Effect of Water Management on Zinc Concentration in Rice Grains

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Abstract
The study was conducted to evaluate the effect of water management on grain Zn concentration and uptake. A pot experiment was conducted at University of the Philippines Los Baños, Soils and Agro-Ecosystems Division screen house from June to October, 2005. Results revealed that continuous flooding (W_1) increased grain yields of MS13 and IR72 in Buguey possibly due to increased availability of nutrients brought about by shallow submergence of the soil as reflected on grain NPK uptake. In Alimodian, where inherent fertility status is lower, alternately wetting and drying (W_2) resulted in increased NPK uptake and grain yield. IR72 was more sensitive to changes in water management and soil fertility status. In contrast, the water requirement of MS13 can be reduced without significantly reducing its yield.
Grain Zn concentration and uptake were also influenced by the ability of the soil to supply Zn, rice variety and water management. Zinc concentration in grains was significantly higher in Alimodian with higher level of HCl-extractable Zn. In both soils, grain Zn concentration of MS13 was higher compared to IR72. This indicates that water management had no effect on grain Zn concentration in MS13 when soil Zn concentration is below the critical level set for rice. This confirms the inherent capacity of MS13 as very efficient in absorbing and loading Zn in its grains. By partly drying (W2) the Buguey soil during the growing period of IR72 significantly increased grain Zn concentration.

Key Words
Zinc concentration in grains, water management in rice, continuous flooding, alternate wetting and drying, soil Zn,

Introduction
The International Zinc Nutrition Consultative Group (IZiNCG) estimated that as much as one third of the world's population is at risk from inadequate zinc intake. Although the human body needs tiny amounts of vitamins and minerals for normal growth and development, their absence costs lives and causes disabilities and mental impairment (www. IZiNCG.org). Even a small increase in micronutrient content in rice would have a significant impact on the human health since cereal - based diets are the major source of nutrients for the majority of the world's population especially poor Asians. Both the nutrient content, especially iron and zinc, of the cereal grains and its bioavailability to the people consuming them are of fundamental importance. FAO believed that the nutrient content of rice can be improved substantially by using both traditional selective plant breeding and new biotechnology approaches.
In response, a concerted effort of plant breeders resulted in a significant progress in rice – a high yielding, disease resistant, iron enriched, and aromatic variety was identified (IR 68144-3B-2-2-3) and released as Maligaya Special #13 (MS-13). The said variety is able to tolerate low concentration of available iron and zinc in the soil and it is more efficient in taking up and loading these trace elements into the grains (Alloway, 2004).

There are reports, however, that some rice varieties that are efficient in loading high Fe and Zn densities in their grain do not consistently manifest the same characteristics in other conditions or areas. This shows that plant uptake of Zn depends not only upon species, age, or parts of the plant, but also on the amount that is available in the soil (Chlopecka *et al.* 1996).
The breeder's efforts in rice biofortification must then be complemented by identifying water management practices that can influence Zn availability in soils and subsequently Zn concentration in rice grains so that biofortification program would be more cost-effective and sustainable endeavor. This study was conducted to identify the water management practice that would lead to increased availability of soil Zn and subsequently to (1) increased grain Zn concentration; (2) investigate the relationship between soil Zn

concentration and Zn uptake; (3) determine the influence of soil properties on grain yield, Zn concentration and uptake;

Methods

Soil sampling and preparation

Soils used in the experiment were identified to have low zinc content through Minus One Element Technique (MOET) of previous studies conducted by Descalsota *et al.* (2002). Soil samples were collected from the top 0 - 20 cm layer of lowland rice fields at Guisguis, Sariaya (Buguey soil) and Bamban, Tagkawayan (Alimodian soil), Quezon province. The collected soil samples were kept submerged for about four weeks with alternate mixing to maintain the reduced condition of the soils. Minus one element technique (MOET) was conducted on the soils for further nutrient content evaluation.

Soil Taxonomic Classification

Buguey soil series was classified as mixed, isohyperthermic, typic Ustipsamments. This soil was developed from the recent alluvium and recent coastal deposits. Alimodian soil series was classified as fine montmorillonitic, isohyperthermic Udorthentic Chromudert. The soil was formed from the unconsolidated sediments from sandstone-shale materials.

Pot Set-up

10 kg of Buguey soil and 12 kg Alimodian soil were placed in the plastic containers. Holes were made at the bottom of the plastic pails and placed with rubber stoppers with rubber and glass tubing to facilitate draining of water. Properly marked sticks were placed in each pot to serve as guide for the level of floodwater and electrodes to monitor the soil redox potential (Eh) (Plate 1).

Plate 1. Pot experimental setup

Soil and Plant Analysis

Soil analysis for pH, organic matter (OM), total N, available P, exchangeable K, and available Zn were performed before planting. Plant tissue concentration of N, P, K and Zn content in dehulled brown grains from all treatments were analyzed. N, P, K and Zn uptake in grain and straw were also determined.

Treatments

The different treatment combinations were replicated three times and were laid out in completely randomized design (CRD) (Plate 1a). The factors employed for the treatment combinations were as follows:

Factor 1: Rice varieties (V)

V_1 - MS 13 (IR68144-3B-2-2-3)

V_2 - IR72

Factor 2: Lowland Rice soils (S)

S_1–Buguey loamy sand (Sariaya)

S_2–Alimodian silty clayloam (Tagkawayan)

Factor 3: Water Management (W)

W_1 - Continuously flooded (the pots were irrigated to at least 5 cm of standing water 5 days after transplanting (5 DAT) and were kept flooded until 2 weeks before harvest (WBH)

W_2 - Alternate wetting and drying cycle (the pots were irrigated to at least 5 cm water starting 5 DAT and allowed to dry until the soil starts to crack before it was again flooded. The cycle was repeated until 2 WBH)

W_3 - Drying at maximum tillering stage (the pots were irrigated to at least 5 cm water starting 5 DAT then drained to saturated at tillering stage (no. of days depended on the variety used) then it was kept flooded again until 2 WBH)

Fertilizer Application

A total of 150 – 90 – 60 kg $N-P_2O_5-K_2O$/ha were applied. Nitrogen fertilizer was applied in three splits (30 % basal, 50 % topdressed 5-7 days before panicle initiation (DBPI) and 20 % topdressed 5-7 days before flowering). All of P was applied as basal and K was split twice (50 % basal and 50 % 5-7 DBPI).

Management of different moisture regimes were strictly followed as specified in the treatments using distilled water to avoid introduction of zinc from other sources.

Results

Soil physico-chemical properties

Table 2 lists the initial physicochemical characteristics of the soils used in the experiment.

Table 2. Physicochemical characteristics of the two soils used in the preliminary experiment.

SOIL PROPERTIES	BUGUEY SOIL	ALIMODIAN SOIL
Particle size distribution		
% sand	44	17
% silt	38	47
% clay	19	36
Texture	sandy clay loam	silty clay loam
pH	6.65	5.15
Organic matter content (%)	6.89	2.57
Nitrogen (%)	0.34	0.25
Available Phosphorus (mg/kg)	59.48	4.98
Exchangeable Potassium (mg/kg)	0.288	0.129
0.05N HCl Extractable Zinc (mg/kg)	0.360	1.07

Minus – One Element Technique (MOET)

Minus one element technique is a simple and easy method of assessing soil fertility status. Plate 2 shows the result of the MOET conducted in Buguey. The growth of the rice plants indicated that nitrogen (N), potassium (K) and sulfur (S) are deficient in the soil, but sufficient in phosphorus (P), cupper (Cu) and zinc (Zn). Fertilizers with N K S must be applied as corrective measures for normal growth and development and for a better yield.

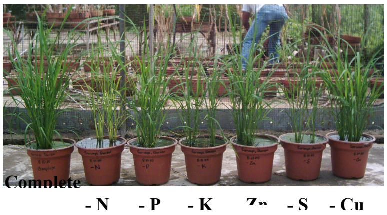

Plate 2. MOET test in Buguey soil.

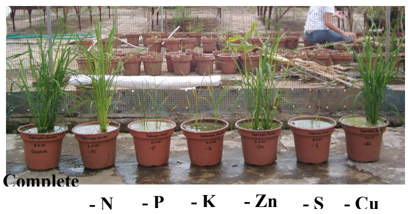

Plate 3. MOET test in Alimodian soil.

In Alimodian, almost all nutrients were very deficient except Cu (Plate 3). Nutrient deficiencies were so evident and physiological and agronomical characteristics of the plants were greatly affected. Without proper and balanced fertilization, this may lead to yield reduction or even yield loss.

Grain Yield and NPK Uptake

Grain yield was markedly influenced by water management (W) and soil (S) (Figure 1). The effect of water management however differed between the two soils as indicated by a significant interaction between W x S. In Buguey, higher grain yields were obtained under continuous flooding (W_1). This trend was in agreement with the results of a field experiment conducted by Agarwal *et al.* (1985) wherein continuous shallow submergence (5±2 cm) throughout plant life proved to be the best water regime. The differences in grain yield were however not statistically significant indicating that reducing water supply did not significantly reduce grain yield.

In Alimodian, alternate wetting and drying cycle (W_2) resulted in the highest grain yield. Subjecting this soil to W_2 resulted in increased solubility and availability of nutrients. The increased grain yield was related to the apparent increase in nitrogen (N) uptake of both varieties as shown in Figure 2. It was evidently showed that the effect of drying was governed by such factors like soil type and inherent fertility of the soil.

The two varieties also differed in their response to the treatments imposed. A significant interaction between variety (V) x soil (S) was observed. In Buguey, IR72 consistently yielded higher than MS13 under all water management practices. An average yield of 34.58 g pot^{-1} was recorded for IR72 as compared to 28.85 g pot^{-1} for MS13. The grain yield of the two varieties however did not differ markedly in Alimodian. An average yield of 24.05 g pot^{-1} and 24.20 g pot^{-1} was recorded for IR72 and MS13, respectively.

IR72 appeared to be more influenced by water management and soil fertility status. The grain yield of MS13 was only significantly reduced when the soil was drained at maximum tillering stage (W_3).

Total NPK uptake in grains followed the same trend as grain yield (Figure 2). In Buguey, W_1 resulted in higher NPK uptake followed by W_3 then by W_2. In Alimodian, total NPK uptake was in the order: $W_2 > W_3 > W_1$.

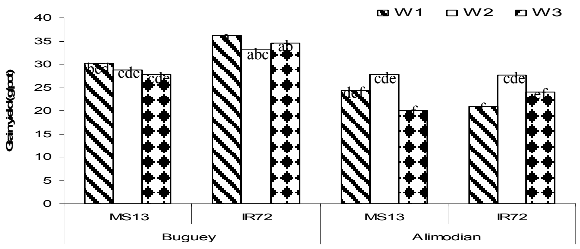

Figure 1. Effect of water management on grain yield of two rice varieties grown on two soils.

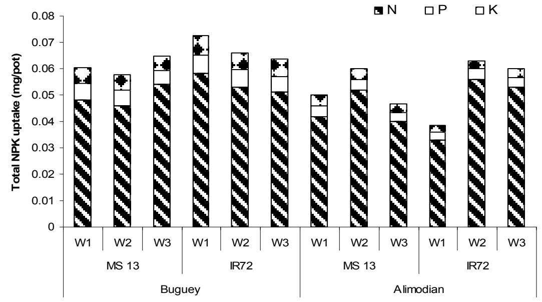

Figure 2. Effect of water management on total NPK uptake in grains of two rice varieties grown on two soils.

Zinc Concentration and Uptake in Grains

Grain Zn concentration in both varieties was significantly higher in Alimodian, regardless of water management (Figure 3). Alimodian has a higher ability to supply Zn as it was found to contain about three times as much 0.05N HCl – extractable Zn (1.07 mg/kg) than Buguey (0.360 mg/kg).

In both soils, Zn concentration in the grains of MS13 was higher than in IR72. In Buguey, the average grain Zn concentration was 25.89 mg/kg for MS13 and 19.22 mg/kg for IR72. In Alimodian, MS13 had a grain Zn concentration of 34.11 mg/kg while IR72 had 31.67 mg/kg. The ability of MS13 to absorb Zn from the soil and load it to its grains is very evident in Buguey which has a much lower Zn content.

Zinc concentration in grains of both varieties grown in Buguey followed the order: $W_2 > W_3 > W_1$ while in Alimodian highest was in W_3 followed by W_1 and then W_2.

Significant interaction between W x V was also observed. Grain Zn concentration and uptake (Figure 4) of MS13 was not significantly influenced by water management. For IR72, however, W_2 significantly increased Zn concentration and uptake in grains, particularly in Buguey where Zn content is below the critical level.

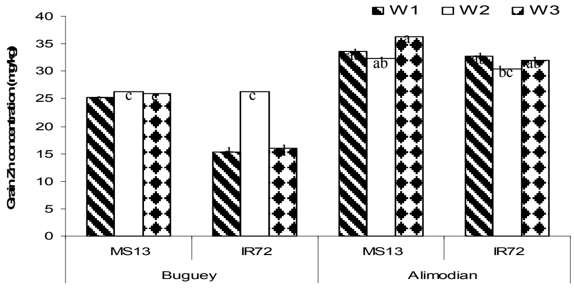

Figure 3. Grain Zn concentration of two rice varieties in two soils as influenced by water management.

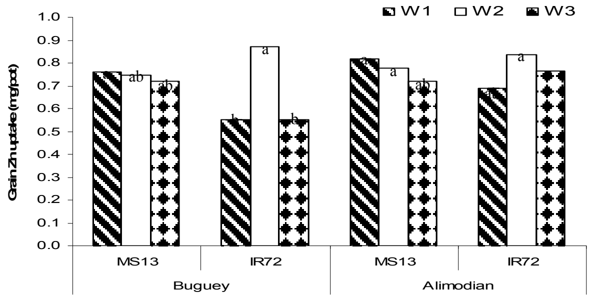

Figure 4. Grain Zn uptake of two rice varieties in two soils as influenced by water management.

Conclusion

Grain Zn concentration and uptake of MS13 was not affected by water management practice particularly under low Zn levels as in the case of Buguey. A high yielding variety (IR72) was more sensitive to changes in water management and soil fertility status. Its capacity to absorb more Zn and load it to its grain as compared to IR72 became very evident when the Zn level of the soil is below the critical level set for rice. MS13, which has been introduced for the biofortification program, can be grown under different water management practices in Zn-deficient soils particularly on soils with high inherent fertility status without significant effect on its agronomic performance and mostly the Zn concentration in grains.

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