Increasing Wheat and Rice Productivity in the Sub-Tropics Using Micronutrient Enriched Seed

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Abstract

Many soils in the high rainfall sub-tropics are deficient in micronutrients, especially zinc (Zn), boron (B), and molybdenum (Mo). In vivo micronutrient enrichment of seed via foliar applications of micronutrients on the mother plants was evaluated as a strategy to address soil micronutrient deficiencies because farmers have limited access to soil testing for micronutrients. Seed enrichment was expected to alleviate soil deficiencies and to provide resistance against seedling root diseases. Fertiliser salts of Zn, Mo, nickel (Ni), copper (Cu), manganese (Mn), and boron (B) were sprayed at recommended concentrations five or ten times during the growth stages of wheat and rice, respectively. Both wheat and rice seed were enriched with all micronutrients, except B. Wheat seedling emergence and vigour were enhanced with seed enriched with micronutrients compared to unenriched seed. We believe this is due to increased resistance to soil borne pathogens. Wheat and rice seeds enriched with micronutrients that were sown in farmers' fields had increased yields relative to unenriched control seeds. Wheat yields increased an average of 25% in twelve of forty-seven on-farm trials in northwest Bangladesh. Rice yields increased an average of 22% in twelve of seventeen on-farm trials in the same area. Results indicate that seed enriched with micronutrients could improve yields of both wheat and rice in areas with micronutrient deficient soils without soil testing.

Introduction

Micronutrients stored in seeds and grain are essential for initial crop growth during germination and early seedling establishment. Inadequate reserves of seed micronutrient stores result in poor seed viability and diminished seedling vigour, especially when the seeds are sown in soils poor in micronutrients or when certain biotic (e.g., soil-borne pathogens) or abiotic (e.g., drought) stresses occur (Welch 1986; 1999). The rice-wheat cropping pattern of Bangladesh is primarily found on lighter-textured soils with wheat grown immediately following the monsoon rice crop. Yields of rice and wheat in Bangladesh are low, averaging 3.5t ha^{-1} and 2.1t ha^{-1}, respectively (FAOSTAT 2004). These low yields indicate that there are many constraints to crop productivity, including soil micronutrient deficiencies (Figure 1), poor crop establishment, and poor root health (Duxbury et al. 2004). High cropping intensity combined with little retention of crop residues and limited return of animal manure to soils exacerbates soil micronutrient deficiencies. Unfortunately, soil testing facilities for micronutrients are not widely available in the region. Furthermore, few farmers in Bangladesh use micronutrient inputs, even in areas with known soil micronutrient deficiency problems.

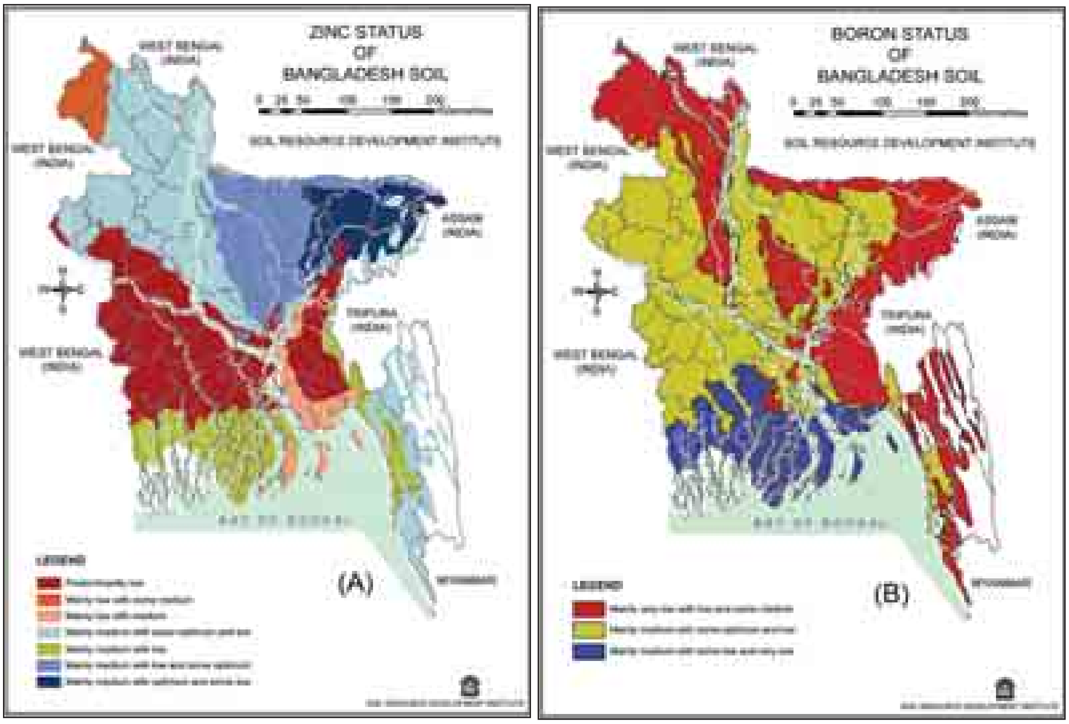

Figure 1: **Soil zinc (A) and boron (B) status in Bangladesh.** Source: Soil Resource Development Institute, Bangladesh Agricultural Research Council. Note: Areas shaded red, yellow, and pink indicate regions with low zinc/boron status.

Low stand density of wheat is often found despite relatively high farmer seeding rates (up to 200 kg ha^{-1}) (Meisner et al. 2003), which suggests that seed quality may also contribute to low yields. Most farmers' produce their own seed as the government supplier, Bangladesh Agricultural Development Corporation (BADC), can only provide 12–15% of the total seed requirement and private suppliers provide insufficient quantities.

Widespread soil micronutrient deficiencies and poor seed quality prompted us to test the hypothesis that seed enriched with micronutrients in vivo will provide yield benefits compared to unenriched seed in micronutrient deficient soils. Furthermore enriched seed would improve seed quality and seedling vigour by increasing seedling tolerance/resistance to soil-borne pathogens. As a result, enriching seed with micronutrients may be a strategy for overcoming micronutrient deficiencies and soil health problems at the farm level.

Materials and Methods

Seeds were enriched with micronutrients by foliar application during growth of the mother plants at the Wheat Research Centre, Nashipur, Bangladesh. Seed enrichment was undertaken for the wheat variety Kanchan, the major wheat variety grown in Bangladesh; the newly-released wheat varieties Sourav, Gourab, and Shatabdi; and the rice varieties, BR11, BR32, and BR33. The total amount of micronutrients applied per crop was 4 kg ha^{-1} for Zn and Mn; 1 kg ha^{-1} for Cu; and 0.5 kg ha^{-1} for B, Mo, and Ni. Nutrients were sprayed in five equal splits for wheat, beginning two weeks after sowing and continuing up to anthesis, and in 10 equal splits for rice. The nutrient sources used were zinc, copper, manganese, and nickel sulphates, boric acid, and sodium molybdate. Plants not receiving foliar sprays were grown at the same time to generate seed for use in unenriched control treatments. Various micronutrient combinations were used, including the complete suite and the complete suite minus individual nutrients. A Zn-only foliar spray treatment was also included. Not all treatments were included each time that enriched seeds were generated or with each variety.

Wheat and rice grains produced through foliar sprays were harvested and stored separately from unenriched grain. Grain samples were digested in nitric acid and analysed for micronutrient content by inductively-coupled plasma (ICP) atomic emission spectroscopy.

Trials were undertaken at the research station and on farmers' fields in northwest Bangladesh to compare the performance of enriched seeds, unenriched control seeds, and farmers' seeds for the various wheat and rice varieties. The trials carried out in each of three 'upazillas' (a rural administrative subdivision of a district) (Dinajpur Sadar, Kaharol, Kaunia) varied in design and replication. In the 1996/97 wheat season, seeds from various micronutrient treatments were used in an unreplicated design. Subsequently, only seeds from the complete micronutrient treatment were used with two replications in 1997/98 and three replications thereafter. A replicated plot trial with the rice variety BR32 was carried out at nine farms in Dinajpur Sadar, Kaharol, and Kaunia upazillas plus one additional farm at Chuadanga during the 2000 monsoon rice season. Plot size for farmer trials was three by four metres and seed was planted in rows by hand (20 cm apart, 15 rows/plot) to avoid problems with seed being planted at different depths. All soils were sandy in texture.

In addition to the field trials, a pot study was undertaken with Kanchan in 1998/99 to improve understanding of the impacts of micronutrient enrichment on seedling emergence, survival, and vigour. Pots were set up in groups of three using micronutrient enriched, control unenriched, and farmers' seeds in soil from a particular farm. Seeds were planted in pots which were buried in the ground at the Wheat Research Centre (WRC), Nashipur. A total of nine soils (three each from farms in Dinajpur Sadar, Kaharol, and Kaunia) were used with two replicates of each seed source. The soil was watered as necessary to ensure good growth. Seedling emergence, plant biomass, and root health evaluations were determined at 40 days after seeding. Root health evaluations used a rating scale of 1 (healthy roots, no visible disease symptoms) to 9 (greater than 75% of root tissue is diseased, reduced in size, and with advanced signs of decay) (CIAT 1987).

Results and Discussion

Seed Enrichment with Micronutrients

Significant increases in Zn, Mn, Cu, Mo, and Ni content were found for each of the four wheat varieties tested relative to unenriched controls (Figure 2: Ni not shown). Volatility of B during acid digestion precluded accurate results for B enrichment by wet digestion, but no enrichment was evident. Averaged across the four varieties, micronutrient concentrations of wheat seeds were enriched 10 to 20 fold for Mo and Ni; 1.6 to 2.0 fold for Zn; and 1.1 to 1.5 fold for Mn and Cu (Figure 3).

Foliar applications of micronutrients to rice variety BR11 increased micronutrient content of the seed slightly. Greater differences were observed for rice variety BR32 relative to unsprayed controls, with seed concentration enriched 6 fold for Mo; 1.5 fold for Mn; 2.6 fold for Zn, and 3 fold for Cu (Figure 4).

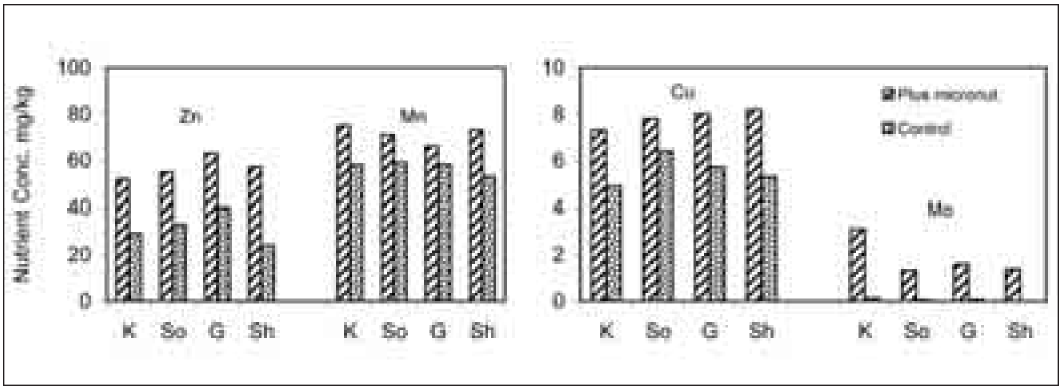

Figure 2: **Effect of foliar application of micronutrients on Zn, Mn, Cu, and Mo contents of whole grain of Kanchan (K), Sourav (So), Gourab (G), and Shatabdi (Sh) wheat varieties**

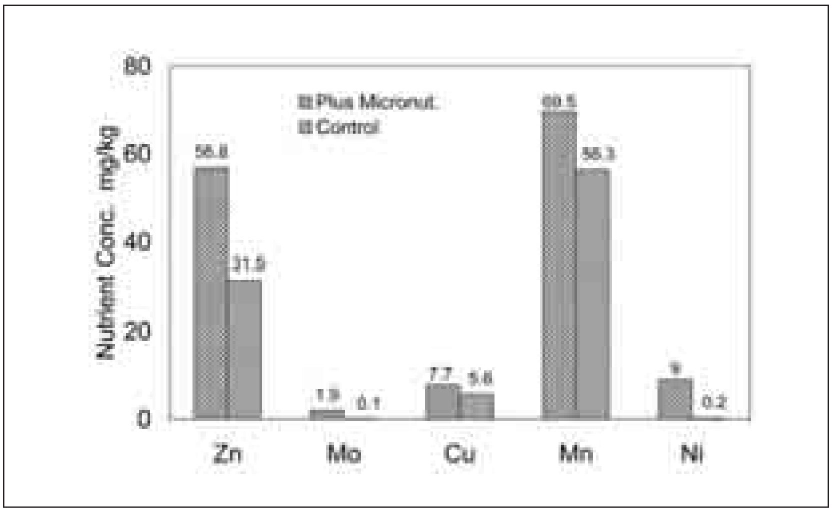

Figure 3: **Effect of foliar application of micronutrients on Zn, Mn, Cu, Mo, and Ni contents of wheat grain (average of 4 varieties)**

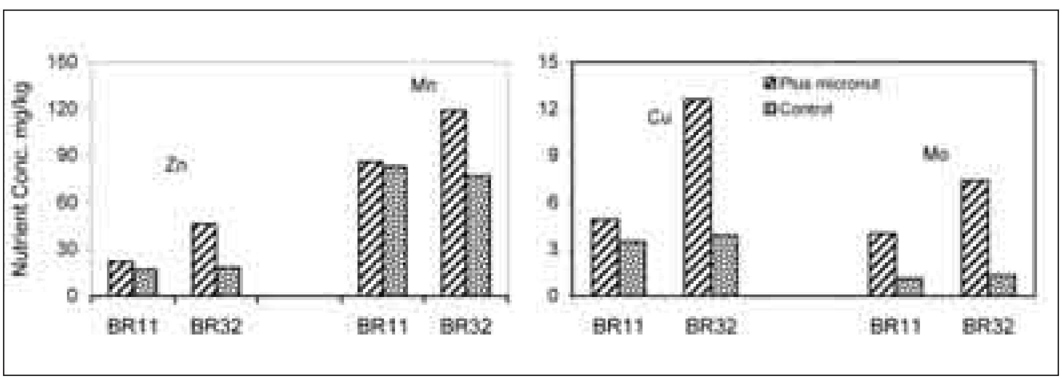

Figure 4: **Effect of foliar application of micronutrients on Zn, Mn, Cu, and Mo contents of whole grain of BR11 and BR32 rice varieties**

Effect of micronutrient-enriched seeds on wheat yields

At the research station, wheat yields were significantly increased ($p<0.05$) with micronutrient enriched seeds compared to the control unenriched seed in trials over three consecutive years for four different varieties of wheat (Table 1). The average increase ranged from 7 to 18 %, with Gourab being the least responsive and Kanchan the most responsive. Average yields were similar for all varieties, both with (3.8-4.1 t/ha) and without (3.4-3.6 t/ha) seed enrichment with micronutrients.

Treatments in which wheat seed was enriched with Zn only gave the same yield as complete seed enrichment (Zn, Mo, Cu, Mn, and Ni), indicating that the observed yield responses were primarily due to higher levels of Zn in enriched seed (data not shown). However, yield response of the variety Shatabdi was shown to be due to seed enrichment with both zinc and molybdenum at a second site at the research station (Table 2).

Table 1: **Effect of micronutrient enrichment of seeds on wheat yields at the Wheat Research Centre, Nashipur**

Variety and seed type	Grain yield t/ha				Increase over control %
	2000	2001	2002	Mean	
Kanchan					
Enriched	3.60[1]	4.59	3.98	4.06	18
Control	2.82	4.09	3.41	3.44	
Sourav					
Enriched	4.02	3.91ns	4.07	4.00	15
Control	3.16	3.81ns	3.49	3.49	
Gourab					
Enriched	3.20	4.21ns	4.02	3.81	7
Control	2.88	4.18ns	3.64	3.56	
Shatabdi					
Enriched	2.89	4.65	4.29	3.94	12
Control	2.34	4.28	3.91	3.51	

[1]Yield with micronutrie nt (MN) enriched see d was significantly greater ($p< 0.05$) than that with unenriched control seed except where indicated by ns (non significant)

Table 2: **Effect of selective micronutrient enrichment of seeds on yield of Shatabdi wheat at the Wheat Research Centre, Nashipur**

Treatment	Grain yield (t/ha)	
	2001	2003
Enriched Seed		
Complete[1]	4.20 ab[2]	4.20 a
Zn only	4.07 b	3.93 b
Zn + Mo only	4.32 a	4.22 a
Unenriched Seed	3.76 c	3.58 c

[1] Includes Zn, Mo, Cu, Mn, and Ni

[2] Letters indicate significant differences within columns at $p< 0.05$

Between 1996 and 2000, 47 trials were carried out on farmers' fields to compare wheat yields from seeds generated at the research station (micronutrient enriched and unenriched) with yields from farmers' seed. Figure 5 shows the results from a subset of the farmer trials. Yield was higher with enriched seed in 12 out of 47 trials, reflecting both spatial and temporal variability. The mean increase in wheat yield in the trials in which the micronutrient enriched seed out-performed unenriched seed was 25% (0.69 t/ha).

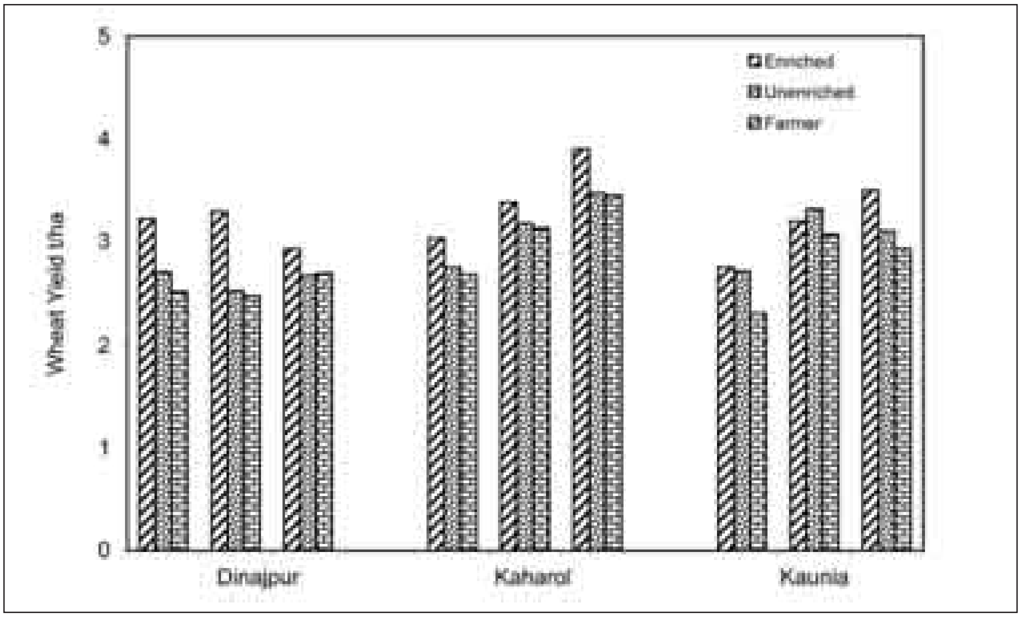

Figure 5: **Effect of micronutrient-enriched seed on wheat yields at selected farmers' fields in northwest Bangladesh**

Impact of soil B deficiency and wheat variety on yield

As Figure 1B indicates, soil boron levels in Bangladesh are low, and this can lead to sterility and significant yield losses of wheat. Although we did not find B enrichment in wheat seeds that had received foliar B applications, yield responses to enriched seed were positive compared to unenriched controls at sites were B deficiency was observed (Figure 6). We postulate that the yield response to enriched seed at these sites was due to Zn and/or Mo. On-farm trials with the varieties Kanchan and Shatabdi included addition of 1 kg B ha^{-1} to soils as borax. Compared to non-enriched control seed, yields were increased by 21-31% with micronutrient-enriched seed plus boron fertilisation; by 11–13% with enriched seed alone; and by 11-23% with control seed plus boron fertilisation (Figure 6). Shatabdi was more responsive to B addition than Kanchan, indicating that it is more susceptible to B deficiency. Mean yield with farmers' seed, which was Kanchan, was 12% less than that with control seed, indicating that farmers' seed was of lower quality compared to the seed produced at the research station.

Impact of micronutrient enriched seed on rice yield

Replicated plots with micronutrient enriched rice seeds of varieties BR11 and BR32 were planted at the Wheat Research Centre (WRC) to evaluate the impact of micronutrient seed enrichment on rice productivity. Enriched seeds were compared with unenriched control seeds. A third treatment tested the effect of additional micronutrient spraying on previously enriched seeds. Seed enrichment significantly ($p<0.05$) increased the yield of BR32 by 1.1 t/ha, an increase of 37% over the control (Figure 7). Extra spraying with micronutrients had no additional benefit, thereby demonstrating that the seed enrichment was sufficient to overcome soil micronutrient deficiencies. No micronutrient treatment effects were observed with BR11. Yields of BR11 were roughly a third of those obtained with BR32, because of selective attack on this variety by gall midge.

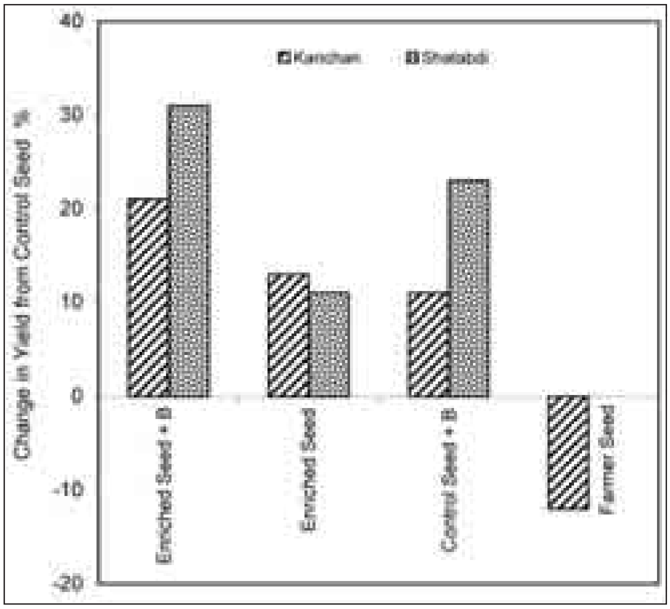

Figure 6: **Effect of seed enrichment and B application to soil on wheat yield (average of 9 farms).** Note: Mean control seed yields were 3.0 t/ha for both varieties

Likewise, on farmers' fields, BR32 micronutrient-enriched seed produced higher yields in six out of nine trials (Figure 8). The average yield increase was 25%, with a range in response of 15 to 41%. Rice plants from micronutrient-enriched seed were also observed to be more resistant to lodging.

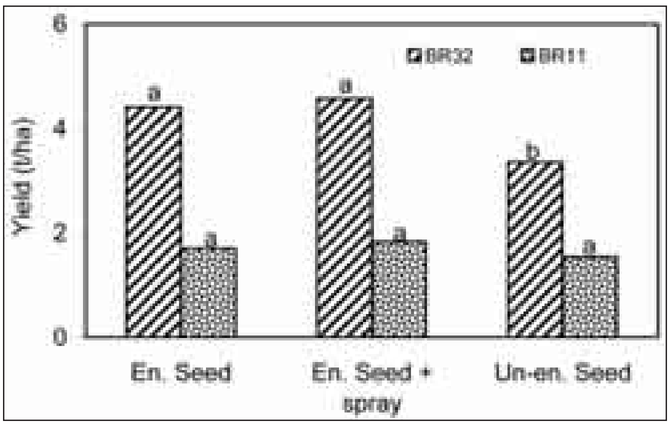

Figure 7: **Impact of micronutrient enriched (En) seed and enriched seed plus additional micronutrient sprays on rice yield relative to unenriched (Un-en) (control) seed for varieties BR11 and BR32.** Note: letters indicate significant differences at $p < 0.05$ within a variety.

Further investigations at the WRC with differentially enriched rice seed suggest that both Zn and Mo were responsible for the observed yield responses (Table 3). Rice seed enriched with Zn only produced yields that indicated a partial response. Likewise, when all micronutrients except Mo were included, yields were lower than with the complete micronutrient treatment although still significantly higher than unenriched controls, suggesting that Mo deficiencies were also addressed by seed enrichment. Similar responses to differentially enriched rice seed were seen on farmers' plots (data not shown).

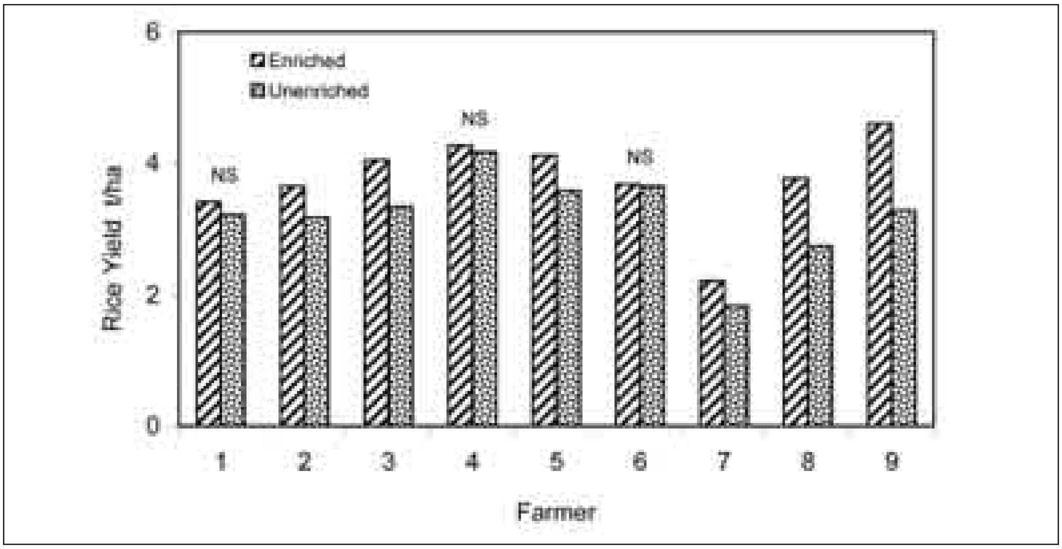

Figure 8: **Impact of micronutrient-enriched rice (BR32) seed in farmers' fields.** Note: Differences between treatments significant at $p<0.05$ unless indicated (NS)

Table 3: **Effect of differential micronutrient seed enrichment on yield of BR32 rice at the Wheat Research Centre, Nashipur**

Treatment	**Rice yield t/ha**
Complete (Zn, Mn, Cu, Mo, B)	4.6 a
Zn only	4.0 b
Complete minus Mo	4.1 b
Control	3.6 c
Note: Letters indicate significant differences at $p <0.1$	

Why are yields higher with micronutrient-enriched seed?

Rice and wheat yield responses to micronutrient-enriched seed were likely to be the result of improved germination, seedling emergence, vigour, and root health due to increased resistance to root infections from soil-borne pathogens. Healthier root systems would also increase the capacity of the plant to acquire nutrients and water from the soil. Work by Thongbai et al. (1993), Grewal and Graham (1996), and McCay-Buis et al. (1995) has shown that seed with high levels of both Zn and Mn provides resistance to take-all, root rot, and crown rot diseases in small grains. Likewise Rengel and Graham (1995 a, b) found that high zinc seed promoted crop growth and increased yield when planted in soils deficient in this nutrient. Previous work by Chatterjee and Nautiyal (2001) confirms the importance of molybdenum in improving the germination and seedling vigour of wheat.

Micronutrient-enriched seed performed better than non-enriched control seed in the wheat seedling emergence and seedling performance soil-pot study using nine farmers' soils (Figure 9). In many cases, control seed performed better than farmers' seed, which supports previous observations that poor quality farmers' seed limits crop performance. Overall,

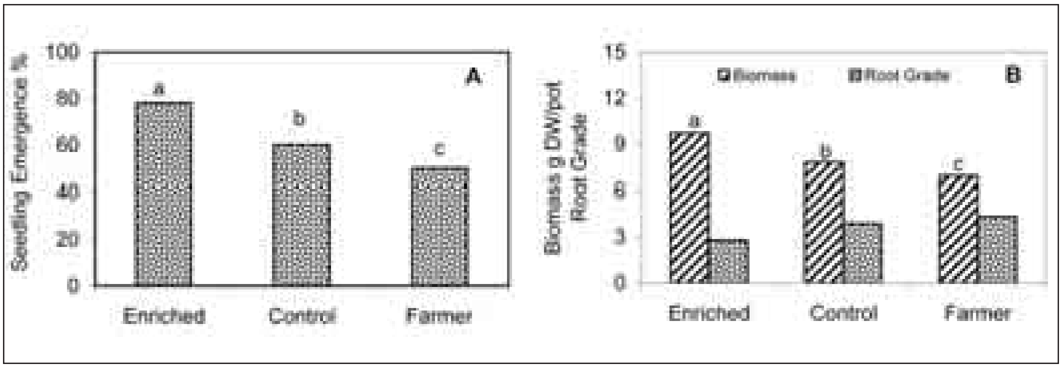

Figure 9: **Impact of micronutrient seed enrichment on seedling emergence (A), and biomass and root health (B) for Kanchan wheat.** Note: Data are means from 9 farmers' soils; letters indicate significant differences at $p<0.05$

seedling emergence increased from 50% with farmers' seed, to 61% with control seed, and to 78% with micronutrient enriched seed (Figure 9A). Similarly, the biomass of 40-day old plants from micronutrient-enriched seed was 24 and 40 % higher than that from control and farmers' seed, respectively (Figure 9B). Root health of plants grown from micronutrient-enriched seed was rated as good (score of 2.8 on the 1-9 scale) compared to that from non-enriched seed which was rated as slightly worse than moderate (score of 4.3) (Figure 9B). The root health data indicate that seedlings grown from micronutrient-enriched seed had a greater ability to resist or tolerate root infections from soil-borne pathogens.

Seed enrichment with micronutrients also had an effect on resistance to soil-borne pathogens later on during crop growth. Bipolaris leaf blight (BpLB) was evaluated after flowering in a replicated trial at WRC with micronutrient-enriched and unenriched seed treatments of four wheat varieties. Less BpLB was found on wheat plants grown from enriched seed for all wheat varieties (Figure 10).

Can micronutrient-enriched seed be a strategy to overcome micronutrient deficiencies at the farm level?

While micronutrient enrichment of both wheat and rice grain can be achieved at the experimental level by foliar application of micronutrients, this method is too laborious and not practical for farmers. Efforts were undertaken to produce micronutrient-enriched wheat and rice seed on farmers' plots using soil fertilisation instead of foliar sprays. In trials on six farms, soil fertilisation was almost as effective as foliar sprays at increasing the concentration of micronutrients (Zn and Mo) in wheat grain (Figure 11). On average, the concentration of Zn in the wheat grain increased by a factor of 1.7 and of Mo by a factor of 13.

Unfortunately, soil fertilisation with micronutrients did not increase concentration of Zn or Cu in rice grain, although it did achieve a two-fold increase of Mo (Figure12). This result is consistent with Sarah Johnson's findings that Zn availability decreases quickly when soils are flooded (see these proceedings). Other strategies under consideration to enrich rice grain with Zn under farmers' conditions are applications of Zn to floodwater (post anthesis) or applying Zn to aerobic rice seedbeds to overcome Zn deficiency during crop growth.

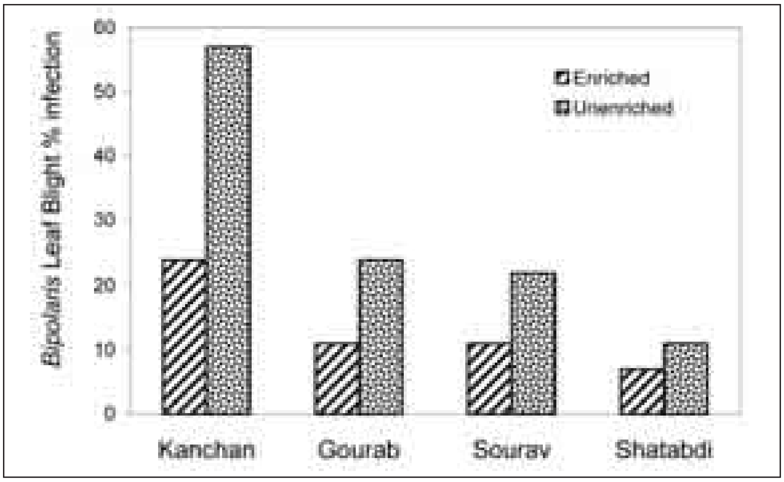

Figure 10: **Effect of micronutrient seed enrichment on infection by *Bipolaris* leaf blight in four wheat varieties**

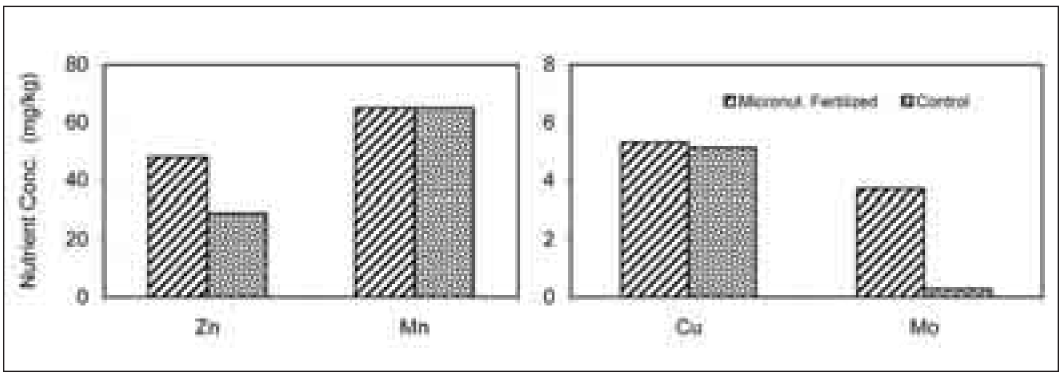

Figure 11: **Effect of soil fertilisation with micronutrients on wheat micronutrient content from farms in Bangladesh; data are means from 6 farms**

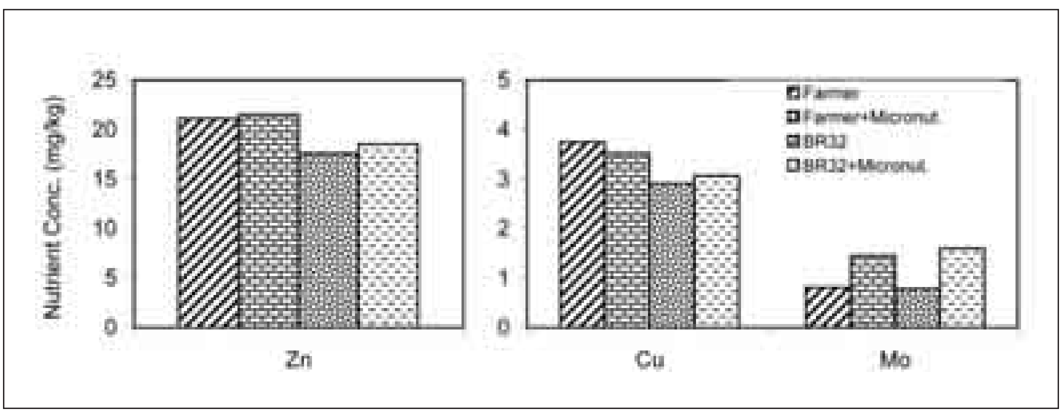

Figure 12: **Effect of soil fertilisation with Zn, Cu, and Mo on rice grain micronutrient content.** Note: Data are means from 13 farms using the farmers' rice varieties and BR32

Conclusions

Soil micronutrient deficiencies are prevalent in Bangladesh and contribute to poor seed viability as well as diminished seedling vigour under biotic stress (soil-borne pathogens). Poor seedling performance ultimately leads to low crop yields. Micronutrient seed enrichment provides an avenue to alleviate soil micronutrient deficiencies and to provide resistance against seedling root diseases.

Seed enrichment with Zn, Cu, Mn, and Mo was achieved in several wheat and rice varieties by foliar application of micronutrients. Micronutrient-enriched wheat seed out-performed unenriched seed on 26% of tested farms, with a mean increase in wheat yield of 0.69t ha^{-1}. Likewise rice yields were increased 15-41% in farmer trials with micronutrient-enriched seed relative to unenriched seed.

Data for wheat seedling emergence, biomass, and root grade supported our hypothesis that micronutrient seed enrichment improves seedling vigour and root health by increasing resistance to soil-borne pathogens. Treatments with micronutrient-enriched seed also showed significantly less *Bipolaris* leaf blight infection when compared to unenriched control seed.

Foliar spraying is not practical for Bangladeshi farmers as a means of generating their own micronutrient-enriched seed. Farmers can easily generate micronutrient-enriched wheat seed by soil fertilisation but more research is needed to develop simple methods to enrich rice seed.

Acknowledgements

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