the same letter in a column are not significantly different at the 5% level of probability. * Significantly different at the 5% level of probability. Ns = Not significantly different at the 5% level of probability.



0 mg/l 80 mg/l

Figure 1 Root appearances caused by 0 and 80 mg/l vandaium.

0 mg/l 80 mg/l

Figure 2 Rice leafy stem appearances caused by 0 and 80 mg/l vanadium.

respectively, after the beginning of treatment (Table 3). The rice plants treated with 0 mg/l vanadium for 70 days were found to give the highest number of seeds per panicle at 222.18 whereas the ones treated with 1, 10 and 20 mg/l vanadium gave 216.73, 171.95 and 167.23 seeds per panicle, respectively (Table 3). The rice plants treated with 0 mg/l vanadium for 70 days also gave the highest seed weight per panicle and 100 seed weight of 58.55 and 2.40 g, respectively.

From all the results of the experiment, it can be inferred that vanadium at higher concentrations such as 40 and 80 mg/l caused the decrement of not only the vegetative but also the reproductive growths of the rice plant.

Determination of vanadium concentrations in plant tissue

Vanadium concentrations in different parts of the treated rice plants were analyzed by pre concentration and on-line clean up sample matrix using ion-interaction high performance liquid chromatography method and the results showed that the highest concentration was found in the rice root whereas the second and third orders came from the rice leafy stem and seed, respectively, as shown in the following Table 4.

CONCLUSION

Vanadium of higher concentrations, 40

Table 3 Number of panicles per hill, number of seeds per panicle, seed weight per hill and 100-seed weight of rice plants treated with 0, 1, 10, 20, 40 and 80 mg/l vanadium for 70 days.

Vanadium concentration (mg/l)	Number of panicles per hill[1/]	Number of seeds per panicle	Seed weight per hill (g)	100-seed weight (g)
0	11.00[a]	222.18[a]	58.55[a]	2.40[a]
1	10.88[a]	216.73[b]	47.53[b]	2.02[b]
10	7.75[b]	171.95[c]	24.18[c]	1.82[c]
20	7.38[b]	167.23[d]	18.28[d]	1.48[d]
40	0[c]	0[e]	0[e]	0[e]
80	0[c]	0[e]	0[e]	0[e]
F-test	*	*	*	*
% C.V.	5.57	2.07	7.18	1.85

[1/] Means followed by the same letter in a column are not significantly different at the 5% level of probability by DMRT. * Significantly different at the 5% level of probability. ns Not significantly different at the 5% level of probability.

Table 4 Vanadium concentrations (mg/l) found in different parts of rice plants treated with different concentrations of vanadium under hydroponic culturing.

NH_4VO_3 added in Knop's solution, mg/l	[V] found in rice tissues (mg/kg)		
	Seed	Leafy stem	Root
0	0.30	6.60	12.30
1	0.50	26.90	320.60
10	1.70	95.90	2017.20
20	7.80	338.70	2008.00
40	ND	987.60	2892.10
80	ND	2607.30	4859.20

ND = not determined due to the death of treated rice plants before the flowering stage

and 80 mg/l decreased both vegetative and reproductive growths of the rice plants treated for 42 and 70 days, respectively. For vegetative growth, vanadium significantly decreased plant height and stem diameter, number of tillers per hill, fresh and dried stem weights, root length, fresh and dried root weights. In terms of reproductive growth, the rice plants treated with 40 and 80 mg/l vanadium died before their flowering stage. The vanadium concentrations were found in the rice root greater than leafy stem and seed, in decreasing order.

ACKNOWLEDGEMENTS

The authors would like to thank Faculty of Science and Technology, Thammasat University for providing fund for this research.

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