**HarvestPlus-Zinc Fertilizer Project**

**"HarvestZinc"**

**Use of Zinc-Containing Fertilizers for Enriching Staple Grains with Zinc and Improving Yield**

**EXTENDED ABSTRACT**

(July 2011-January 2014)

**Coordinating Institution**

Sabanci University, Istanbul-Turkey

**Supporting Partners**

**Mosaic Company,** USA

**K+S KALI GmbH**, Germany

**International Zinc Association,** Belgium

**OMEX Agrifluids**, England

**International Fertilizer Industry Association**, France

**International Plant Nutrition Institute**, USA

**Bayer CropScience**, Germany

**ADOB**, Poland

**Valagro**, Italy

**FBSciences**, USA

**ATP Nutrition**, Canada

**Collaborating Countries**

**BRAZIL:** Agronomy Institute, Campinas
**CHINA:** China Agricultural University

**INDIA:** Punjab Agricultural University

**PAKISTAN:** Pakistan Atomic Energy Commission

**THAILAND:** Chiang Mai University

**TURKEY:** Ministry of Agriculture

**ZAMBİA :** Golden Valley Agricultural Research Trust( GART) and University of Zambia.

**EXTENDED ABSTRACT**

Seven countries are participating in this 2nd phase of the project. Wheat, rice, sorghum and common beans are the crops under study. Turkey, China, India, Pakistan and Zambia are conducting wheat experiments, while rice experiments are being carried out in China, Thailand and India. Brazil is working with common beans and Zambia is setting sorghum experiments in addition to wheat. Two different experiments, first of which to compare soil application of Zn-containing fertilizers and the second for comparison of Zn-containing foliar solutions, are being conducted in each country on each crop, except for Turkey where a 3rd experiment is also being carried out. In this 3rd experiment, different timings of foliar Zn treatments, alone or in combination with urea or pesticides, are being compared for effectiveness on improving grain Zn concentrations. In the second year (2012-2013), use of pH-reducing methods by inclusion of HCl or citric acid at foliar ZnSO4 applications was added to the experimental treatments, with the expectation to improve leaf penetration and translocation of applied Zn into wheat grains.

In all experiments, the treatments are compared with the local controls (LC). LC treatments are determined by the collaborating countries themselves based on their standard recommendations of basic fertilizers (N and P in all, K in some) for a given ecological region.

Project activities have been conducted under 3 Tasks:

**TASK-1:** SOIL APPLICATION OF ZINC-CONTAINING FERTILIZERS AND USE OF SEEDS DIFFERING IN ZINC CONCENTRATIONS

**TASK-II:** APPLICATION OF Foliar ZINC Fertilizers

**TASK-III:** DISSEMINATION AND IMPLEMENTATION OF THE PROJECT RESULTS

Below the results are summarized for those three Tasks

**TASK-I: Soil Applied Fertilizers**

**Seed Zinc: Effect on stand establishment**

The effect of Zn treatments on stand establishment was evaluated in all 5 countries working on wheat. Number of emerged plants was counted, and the seedling heights during early growing period were measured In Turkey, China, India and Pakistan; while visually-assessed vigor scores were used instead of seedling heights in Zambia. Early growth vigor of wheat was significantly affected in China and Pakistan. It was not significantly affected in the other countries. Although not significantly, Mosaic-MESZ treatments tended to improve early plant vigor in Zambia. In Zambia, priming had an adverse effect on emergence counts, at one of the two experimental sites in both years. It was also the case at one site, in one year in China. Considering that seed priming also tended to reduce stand establishment of rice in Thailand and common beans in Brazil, the priming-solution concentration used was reduced in 2nd year in those countries.

Both number of emerged seedlings and seedling heights were affected in China and Pakistan, the effect being much more pronounced in the latter. The main difference between the results from these 2 countries was the fact that both methods of using high-Zn seeds improved stand establishment in Pakistan, while priming seeds in Zn solution had an adverse effect on stand establishment in China, except for 1 experiment in 2012-2013, where priming also improved emergence.

The effect of using high-Zn seed on emergence counts are given in **TABLE-1** for China and Pakistan.

**TABLE 1.** Effect of Zn-enriched seeds on improvement of wheat seedling emergence in China and Pakistan.

|  |  |
| --- | --- |
| **TREATMENT** | **NUMBER OF EMERGED PLANTS m-2** |
| **CHINA** | **\*PAKISTAN** |
| **SITE 1** | **SITE 2** | **2011-2012** | **2012-2013** | **DEMO** |
| **2011** | **2012** | **2011** | **2012** |  |
| CONTROL (LC) | 295 | 360 | 436 | 275 | 197 | 192 | 168 |
| LC + high seed Zn through Foliar Zn Spray | 350 | 425 | 477 | 351 | 332 | 368 | 215 |
|  |
| **\*\*IMPROVEMENT (%)** | **18.6** | **18.1** | **n.s.** | **27.6** | **68.5** | **91.7** | **28.0** |

\*The values given for Pakistan are means of 3 experiments in 2011-12, 2 experiments in 2012-13 and 5 demonstration/trials in 2012-13

\*\*Improvement due to foliarly increased seed Zn as compared to LC.

As can be seen in **TABLE-1**, using high-Zn seed improved number of emerged seedlings in 3 of the 4 experiments in China, and all tests in Pakistan. The particularly striking effect was found in Pakistan. In 2013-2014 trials of Pakistan, a better emergence has also been observed in plots where Zn-enriched seeds were used.

In the experiments conducted in India, there were also differences in emergence counts due to seed Zn-enrichment but these differences were not statistically significant. However, on the average of all 6 field experiments in 2 years, seed Zn enrichment with foliar application improved emergence rates by about 9 % over control treatment. In Zambia, there were no differences in emergence counts. In case of rice, as mentioned, below, there were significant increases in grain yield by using Zn-enriched seeds in China, India and Thailand (in the second year).

**Soil Applied Fertilizers and Grain Yield: Wheat**

Soil application of Zn-containing fertilizers did not result in significant yield improvements in Turkey, China, and Zambia. There were, however, distinct (but non-significant) increases in grain yield of wheat in some locations of those countries. Significant changes in yield due to treatments were found in India and Pakistan. In China, the fact that rice yields responded to soil application of Zn shows the relatively higher Zn efficiency of wheat as compared to rice.

In contrast to the ineffectiveness of the soil applied Zn fertilizers in experiments in China, demonstration plots on farmers’ fields resulted in mostly significant increases in grain yields due to seed enrichment, ranging from 0.3% to 51 %, with a yield improvement of 18.3% as average of 5 fields.

Wheat experiments were conducted at 3 sites in each of India and Pakistan in 2011-2012; at 3 sites in India and 2 sites in Pakistan in 2012-2013. In all of these 11 experiments, soil application of Zn improved wheat grain yields as compared to control treatments. However, the superiority of the different soil applied Zn treatments varied from site to site, presumably due to variations in climatic and soil conditions.

Since the variables in the experiment are too many to make clearly visible comparisons, groups of Zn-compounds are compared with LC (Local Control) and LC + ZnSO4 in **TABLE- 2** and **TABLE-3.**

**TABLE 2.** Effect of MOSAIC-MESZ fertilizers on grain yield of wheat in India and Pakistan as compared to the LC and LC+ZnSO4 treatments. Mosaic-II represents the double rate of the Mosaic-I.

|  |  |
| --- | --- |
| **TREATMENT** | **\*GRAIN YIELD (t ha-1)** |
| **INDIA** | **PAKISTAN** |
| **2011-2012** | **2012-2013** | **2011-2012** | **2012-2013** |
| LC (local control) | 5.37 | 5.25 | 4.38 | 3.91 |
|  |
| LC + ZnSO4 | 5.95 | 5.59 | 5.20 | 4.39 |
| % IMPROVEMENT\*\* | **10.8** | **6.5** | **18.7** | **12.3** |
|  |
| LC + MOSAIC-I | 6.01 | 5.60 | 4.87 | 4.54 |
| % IMPROVEMENT \*\* | **11.9** | **6.6** | **11.2** | **16.1** |
|  |
| LC + MOSAIC-II | 6.05 | 5.58 | 4.96 | 4.21 |
| % IMPROVEMENT\*\* | **12.7** | **6.5** | **13.2** | **7.7** |

\* Values are means of 3 experiments each, except for Pakistan 2012-2013 values, which are means of 2 experiments.

\*\*Improvement over LC.

As can be seen in **TABLE 2,** effect of both MOSAIC-MESZ fertilizers on grain yields were generally similar to that of ZnSO4 in India. But there were differences from year to year in Pakistan. In 2011-2012, ZnSO4 had a greater effect, whereas in 2012-2013, MOSAIC-I was superior to ZnSO4.Two other fertilizers, Kali KornKali and ADOB-HBEDZn are compared with LC and LC + ZnSO4 in **TABLE 3.** When averaged over experiments in each year, yield increases by Kali KornKali and ADOB-HBEDZn were similar to those by ZnSO4,except in 2012-2013 experiments in Pakistan, where bothKali KornKali and ADOB-HBEDZn resulted in higher rates of yield increase than ZnSO4 **(TABLE 3).** Therefore, these 2 fertilizers seem to be promising alternatives to ZnSO4, according to the first 2 year results, at least in these countries.

Similar to the better stand establishment of wheat, seed Zn-enrichment by foliar Zn supply in China resulted in positive (and significant in 2012) increases in grain yield, especially in the 2nd year. The increases in wheat grain yield by using Zn-enriched seeds in 2012 were 13 % and 9 % at two locations.

**TABLE 3**. Effect of Kali KornKali and ADOB HBEDZn fertilizers on grain yield of wheat in India and Pakistan as compared to LC and LC + ZnSO4 treatments.

|  |  |
| --- | --- |
| **TREATMENT** | **\*GRAIN YIELD (t ha-1)** |
| **INDIA** | **PAKISTAN** |
| **2011-2012** | **2012-2013** | **2011-2012** | **2012-2013** |
| LC | 5.37 | 5.25 | 4.38 | 3.91 |
|  |
| LC + ZnSO4 | 5.95 | 5.59 | 5.20 | 4.39 |
| % IMPROVEMENT\*\* | **10.8** | **6.5** | **18.7** | **12.3** |
|  |
| LC + Kali KornKali | 6.07 | 5.60 | 5.26 | 4.57 |
| % IMPROVEMENT \*\* | **11.5** | **6.7** | **20.1** | **16.9** |
|  |
| LC + ADOB HBEDZn | 5.89 | 5.56 | 5.21 | 4.68 |
| % IMPROVEMENT\*\* | **9.7** | **5.9** | **18.9** | **19.7** |

\* Values are means of 3 experiments each, except for Pakistan 2012-2013 values, which are means of 2 experiments.

\*\*Improvement over LC.

**Soil Applied Fertilizers and Grain Yield: Rice**

Rice trials have been completed in China, India and Thailand. Grain yield of rice was affected by soil Zn applications in all those 3 countries. In the first year (2011) experiments in China, Zn-enriched seed and split urea were the best treatments resulting in 8 and 9 % yield increase, respectively, at one site, while Mosaic fertilizers resulted in the highest yield increase (11 %) over the control at the other site.

In the 2012-experiments, split urea was the best at the same location as in 2011, but results differed from the first year at the other location, where ADOB HBEDZn and use Zn-enriched seed were the best treatments. ADOB HBEDZn was the superior treatment in India, resulting in 10 % yield increase at one site and 10.9 % at the other in 2011. In case of 2012, there was 9.7 % yield increase at one site and 7.5 % at the other. However, the differences among most treatments (except for the control) were not statistically significant.

The greatest yield response of rice to soil Zn applications was obtained in Thailand in 2011-2012. Kali KornKali and ADOB HBEDZn were the most effective treatments. They resulted in 41.1 and 37.3 % yield increase, respectively, at one site; and both resulted in 18.2 % yield increase at the other. In 2012-2013, however, there was no treatment effect on grain yield at 1 site, while ADOB HBEDZn resulted in the highest yield improvement (19.5 %) at the other.

**Soil Applied Fertilizers and Grain Yield: Sorghum and Common Bean**

The sorghum experiments are being conducted in Zambia and the common bean experiments in Brazil only. Sorghum grain yields were not improved by soil application of Zn-containing fertilizers in 2011-2012 growing season. However, in the second year of the experiment, Mosaic MESZ II significantly improved sorghum yield, resulting in 55% yield increase, at one site. At the other site, Mosaic MESZ inclined to be one of the two best treatments, after ADOBHBED Zn, but the yield differences at this site were not statistically significant due to high CV and LSD values and generally low yield levels. It was also the case in the common bean experiments in Brazil, no significant improvement of seed yield was obtained by soil or foliar application of Zn fertilizers. An interesting observation was reported in relation to Mosaic fertilizers. In one location MESZ fertilizer was the best in terms of seed yield, while in other (second) location it resulted in the lowest yield. Results indicated that sulfur (S) deficiency was an important reason for the reduced performance of MESZ fertilizer in the second location, since differential S application rates were applied by the partners in Brazil (in contrast to the protocol). Despite existence of S in MESZ, the plots of MESZ treatments were treated with less amount of S fertilizer than other treatments, which is also associated with less amount of S in leaf tissue. In the currently on-going experiments this mistake has been corrected. Hence, the yield differences in the second year were not significant.

**Soil Applied Fertilizers and Grain Zinc: Wheat**

The grain Zn results of wheat were evaluated in this report by using data from Turkey, China, India, Pakistan for 2011-2012 and 2012-2013, and from Zambia for 2011-2012 (in total 20 field experiments). Of these 20 experiments, there were significant improvements due to soil treatments over control in 15 experiments. In 1 of the 4 experiments in China, 2 of the 6 experiments in India and the 2 of the 5 experiments in Pakistan, treatments did not improve grain Zn concentrations significantly.

The most outstanding result was the distinct superiority of the Treatment 5 (Mosaic-I with foliar Zn spray) to the control treatment and, in most cases, to other treatments. While Treatment 5 improved grain Zn of wheat in 15 experiments in 5 countries, ADOBHBED-Zn was the second most effective chemical, resulting in significant increases in 9 experiments; followed by Treatment 2 (LC + soil-applied ZnSO4) being significantly effective in 6 experiments. Other treatments were rarely effective. The effects of Treatment 5 as compared to soil application of ZnSO4, MOSAIC I and local control is given in **TABLE 4.** Since the number of experiments is too big to fit in a table, country averages are given. Data given for Turkey and China are averages of 4 experiments each, while the data for India and Pakistan are averages of 6 and 5 experiments, respectively. Zambia data belong to a single experiment.

**TABLE 4**. Effect of foliar ZnSO4 supplement on grain Zn concentration of wheat as compared to LC and LC + ZnSO4 and LC + MOSAIC I treatments.

|  |  |
| --- | --- |
| **TREATMENT** | **GRAIN Zn CONCENTRATION (mg kg-1)** |
| **TURKEY** | **CHINA** | **INDIA** | **PAKISTAN** | **ZAMBIA** |
| LC | 27.2 | 27.6 | 28.7 | 23.4 | 26.8 |
|  |
| LC + ZnSO4 | 28.9 | 30.7 | 30.5 | 28.4 | 34.0 |
| % IMPROVEMENT \* | **n.s.** | **n.s.** | **n.s.** | **21.4** | **26.9** |
|  |
| LC + MOSAIC I | 28.9 | 25.9 | 30.5 | 26.7 | 25.5 |
| % IMPROVEMENT \* | **n.s**. | **n.s.** | **n.s.** | **n.s.** | **n.s.** |
|  |
| LC +MOSAIC I+FOLIAR-Zn  | 32.9 | 34.1 | 37.7 | 28.9 | 38.5 |
| % IMPROVEMENT \* | **21.0** | **23.6** | **31.4** | **23.5** | **43.7** |

\*Improvement over LC.

Although a combined analysis was not performed for countries, the effects were denoted as n.s. if they were not significant in more than only one experiment in a given country and the differences were too small. As can be seen in **TABLE 4**, soil application of ZnSO4 significantly increased grain Zn concentration of wheat only in Pakistan, where it was effective in all 3 experiments in the first year, and Zambia. Addition of a single foliar ZnSO4 application at late stages of growth made a great contribution to grain Zn concentration in 15 experiments out of total 20 in 5 countries in two years. This confirms the previous results, including the ones from the first phase of this project, indicating superiority of foliar applications to soil applications as far as grain Zn concentrations are concerned.

Another outstanding chemical, in this aspect, was ADOB-HBEDZn. It significantly improved grain Zn concentration of wheat in 9 of the 20 experiments evaluated. The related results are shown in **TABLE 5.** Other soil-applied fertilizers were not so effective in increasing grain Zn except for a few cases. Higher efficiency of ADOB Zn-HBED might be relied to the existence of Zn in chelated form in this fertilizer.

**TABLE 5.** Effect of soil ADOB-HBEDZn application on grain Zn concentration of wheat as compared to LC treatment (Only the experiments where it was effective are included).

|  |  |  |
| --- | --- | --- |
|  | **LOCATION** | **GRAIN Zn CONCENTRATION (mg kg-1)** |
| **LC** | **ADOB-HBEDZn** | **IMPROVEMENT\*** **(%)** |
| \*\*TURKEY | SITE 1 | 32.6 | 36.5 | 12.0 |
|  | SITE 2 | 23.4 | 32.2 | 37.6 |
|  |
| \*\*CHINA | SITE 1 | 32.5 | 37.3 | 14.8 |
|  | SITE 2 | 22.0 | 30.5 | 38.6 |
|  |
| \*\*PAKISTAN | SITE 1 | 21.5 | 30.6 | 42.3 |
|  | SITE 2 | 13.5 | 25.3 | 46.6 |
|  |
| \*\*\*INDIA | SITE 1 | 24.6 | 28.6 | 16.3 |
|  | SITE 2 | 26.7 | 31.0 | 16.1 |
|  |  |  |  |  |
| ZAMBIA |  | 26.8 | 34.3 | 28.0 |

\*Improvement over LC.

\*\*Turkey, China, and Pakistan values belong to 2011-2012. In 2012-2013, the effect was not significant in these countries.

\*\*\*Values given for India belong to 2012-2013. The effect was not significant in 2011-2012.

**Soil Applied Fertilizers and Grain Zinc: Rice**

When Zn was not applied, grain Zn concentrations of rice were lower than that of wheat, confirming previous results. In 1 of the total 14 experiments in 2 years (an experiment conducted in India) soil applications did not significantly affect grain Zn concentration. In the other 13 experiments, Treatment 5 (MESZ+Foliar Zn), the only treatment involving foliar Zn application, resulted in the highest grain Zn concentration, except for 1 site where soil Zn application was better. This was also seen in the wheat experiments, confirming once again the superiority of foliar applications in improving grain Zn. Corresponding results are presented shown in **ANNEX 6.** Among the other soil applied fertilizers, KornKali significantly improved grain Zn in 3 of the 10 experiments conducted in two years, and ADOBHBED-Zn was effective in that aspect in two of them.

**TABLE 6.** Effect of foliar ZnSO4 supplement on grain Zn concentration of rice as compared to LC and LC + ZnSO4 and LC + MOSAIC I treatments (Each value is a mean of 2 experiments).

|  |  |
| --- | --- |
| **TREATMENT** | **GRAIN Zn CONCENTRATION (mg kg-1)** |
| **CHINA** | **INDIA** | **THAILAND** |
| **2011** | **2012** | **2011** | **2012** | **2013** | **2011** | **2012** |
| LC | 19.1 | 19.9 | 20.0 | 20.3 | 18.8 | 17.1 | 16.0 |
|  |
| LC + ZnSO4 | 24.4 | 20.7 | 20.3 | 20.5 | 19.2 | 19.8 | 18.0 |
| **% IMPROVEMENT\*** | **27.7** | **4.0** | **1.5** | **1.0** | **2.1** | **15.8** | **12.5** |
|  |
| LC + MOSAIC I | 21.4 | 19.9 | 20.3 | 19.7 | 19.6 | 17.7 | 17.0 |
| **% IMPROVEMENT\*** | **12.0** | **-** | **1.5** | **-** | **4.2** | **3.4** | **6.3** |
|  |
| LC+MOSAIC I + FOLIAR Zn | 23.9 | 24.2 | 26.9 | 23.7 | 23.3 | 22.6 | 23.7 |
| **% IMPROVEMENT\*** | **16.8** | **21.6** | **34.5** | **16.7** | **23.9** | **32.2** | **48.1** |

\*Improvement over LC.

**Soil Applied Fertilizers and Grain Zinc: Sorghum and Common Beans**

Grain Zn analyses of sorghum revealed some significant effects of applications of Zn containing fertilizers on grain Zn concentrations at 3 of the 4 experiments conducted in two years. The greatest improvement was obtained by Treatment 5 (the only treatment involving foliar supplement of Zn in EXP 1), increasing grain Zn concentration from 19.7 mg kg-1 in control plots to 31.0 mg kg-1 (57.4 % improvement) as an average of 4 experiments (**Table 7**).

**TABLE 7.** Effect of foliar ZnSO4 supplement on grain Zn concentration of sorghum in Zambia as compared to LC and LC + ZnSO4 and LC + MOSAIC-I treatments.

|  |  |
| --- | --- |
| **TREATMENT** | **GRAIN Zn CONCENTRATION (mg kg-1)** |
| **2011-2012** | **2012-2013** |
| SITE 1 | SITE 2 | SITE 1 | SITE 2 |
| LC | 14.7 | 25.9 | 12.3 | 25.8 |
|  |
| LC + ZnSO4 | 15.9 | 24.6 | 11.9 | 26.3 |
| **% IMPROVEMENT\*** | **n.s.** | **n.s.** | **n.s.** | **n.s.** |
|  |
| LC + MOSAIC-I | 17.7 | 25.5 | 12.5 | 23.5 |
| **% IMPROVEMENT\*** | **n.s.** | **n.s.** | **n.s.** | **n.s.** |
|  |
| LC+MOSAIC-I + FOLIAR Zn | 17.5 | 42.9 | 28.5 | 35.0 |
| **% IMPROVEMENT\*** | **n.s.** | **65.6** | **131.7** | **35.7** |

\*Improvement over LC.

In one of the 4 experiments with common beans in Brazil, Treatment 5, the only treatment involving foliar application, resulted in the highest seed Zn concentration. It increased seed Zn concentration from 29 (LC) to 37 mg kg-1, with a 27.6 % improvement over control. In the same experiment, ADOBHBED-Zn was the other treatment resulting in statistically significant improvement, although the increase was small. In other experiments of soil applications, none of the treatments improved seed Zn significantly, except for one where ZnSO4 increased grain Zn narrowly but significantly.

**Soil Applied Fertilizers: *Outcomes / Significance***

* Foliar applications of Zn proved once more to be superior to soil applications in improving grain Zn concentrations. On the other hand, they are less effective in increasing grain yields. This makes it compulsory to search for some means to improve adoptability of agronomic biofortification of cereal grains with Zn. It is very obvious that a combination of soil and foliar applications is needed for ensuring better grain yield and higher grain Zn
* Seed enrichment through foliar application on the previous crop resulted in better emergence rates and stand establishment in most of the locations, especially in China and Pakistan in both years and Thailand in 2012. This positive effect of high seed Zn was generally reflected well in grain yields.
* Priming seeds with 5 mM ZnSO4 for 1 hour resulted in adverse effects in some cases. In the second year trials 1 mM ZnSO4 has been used with less or no adverse effects. It is very obvious that seed Zn-enrichment through foliar application is superior to the seed Zn priming in terms of better stand establishment and grain yield performance
* Twice application of foliar ZnSO4 generally gave better results than single application. Single foliar Zn application was, however still highly effective in resulting in significant increases in grain Zn (see Task-2).

***Publications***

See Task 3 regarding the publications and visibility activities of the project

***Lessons Learned***

The reports from some of the partners indicated that 5 mM ZnSO4 used for seed priming resulted in adverse effects on stand establishment and seedling vigor, especially in Brazil for common bean, in Zambia in sorghum and in one location in China. Based on these observations, the Zn concentration used for seed priming has been reduced to 1 mM from 5 mM.

**TASK-II: Foliar Applied Fertilizers**

**Foliar Applied Fertilizers and Grain Yield: Wheat**

Of the 5 countries where wheat experiments are conducted, foliar application of Zn-containing fertilizers did not significantly affect grain yields in Turkey, China, India and Zambia. However, in case of the most foliar treatments there were non-significant increases in grain yield

Significant increases in grain yield by foliar Zn application were found in Pakistan. Although results varied among sites in Pakistan, foliar spray of ZnSO4 at early milk stage resulted in the highest yield increase (32.2%) from 3.78 to 5.00 t ha-1, on the average of the 3 sites in 2011-2012; whereas Kali-EPSO-Zn and Antracol-Zn were the best treatments in 2012-2013, improving grain yield from 4.26 to 6.03 (41.5% improvement) and 5.94 (39.4% improvement)

 t ha-1, respectively.

**Foliar Applied Fertilizers and Grain Yield: Rice**

Foliar application of Zn-containing fertilizers significantly affected rice yields only at some experiments. There was no significant effect in experiments in India in either year. In China, there was no effect at 1 location in either year of the experiment but the yields were affected at the other location in both years. In the first year, twice application of ZnSO4 resulted in the highest yield improvement, increasing rice yield from 6.73 (Local Control) to 7.59 t ha-1, with a 12.8 % improvement. The next year, KaliEpso resulted in the highest yield with 10.5 t ha-1. It meant a 7.8 % improvement over the LC plots which gave 9.74 t ha-1 grain yields. In Thailand, there were significant effects in all 4 experiments in 2 years. OMEX Type III was one of the best treatments in 3 of the 4 experiments. Valagro and Antracol were the best treatments at the 2nd year experiments.

**Foliar Applied Fertilizers and Grain Yield: Sorghum and Common Bean**

The sorghum experiments are conducted in Zambia and the common bean experiments in Brazil only. Sorghum grain yields were not improved by foliar application of Zn solutions (EXP 2). It was also the case in the common bean experiments in Brazil, no significant improvement of seed yield was obtained by foliar application of Zn fertilizers.

**Foliar Applied Fertilizers and Grain Zinc: Wheat**

Since this experiment is evaluated in several aspects, they will be summarized separately.

**Effect of timing of foliar ZnSO4 application**

Timing of single application gave different results in different experiments. One steady result in this aspect was the superiority of twice application to single application in most cases. This comparison is shown in **TABLE 8** for Turkey and China, and in **TABLE 9** for India, Pakistan and Zambia.

**TABLE 8:** Comparison between effects of foliar ZnSO4 application twice and single application on grain Zn concentration of wheat in Turkey and China.

|  |  |
| --- | --- |
| **TREATMENT** | **\*\*GRAIN Zn CONCENTRATION (mg kg-1)** |
| **TURKEY** | **CHINA** |
| **YEAR 1** | **YEAR 2** | **YEAR 1** | **YEAR 2** |
| 1. Local control (LC) | 31.5 | 27.4 | 26.9 | 25.5 |
| 2. LC+ Foliar ZnSO4 (booting) | 35.6 | 32.3 | 35.2 | 33.9 |
| 3. LC+ Foliar ZnSO4 (early milk) | 33.0 | 34.3 | 36.1 | 37.2 |
| 4. LC+ Foliar ZnSO4 (booting + early milk) | 39.5 | 38.3 | 44.2 | 40.8 |
|  |
| \***IMPROVEMENT (%)** | **25.4** | **39.8** | **64.3** | **60.0** |

\*Improvement over LC by twice application.

\*\*Each value is average of two sites.

**TABLE 9:** Comparison between effects of foliar ZnSO4 application twice and single application on grain Zn concentration of wheat in India, Pakistan and Zambia.

|  |  |
| --- | --- |
| **TREATMENT** | **\*\*GRAIN Zn CONCENTRATION (mg kg-1)** |
| **INDIA** | **PAKISTAN** | **ZAMBIA** |
| **YEAR 1** | **YEAR 2** | **YEAR 1** | **YEAR 2** | **2011-2012** |
| 1. Local control (LC) | 32.1 | 26.4 | 22.1 | 31.1 | 31.2 |
| 2. LC+ Foliar ZnSO4 (booting) | 39.3 | 34.3 | 27.4 | 41.7 | 35.1 |
| 3. LC+ Foliar ZnSO4 (early milk) | 38.7 | 36.2 | 28.9 | 40.6 | 34.9 |
| 4. LC+ Foliar ZnSO4 (booting + early milk) | 40.4 | 43.3 | 34.0 | 38.9 | 40.9 |
|  |
| \***IMPROVEMENT (%)** | **20.6** | **64.0** | **62.9** | **25.1** | **31.1** |

\*Improvement over LC by twice application.

\*\*Values for Pakistan are means of 3 experiments in 2011-2012, and 2 experiments in 2012-20

13. Values for India are means of 3 experiments each year. Zambia values are means of two sites.

***Effect of other Zn-compounds***

Effect of the other Zn-compounds on wheat grain Zn is shown in **TABLE 10** for Turkey and China, and in **TABLE 11** for India, Pakistan and Zambia. It is important to highlight that all Zn compounds have been sprayed to foliar only once.

**TABLE 10**: Effect of foliar-applied commercial Zn-containing fertilizers on grain Zn concentration of wheat in Turkey and China.

|  |  |
| --- | --- |
| **TREATMENT** | **\*GRAIN Zn CONCENTRATION (mg kg-1)** |
| **TURKEY** | **CHINA** |
| **YEAR 1** | **YEAR 2** | **YEAR 1** | **YEAR 2** |
| 1. Local control (LC) | 31.5 | 27.4 | 26.9 | 25.5 |
| 5 LC+ OMEX II | 34.3 | 38.5 | 38.5 | 38.3 |
| 6. LC+ OMEX III | 30.5 | 34.1 | 38.4 | 34.4 |
| 7. LC+Kali-EPSO | 33.3 | 31.9 | 38.2 | 34.3 |
| 8. LC+ ADOB ZnIDHA | 33.8 | 35.9 | 39.3 | 33.3 |
| 9. LC+ Valagro Brexil | 35.0 | 35.8 | 44.7 | 33.3 |
| 10. LC+ Antracol | 32.6 | 30.4 | 29.9 | 31.3 |
| 12. LC+ FBScience | 36.5 | 34.2 | 39.3 | 36.4 |

 \*Each value is average of two sites.

The effect of different fertilizers, as compared to local control can be summarized as follows: Depending on country and location, most of the foliar Zn-fertilizers/compounds appeared to be very promising in improving wheat grain Zn concentration. OMEX II improved grain Zn of wheat significantly at 18 of the total 20 experiments conducted in 5 countries in two years. ADOB ZnIDHA and Valagro Brexil followed it in efficiency, improving grain Zn of wheat significantly in 15 experiments. FBScience, OMEX III, Kali-EPSO, and Anthracol improved grain Zn in 13, 12, 11, and 8 experiments, respectively. The most important observation here is that, in 19 of the total 20 experiments, at least one of these chemicals was effective in improving grain Zn of wheat.

**TABLE 11:** Effect of foliar-applied commercial Zn-containing fertilizers on grain Zn concentration of wheat in India, Pakistan and Zambia.

|  |  |
| --- | --- |
| **TREATMENT** | **GRAIN Zn CONCENTRATION (mg kg-1)** |
| **INDIA** | **PAKISTAN** | **ZAMBIA** |
| **YEAR 1** | **YEAR 2** | **YEAR 1** | **YEAR 2** | **2011-2012** |
| 1. Local control (LC) | 32.1 | 26.4 | 22.1 | 31.1 | 31.2 |
| 5 LC+ OMEX II | 43.6 | 37.9 | 27.7 | 44.8 | 57.3 |
| 6. LC+ OMEX III | 36.9 | 35.4 | 24.7 | 32.9 | 48.0 |
| 7. LC+Kali-EPSO | 39.2 | 36.1 | 26.4 | 33.9 | 45.3 |
| 8. LC+ ADOB ZnIDHA | 39.5 | 35.0 | 27.6 | 32.8 | 41.9 |
| 9. LC+ Valagro Brexil | 40.9 | 36.3 | 27.1 | 31.8 | 49.4 |
| 10. LC+ Antracol | 37.9 | 34.4 | 23.5 | 34.7 | 36.6 |
| 12. LC+ FBSci-ZicRON | 37.9 | 34.4 | 26.4 | 32.7 | 39.4 |

 \*Values for Pakistan are means of 3 experiments in 2011-2012, and 2 experiments in 2012-2013. Values for India are means of 3 experiments each year. Zambia values are means of two sites.

In summary, when data averaged over experiments are studied (**TABLES 10 and 11**), it is seen that in all countries and almost all years, OMEX II was the chemical resulting in the highest grain Zn concentrations. Only exceptions to this were the first year averages of Turkey and China, where its leading position was replaced by Valagro Brexil. In one of the two years in Turkey and China, in both years in India and Pakistan, and in Zambia, OMEX II resulted in the highest grain Zn. HP 2011 and HP 2012 also increased grain Zn concentration of wheat significantly at both sites in Turkey (see **ADDENDUM:** Country Report). LC + HP 2011 (Treatment 13) and LC + HP 2012 (Treatment 14) both resulted in statistically significant improvements in grain Zn concentrations at both locations in both years. In fact, HP 2011 was the best treatment among all at Eskisehir location, resulting in the highest grain Zn (43.0 mg kg-1) in the first year, and the second highest in the second year (43.5 mg kg-1), after twice application of ZnSO4 (43.8 mg kg-1). At Konya location, HP 2012 was the second most effective treatment in the first year, after twice application of ZnSO4, and the best in the second year, resulting in grain Zn concentrations of 33.6 and 40.5 mg kg-1, respectively.

It was also important to highlight that foliar Zn fertilizers can be sprayed to foliar together with fungicides/insecticides tested in different countries. There was no adverse effect of those pesticides on leaf Zn penetration and seed/grain Zn deposition in wheat. Similar conclusion was also made for rice and other crops tested.

**In the 3rd experiment** conducted only in Turkey, 0.5 % ZnSO4 application at post-flowering period resulted in higher grain Zn than 0.3 % ZnSO4, particularly when urea was not added. When urea added, though, the difference due to concentration was much smaller. This means that the contribution of urea to increasing the effect of applied ZnSO4 on grain Zn was greater when 0.3 % ZnSO4 solution was used. Post-flowering application of 0.5 % ZnSO4 with addition of urea resulted in the highest grain Zn concentration (42.5 mg kg-1) among all 18 treatments, followed by post-flowering application of 0.3 % ZnSO4 with addition of urea (41.1 mg kg-1). This shows the significant contribution of urea to the effectiveness of applied Zn, particularly when the solution concentration is lower, presumably through facilitating the penetration of foliar-applied Zn.

Among the Zn fertilizer forms of Zn (ZnO, ZnSO4, nanoparticle ZnO, ZnCl2 and ZnEDTA), all with 0.3 % concentration, ZnCl2 resulted in the highest grain Zn (40.7 mg kg-1), followed by ZnSO4, ZnEDTA and ZnO. The ZnO forms were not effective.

Very new results obtained from greenhouse and field indicate that reducing pH of solution pH and adding some special adjuvant/tensides in the solution of the foliar Zn fertilizers substantially increased grain Zn concentrations in wheat. Several methods to reduce solution pH have been added to the 3rd experiment conducted in Turkey in the second year. Reducing the solution pH to 6.0 or 4.5 was compared with the control, which was the use of tap water with a pH of 8.3. Treatments were performed twice. pH-reducing treatments were effective in increasing grain Zn as compared to high-pH tap water at both locations, while only lowering pH to 6.0 improved grain Zn, further lowering the pH to 4.5 not being effective. At Eskisehir, the highest grain Zn values were obtained by lowering the solution pH to 6.0 with citric acid, improving grain Zn from 41.0 mg kg-1 with tap water to 51.5 mg kg-1, with a 25.6% improvement. Addition of urea to citric acid did not make a significant contribution. HCl addition down to pH 6.0 was the best treatment at Konya improving grain Zn concentration of wheat from 32.3 to 40.5 mg kg-1, with 25.4% increase.

**Foliar Applied Fertilizers and Grain Zinc: Rice**

***Effect of timing of foliar ZnSO4 application***

Like in wheat, twice application of ZnSO4 resulted in higher grain Zn than single applications at 11 of the 12 experiments evaluated, although the differences were not always significant (**TABLE 12**). Effect of the other Zn-compounds on grain Zn concentration of rice is presented in **TABLE 13.**

**TABLE 12:** Comparison between effects of foliar ZnSO4 application twice and single application on grain Zn concentration of rice in China, Thailand and India (Each value is a mean of 2 experiments).

|  |  |
| --- | --- |
| **TREATMENT** | **GRAIN Zn CONCENTRATION (mg kg-1)** |
| **CHINA** | **THAILAND** | **INDIA** |
| **YEAR 1** | **YEAR 2** | **YEAR 1** | **YEAR 2** | **YEAR 1** | **YEAR 2** | **YEAR 3** |
| 1. Local control (LC) | 19.4 | 21.5 | 17.6 | 19.3 | 19.3 | 18.5 | 18.9 |
| 2. LC+ Foliar ZnSO4 (booting) | 20.5 | 24.2 | 21.8 | 21.6 | 21.2 | 20.1 | 20.5 |
| 3. LC+ Foliar ZnSO4 (early milk) | 22.0 | 24.0 | 22.6 | 23.8 | 23.9 | 22.4 | 22.2 |
| 4. LC+ Foliar ZnSO4 (booting + early milk) | 23.8 | 26.8 | 26.4 | 24.4 | 24.3 | 22.7 | 22.5 |

As can be seen in **TABLE 13,** nearly all Zn compounds increased grain Zn of rice in most cases. The superior compound changed from country to country. Since the most effective chemicals changed with experiments, a summarized result is given below:

**TABLE 13:** Effect of foliar-applied commercial Zn-containing fertilizers on grain Zn concentration of rice in China, Thailand and India (Each value is a mean of 2 experiments).

|  |  |
| --- | --- |
| **TREATMENT** | **GRAIN Zn CONCENTRATION (mg kg-1)** |
| **CHINA** | **THAILAND** | **INDIA** |
| **YEAR 1** | **YEAR 2** | **YEAR 1** | **YEAR 2** | **YEAR 1** | **YEAR 2** | **YEAR 3** |
| 1. Local control (LC) | 19.4 | 21.5 | 17.6 | 19.3 | 19.3 | 18.5 | 18.9 |
| 5 LC+ OMEX II | 22.6 | 26.2 | 20.6 | 22.9 | 25.5 | 21.4 | 22.0 |
| 6. LC+ OMEX III | 22.5 | 24.4 | 21.3 | 21.7 | 24.5 | 22.3 | 21.7 |
| 7. LC+Kali-EPSO | 25.0 | 26.4 | 22.2 | 23.3 | 23.8 | 22.3 | 21.0 |
| 8. LC+ADOB-ZnIDHA | 23.0 | 21.9 | 22.2 | 22.2 | 24.0 | 21.1 | 20.9 |
| 9. LC+ Valagro Brexil | 23.8 | 23.9 | 22.1 | 22.7 | 24.7 | 21.9 | 20.8 |
| 10. LC+ Antracol | 20.8 | 23.4 | 19.4 | 19.8 | 22.8 | 21.3 | 21.0 |
| 12. LC+ FBScience | 24.8 | 25.2 | 23.9 | 21.7 | 22.3 | 19.9 | 21.0 |

Kali-Epso improved grain Zn concentration of rice significantly in 11 of the 14 experiments (All 6 experiments in India, 3 in China, and 2 in Thailand). OMEX II and Valagro Brexil improved grain Zn significantly in 10 of the 14 experiments (All 4 in India, 2 in each of China and Thailand). ADOB-ZnIDHA and OMEX III improved grain Zn significantly in 9 of the 14 experiments (5 out of 6 in India, 2 in each of China and Thailand). FBScience improved grain Zn significantly in 8 experiments (3 in each of India and China, 2 in Thailand). Antracol improved grain Zn of rice in 7 experiments (5 in India, 1 in each of China and Thailand).

The most outstanding observation about rice grain Zn analyses results was that despite percent improvements over control, grain Zn concentrations of rice are still very low as compared to wheat. This fact was also observed and stated in the first phase of the project. However, there have been cases where foliar applications resulted in improvements close to 10 mg kg-1.

**Foliar Applied Fertilizers and Grain zinc: *Sorghum and Common Bean***

In sorghum foliar application experiments, most treatments significantly improved grain Zn concentration. The highest rate of increases were obtained by twice application of ZnSO4 and OMEX Type II at one site, while the highest grain Zn values were obtained by OMEX II and OMEX III treatments at the other, in the first year. In the second year, Valagro Brexil, Anthracol and OMEX Type III resulted in the highest grain Zn at one site, while OMEX II and OMEX III were the most effective, in that aspect, at the other site.

In common bean experiments in Brazil, in the Experiment 2, OMEX II resulted in the highest seed Zn, in all 4 experiments in 2 years, followed by twice application of ZnSO4. The increases in the plots treated with OMEX might be partly due to the yield decreases in OMEX plots in the first year.

**Foliar Applied Fertilizers: *Outcomes / Significance***

* Twice application of foliar ZnSO4 generally gave better results than single application. Timing of single applications gave variable results, presumably due to varying environmental conditions.
* Most of the Zn-containing foliar solutions were found to be highly promising in relation to improvement of grain Zn concentration based on the 2 year results.
* Foliar Zn fertilizers can be sprayed to foliar together with fungicides/insecticides tested in different countries. There was no adverse effect of those pesticides on leaf Zn penetration and see/grain Zn deposition.
* 0.5 % concentration of ZnSO4 solution gave better results than 0.3 %. However, when urea was used together with ZnSO4, this difference was greatly reduced. Urea addition was effective in increasing the effectiveness of ZnSO4, particularly when lower concentration of ZnSO4 was used.
* Among the other Zn forms tested (ZnO,nanoparticle ZnO, ZnCl2, ZnEDTA and ZnSO4) ZnCl2 gave the best result while the ZnO forms were less effective in increasing grain Zn.
* Very new and not-reported results indicate that solution pH and use of some adjuvants/tensides markedly effect the agronomic effectiveness of foliar Zn fertilizers. Reducing solution pH from 8.3 to 6.0 by HCl or citric acid significantly improved grain Zn concentration of wheat in Turkey.

***Lessons Learned***

Solution pH of the foliar Zn fertilizers has unexpectedly high impact on agronomic effectiveness of foliar Zn fertilizers. This is an issue to be considered in future foliar tests and research programs.

**TASK-III: DISSEMINATION AND IMPLEMENTATION OF THE PROJECT RESULTS**

Delivery and implementation of the project results to farmers represent an important step for the success of this project. HarvestZinc project has already started to organize “Zinc Days” event in the target countries for the agronomists/crop consultants, extension staff, farmers, nutritionists and decision makers. The "Zinc Days" event is a major collaborative effort together with the partner countries/institutions to contribute to the mission and goal of the project. This event represents an important delivery activity of the project. From the start of the second phase of the project, 15 "Zinc Days" event has been organized including 6 Zinc Days event in the second year of the project as following:

So far following 15 "Zinc Days" event has been organized. The number of the participants is also given below:

1) **May 10, 2011** Quzhou, Hebei (CHINA) organized by China Agricultıral University (total participants: 235)

2) **June 2, 2011:** Ludhiana (INDIA) organized by Punjab Agricultural University (total participants: 185)

3) **July 27, 2011:** Chiang Mai (THAILAND) organized by Chiang Mai University (total participants:160)

4) **August 15, 2011:** Weinan-Xian (CHINA) organized by Northwest Agriculture and Forestry University (total participants: 285)

5) **December 6, 2011:** Campinas-SP (BRAZIL) organized by the Instituto Agronomica-Campinas (total participants: 185).

6) **March 27, 2012**: Faisalabad (PAKISTAN) Nuclear Institute for Agriculture and Biology (NIAB) (total number of participants: approx. 450)

7) **June 16, 2012:** Mazatlan (MEXICO) organized by CIMMYT(total number of participants: approx 600)

8) **November 25, 2012:** Rudong-Jiangsu (CHINA) organized by Nanjing Agricultural University and China Agricultural University (total number of participants: 200)

9) **March 16, 2012:** Lusaka (ZAMBIA) organized by GART and Zambia University (total number of the farmers close to 4000). GART is a big farmer association in Zambia and organizing every year in March a big farmer event to demonstrate on-going demonstrative and research-based trials and activities.

10) **February 20, 2013:** Bathinda (INDIA) organized by the Punjab Agricultural University (total number of the farmers 60).

11) **March 12, 2013**: Lahore (PAKISTAN) organized Nuclear Institute for Agriculture and Biology (toatal nuber of participants 250)

12) **March 21, 2013** Lusaka (ZAMBIA) organized by GART and Zambia University (total number of the farmers close to 4000)

13) **May 6, 2013:** Anhui (CHINA) organized by China Agricultural University and Anhui Academy of Agricultural Sciences (total number of the participants about 200)

14) **July 31, 2013**: Hyderabad- ICRISAT (INDIA) organized by ICRISAT (total number of the participants about 300)

15) **December 26, 2013**: Eskisehir (TURKEY) organized by Ministry of Agriculture and Sabanci University (Total number of participants are about 300, including 110 farmers).

***Outcomes / Significance***

The "Zinc Days" event represents an important delivery activity of the project. This event is highly useful forum for farmers, agronomists and other end-users (like students) and provides very valuable basic information through oral presentations and educational materials such as videos, colour brochures/booklets, factsheets, various colour pictures of Zn deficiency symptoms from different food crops. Presentations made are generally focused on the following topics:

i) soil and management factors affecting availability and root uptake of zinc

ii) why plants need zinc

iii) soil and foliar zinc fertilizers and application methods

iv) zinc fertilization of selected crops

v) role of zinc-biofortified crops in yield and human nutrition

vi) role of zinc in human nutrition and health

HarvestZinc project was represented in the 3rd International Zinc Symposium, held in Hyderabad in October, 2011. *Plant and Soil*, a leading international journal on plant-soil relationships, published a  **Zinc Special Issue** in December 2012, which contains 23 zinc-related original papers, and most of them were presented at the 3rd International Zinc Symposium in October 2011. Among the papers published, 6 papers were derived from the HarvestZinc project activities.

To view the **Zinc Special Issue** of *Plant and Soil*, please visit: http://link.springer.com/journal/11104/361/1/page/1

Following HarvestZinc project papers have been published in this special Zinc Issue:

1) Zou, C.Q., Y.Q. Zhang, A. Rashid, H. Ram, E. Savasli, Z. Arisoy, I. Ortiz-Monasterio, S. Simunji, Z.H. Wang, V. Sohu, M. Hassan, Y. Kaya, O. Onder, O. Lungu, M.Y. Mujahid, A.K. Joshi, Y. Zelensky, F.S. Zang, and I. Cakmak (2012) **Biofortification of wheat with Zn through Zn fertilization in seven countries.** Plant and Soil (DOI 10.1007/s11104-012-1369-2). see: http://www.springerlink.com/content/h3984n6167887448/

2) Phattarakul N, Rerkasem B, Li L J, Wu L H, Zou C Q, Ram H, Sohu V S, Kang B S, Surek H, Kalayci M, Yazici A, Zhang F S and Cakmak I. **Biofortification of rice grain with Zn through Zn fertilization in different countries.** Plant and Soil. DOI 10.1007/s11104-012-1211 http://www.springerlink.com/content/81r1603373645565/

3) Prom-u-thai C, Rerkasem B, Yazici A and Cakmak I. 2012. **Zn-priming promotes seed germination and seedling vigor of rice**. Journal of Plant Nutrition and Soil Science. 175: 482-488. See: http://onlinelibrary.wiley.com/doi/10.1002/jpln.201100332/abstract

4) Manzeke GM, Mapfumo P, Mtambanengwe F, ChikowoR, Tendayi T, and Cakmak I. 2012. **Soil fertility management effects on maize productivity and grain zinc content in smallholder farming systems of Zimbabwe.** Plant and Soil. DOI 10.1007/s11104-012-1332-2. http://www.springerlink.com/content/8674872216343t32/

5) Kutman UB, Kutman BY, Ceylan Y, Ova EA and Cakmak I. 2012. **Contributions of root uptake and remobilization to grain zinc accumulation in wheat depending on post-anthesis zinc availability and nitrogen nutrition**. Plant and Soil. DOI 10.1007/s11104-012-1300-x. http://www.springerlink.com/content/23r7418w3067t387/

In addition, several MSc and PhD students are involved in this project and conducted their Thesis Projects under the HarvestZinc project. Total number of students who conducted their projects under this project is 10 (5 in Turkey; 2 in India; 2 in China, 1 in Thailand).