Alleviating Micronutrient Deficiencies in Alkaline Soils of the North West Frontier Province of Pakistan: On-farm Seed Priming with Zinc in Wheat and Chickpea

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Abstract

In the North West Frontier Province of Pakistan, most soils are either coarse or fine textured, moderately to strongly calcareous, alkaline, and deficient in zinc. A series of on-station and on-farm trials were implemented between 2002 and 2004 to assess the response of wheat and chickpeas to the addition of zinc.

For wheat, two trials showed that soil applications of about 13 kg ha^{-1} $ZnSO_4$ increased grain yield on average by 338 kg ha^{-1} (15%). Other experiments had shown that priming seeds with water (soaking them for eight hours before sowing) resulted in significant benefits to yields in many crops, including wheat and chickpeas. Preliminary experiments with wheat established that seeds could be primed safely with dilute solutions of zinc sulphate ($ZnSO_4$) and that 0.4% zinc (Zn) was safe and effective. Eight additional trials produced a mean increase of 615 kg ha^{-1} by using seeds primed with 0.4% Zn in comparison with non-primed seeds. Data from two trials that included seeds primed with water alone established that about half of the increase was due to zinc while half was due to the effect of priming with water. The benefit:cost ratio for soil application was only 8:1, whereas for priming seeds with 0.4% zinc it was about 360:1 (about 160 for the response to zinc alone).

The safe, optimum concentration for priming chickpea seeds was much less: 0.05% Zn. In nine trials, this treatment increased the grain yields of chickpeas from 1050 kg ha^{-1} to 1552 kg ha^{-1} in comparison with non-primed seed. Yield increases in individual trials ranged from 10-122%, with a mean of 48%. Data from two trials that included seed primed with water alone established that about half of this increase was due to zinc while half was due to the effect of priming with water. The benefit:cost ratio for priming chickpeas with 0.05% Zn was 1500:1 (about 750:1 for the response to the zinc).

Introduction

The North West Frontier Province (NWFP) of Pakistan contains seven agro-ecological zones across a total geographical area of 10.1 million hectares. The physiography varies from wide alluvial plains to hills and mountains interspersed by narrow valleys. Only two million hectares of the province is cultivated due to the relief and adverse climate. Forty per cent of cultivated land is irrigated by canals; the remaining area depends on rainfall. The province produces around a million tonnes of wheat (mostly irrigated), some six per cent of Pakistan's wheat production, and about 17,000 tonnes of chickpeas (mostly rainfed), about three per cent of the country's production (GoP 2004).

The climate of the cropped area varies from warm humid to hot dry subtropical continental from northern to southern districts, with rainfall from above 650 mm to less than 200 mm per annum. Soils vary, but in general are moderately calcareous and alkaline in nature (see below for details of sites). Zinc (Zn) deficiency in Pakistan was first recognised by Yoshida and Tanaka (1969) when Hadda disease in rice was diagnosed as Zn deficiency. Later, research established the incidence of widespread Zn deficiency in all rice growing tracts of the country (Chaudhry and Sharif 1975; Kausar et al. 1976). Now Zn fertilisation is widely recommended for rice. Zn deficiency has also been reported in wheat (Khattak and Parveen 1986a), maize (Rashid et al. 1979), and other crops (Tahir 1981; Khattak and Parveen 1986a; Rashid and Qayyum 1991).

An FAO study (Sillanpa 1982) on the micronutrient status of soils in Pakistan showed that about 62% of soils in Punjab, 100% in Sindh, and 7% in NWFP were deficient in Zn. Kausar et al. (1976) also indicated that 86% of all samples from the four provinces were Zn deficient. Khattak and Parveen (1986b) reported that, out of 320 soil samples collected from NWFP, 23% were deficient in Zn. This study included samples of forest soils, but district-wise data revealed that nearly 50% of samples were Zn deficient in Karak district and 100% in the loess soils of the Peshawar Valley. Based on extensive research carried out on micronutrients in soils and crops, it has been estimated that about 70% of the presently cultivated area of the country can be considered Zn deficient. Zinc deficiency is the third most serious crop nutrition problem in the country after nitrogen (N) and phosphorous (P) deficiency (Rashid 1996).

Nevertheless, the use of zinc sulphate as a soil additive is not a common practice among farmers in NWFP. In this paper, we test two hypotheses. First, the hypothesis that wheat and chickpeas respond to additional Zn in NWFP conditions was tested. Second, the feasibility of an alternative to soil amelioration was determined.

This alternative approach involves soaking seeds in dilute solutions of zinc sulphate before sowing. It is now well established that ‘on-farm’ seed priming with water alone is effective in bringing about a substantial increase in yields of chickpea (Harris et al. 1999; Musa et al. 2001) and wheat (Harris et al. 2001) in South Asia. There are several advantages to using seed priming to deliver micronutrients to seeds: the effects of uneven application of zinc to the soil are avoided as each seed is exposed to the nutrient; uptake is guaranteed; and the amounts required are likely to be in orders of magnitude less than for soil application. Conversely, risk of toxicity may be increased by priming.

We report below the results from a series of in vitro, on-station, and on-farm trials in which the yield response to addition of zinc was determined for chickpeas and for wheat, and seed priming with zinc sulphate was compared with soil amelioration using the same material. The results were used to prepare a preliminary benefit:cost analysis.

Materials and Methods

Experimental sites

NWFP Agricultural University is located in Peshawar city, the capital of North West Frontier Province. Peshawar has a warm to hot semi-arid sub-tropical continental climate with a mean annual rainfall of about 360 mm. ‘Mini-plot’ and ‘research station’ trials were carried out at the NWFP Agricultural University research station. The soil is a silty clay loam derived from piedmont alluvium, deep and well-developed; and it belongs to the Great Group Haplustalfs, is well drained and moderately calcareous (12% lime), with a pH of 8.3. The soil is deficient in nitrogen and phosphorous but has adequate potassium (K). Organic matter is less than 1%. Canal irrigation is available.

Karak District is approximately 200 km south of Peshawar. Mean annual rainfall is less than 350 mm with a semi-arid, hot subtropical continental climate. Loamy sands and sandy loams have been formed from weathering of surrounding sandstone rocks, deposited by rain torrents, and mostly belong to Great Groups – Torrifluvents and Torripsamments. Underground water is deep and saline. There are few sources of irrigation and agriculture is mostly dependent on rainfall. Soils are non-saline and moderately calcareous (8.5% lime) with an alkaline reaction (pH 8.1). Organic matter is less than 0.5% and crops are predominantly rainfed with some supplementary irrigation from tubewells.

Risalpur, in Nowshera District, also has a semi-arid, hot subtropical continental climate with a mean annual rainfall of less than 550 mm. Soils are either loamy sand formed from Kabul River alluvium, which are used to grow chickpeas under rainfed conditions, or silt loam (water redeposited loess), which are used to grow wheat with canal irrigation. Sandy soils are moderately calcareous (10% lime) with a pH of 8.2 and silt loam soils are strongly calcareous (14% lime) with a pH of 8.3.

Experimental design and cultural details

Experimental trials, five on wheat and eight on chickpeas, were carried out in miniplots at the agricultural research station and on farmers' fields, during two rabi (post-rainy) seasons (2002/03 and 2003/04), to study the effect of Zn seed priming on these crops. Two additional trials were also carried out on the response of wheat to soil applied Zn fertiliser (Table 1). Twenty-two participatory farmer trials (FAMPAR) were completed in four villages during 2003/04 to validate the Zn seed priming effect. Particulars of the trials are given in Tables 1 and 2 for wheat and Table 3 for chickpeas.

All trials apart from FAMPAR trials of wheat (trials 6, 7, and 8 in Table 2) were laid out as random block designs with 3 or 4 replications. The appropriate amount of seed per treatment was sealed in perforated plastic bags and the bags were soaked for 6 hours for chickpeas and 10 hours for wheat. The seeds were soaked either in fresh water (where water priming was included – trials marked § in Tables 2 and 3) or in an aqueous solution of zinc sulphate fertiliser of the required grade (Zn 22.5%, S 12% and pH 3.0) manufactured by the National Fertiliser Corporation of Pakistan: 18.18g per litre for wheat and 2.22g per litre for chickpeas. After soaking, bags were removed, drained off, and seed surfaces dried in the shade to ensure clump-free sowing.

The land to be used was well prepared after irrigation or rainfall; 60 kg P_2O_5 ha^{-1} and 24 kg N ha^{-1} as diammonium phosphate (DAP) were applied before sowing for both crops. No additional nitrogen (N) was added for chickpeas, whereas for wheat, N fertiliser was supplemented as urea in 2 or 3 split doses to a total of 80 kg ha^{-1}. Both crops were sown in rows 30 cm apart at seed rates of 80 kg ha^{-1} for chickpeas (variety Beetle-98 in all trials) and 100 kg ha^{-1} for wheat (variety Gazanavi-98 in trials 1, 2 and 4 in Table 2 or variety Tatara

Table 1: Grain yields of wheat with and without incorporation of 13 kg ha^{-1} zinc sulphate in the soil					
No.	**Site (DOS)**	**Trial type (replications)**	**Yield (no Zn)**	**Yield (+Zn)**	**Increase (%)**
1	Peshawar (15-11-03)	RBD (4)	2143	2459	15 (ns)
2	Peshawar (15-11-03)	RBD (4)	2235	2594	16 (***)
	MEAN		**2189**	**2526**	**15**

Table 2: Grain yields of wheat with and without seed priming for 10 hours in a 0.4% aqueous solution of zinc sulphate (trials marked § also included a treatment in which seed was primed with water alone [data in text])					
No.	**Site (date of sowing)**	**Trial type (replications)**	**Yield (not primed)**	**Yield (primed + Zn)**	**Increase (%)**
1	Peshawar (17-12-03)	Tubs (6)	4250	5067	19 (ns)
2	Peshawar (3-12-03)	Mini-plots (4)	3367	4300	28 (ns)
3	Peshawar (20-11-03)	RBD (4)	3100	3528	14 (ns)
4	Peshawar (3-12-03)	RBD (4)	2234	2676	20 (*)
5	Peshawar§ (2-12-03)	RBD (4)	2215	2722	23 (*)
6	Risalpur (2-12-03)	FAMPAR (10)	2136	2454	15 (ns)
7	Risalpur§ (16/17-11-03)	FAMPAR (4)	3335	4250	27 (*)
8	Karak (20/30-10-03)	FAMPAR (8)	2976	3525	18 (*)
	MEAN		**2952**	**3565**	**21**

Table 3: Grain yields of chickpea with and without seed priming for 6 hours in a 0.05% aqueous solution of zinc sulphate (trials marked § also included a treatment in which seed was primed with water alone [data in text])					
No.	**Site (DOS)**	**Trial type (replications)**	**Yield (not primed)**	**Yield (primed + Zn)**	**Increase (%)**
1	Peshawar (29-11-02)	Mini-plots (3)	816	1814	122 (ns)
2	Peshawar (3-12-03)	Mini-plots (3)	1341	1790	34 (ns)
3	Peshawar§ (11-12-02)	RBD (3)	1219	1344	10 (ns)
4	Peshawar§ (3-12-03)	RBD (3)	819	1307	60 (ns)
5	Karak (21-10-03)	RBD (4)	738	1434	94 (*)
6	Karak (16-10-03)	RBD (4)	1614	1880	16 (ns)
7	Risalpur (26-10-03)	RBD (4)	806	1150	43 (ns)
8	Risalpur (27-10-03)	RBD (4)	794	1413	78 (**)
9	Risalpur (28-10-03)	RBD (4)	1302	1839	41 (*)
	MEAN		**1050**	**1552**	**48**

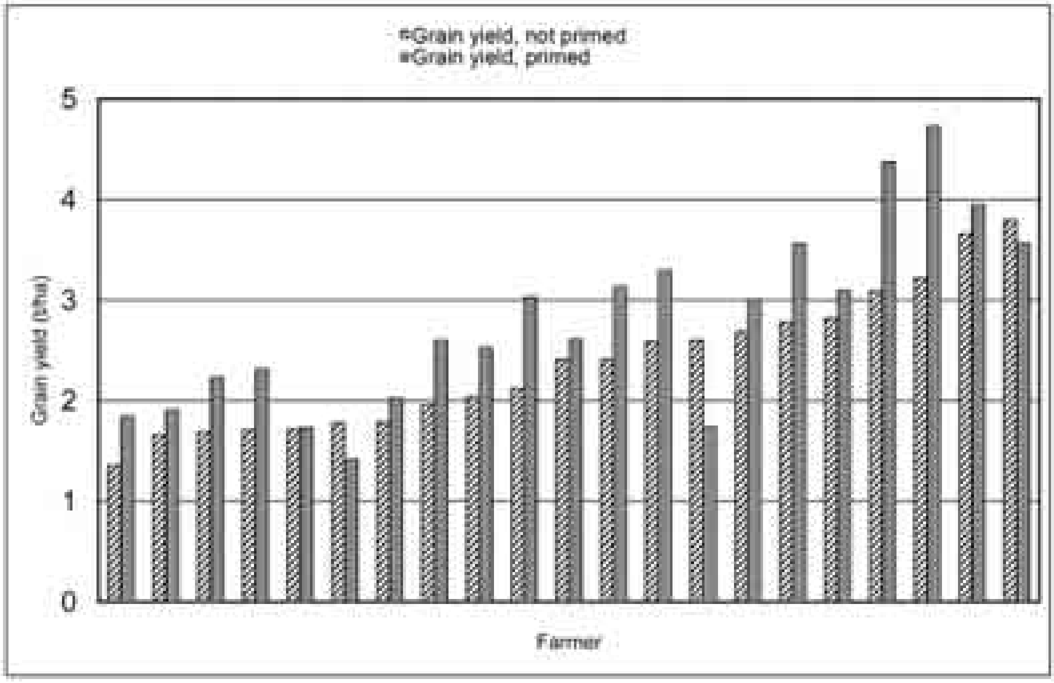

Figure 1: **Grain yields of wheat in 22 participatory trials with farmers (trials 6, 7 and 8 in Table 2)** Notes: striped bars = non-primed seed; hatched bars = seeds primed with 0.4% zinc sulphate for 10 hours before sowing; data are ordered according to yield of the non-primed treatment; standard error of difference between the two treatment means (significant at P = 0.001) was 0.11.

in trials 1 and 2 in Table 1 and trials 3, 5, 6, 7 and 8 in Table 2). Pests and diseases were controlled for chickpeas. All crops were irrigated apart from the rainfed trials of chickpeas at Risalpur (trials 7, 8 and 9 in Table 3). Yields were assessed by harvesting the whole plot (trials 1 and 2 in Table 1, trial 3 in Table 2 and trials 1, 2, 3, 5 and 6 in Table 3), whole rows (trials 1 and 2 in Table 2) or four randomly-selected quadrats of $1m^2$ (trials 4, 5, 6, 7 and 8 in Table 2 and trials 4, 7, 8 and 9 in Table 3).

FAMPAR trials on wheat were carried out in one village of Karak and two in Risalpur (Nowshera) Districts, with each farmer as a replicate. Twenty kg of seed of cv. (variety) Tatara were given to each farmer and half the seed was soaked in 0.4% zinc solution (200g $ZnSO_4$ fertiliser grade in 11 litres fresh water, measured using a plastic bottle of known volume) either by project staff or farmers themselves. Soaked seeds were air dried before sowing. The recommended fertiliser, cultural, and irrigation practices were followed as described above. Yields were assessed as the mean of four $1m^2$ quadrats placed randomly in each plot. All data were subjected to analysis of variance.

Results

Wheat

In the two trials at Peshawar in which zinc sulphate was incorporated into the soil at a rate of about 13 kg ha^{-1}, wheat grain yields increased by 15 % on average, although the increase was not statistically significant in one of the trials (Table 1).

In the eight trials in which zinc was supplied by priming seeds for 10 hours in a 0.4% solution of zinc sulphate before sowing, yield increases ranged from 14 to 28%, with a mean increase of 21%; half of the results were statistically significant and half were not (Table 2). The three FAMPAR trials (6, 7 and 8 in Table 2) showed an overall highly significant 17% mean increase in yield with nineteen of the 22 farmers trials that contributed showing increases in yield (Figure 1).

Chickpeas

In nine trials of chickpeas in which seeds were primed for 6 hours in 0.05% zinc sulphate solution before sowing, yields increased by 10 to 122%, mean 48%, although differences were statistically significant in only three of the trials (Table 3). The mean yield increase in the statistically significant trials (5, 8 and 9 in Table 3) was 71%.

Effect of water or zinc alone

The effect of priming with water can be separated from that due to added zinc by considering additional data from the trials for seed primed with water alone (marked § in Tables 2 and 3). For wheat, priming without zinc produced an 11% increase in grain yield over controls (Table 4); the remaining 10% (of the overall 21%) can be attributed to the zinc. This increase is similar to the 12% increase in wheat grain yield when zinc sulphate was applied to the soil (Table 1). Two chickpea cases were considered (Table 4), one using the mean of both the trials marked § in Table 3, the other omitting the case in which priming with water alone showed no effect. The increase in yield resulting from the effect of zinc was calculated to be either 24 or 30%.

Using representative prices for grain and the cost of zinc sulphate at the appropriate dosage, it is possible to compare the benefit:cost ratios of the two methods of zinc application (Table 5). The ratio is very high for application by priming in wheat (165:1) and chickpea (752:1) because so little zinc sulphate needs to be used. The ratio following application to the soil for wheat (calculated using the yield data from the two trials in Table 2), is much smaller (8:1) because farmers have to use much more zinc sulphate. In addition, it does not include

Table 4: **Estimated yield increase (kg ha^{-1}) due to seed priming and due to the effect of zinc applied through seed priming (percentage increases over controls are shown in brackets)**

Variable	Crop yield (kg ha^{-1})		
	Wheat	Chickpea[B]	Chickpea[C]
Mean yield without priming or zinc	2952	1050	1050
Increase after priming with zinc and water[A]	613 (21%)	502 (48%)	502 (48%)
Increase[§] after priming with water alone	331 (11%)	251 (24%)	191 (18%)
Increase due to zinc[A]	282 (10%)	251 (24%)	311 (30%)

Notes:[§] Using data from two trials in which priming with H_2O alone was included as a treatment
[A] 0.4% Zn for wheat; 0.05% Zn for chickpeas
[B] Using mean data from two trials in which priming with H_2O alone was included as a treatment
[C] Using data from one trial in which priming with H_2O alone was included as a treatment

Table 5: Partial budget and benefit:cost analysis (excluding labour) of providing zinc sulphate to wheat and chickpeas by priming seeds and by direct application to the soil		
Item	**Wheat**	**Chickpea**
Price of grain	Rs10 kg^{-1}	Rs 18 kg^{-1}
Extra grain yield du e to zinc (priming)	282 kg ha^{-1}	[B]251 kg ha^{-1}
Cost of zinc sulphate (priming)	Rs 17 ha^{-1}	Rs 6 ha^{-1}
Extra net income (priming)	Rs 2803 ha^{-1}	Rs 4512 ha^{-1}
Benefit:cost ratio (priming)	165:1	752:1
[a]Benefit:cost ratio (soil application)	8:1	no data

Notes:[a]3380 kg ha^{-1} divided by Rs 442 cost of zinc sulphate at rate of 13 kg ha^{-1}; [b]Using mean data from two trials (case B in Table 4)

the cost of the extra labour required to spread the compound evenly across the field. If the effect of zinc and of priming with water are combined (Tables 2 and 3) the benefit:cost ratios rise to 362:1 for wheat and 1506:1 for chickpeas.

Discussion and Conclusions

There was a positive response to the addition of zinc in all the trials reported in Tables 1, 2, and 3. Although not all the differences were statistically significant, there were no cases in which the addition of zinc reduced yields. Thus the data from these 19 trials suggest consistently that both wheat and chickpea respond positively to zinc addition under the conditions pertaining in NWFP. The size of the response of wheat to the element is similar whether it is applied through seed priming or by incorporation into the soil. However priming, which needs only small amounts of zinc sulphate, shows far higher profitability; the approach becomes even more attractive to resource-poor farmers when the beneficial effect of priming itself is taken into account. The further grain increase, and the fact that priming with water is essentially cost free, almost doubled the benefit:cost ratio.

No data were obtained on the response of chickpeas to soil to which zinc has been applied, but it is likely that the response would also be positive because priming chickpeas directly with zinc had a marked effect. In the case of chickpeas it was also possible to discriminate between the effects of the zinc and that of priming itself, although there is some uncertainty because of the variability of the two trials used to estimate the size of the two effects. The chickpeas seemed to respond more strongly than wheat to both the zinc and the priming, a difference that has been observed before. Harris et al. (2001) reported an average increase of about 15% due to seed priming with water for wheat in South Asia (range 5-36%, reflecting the wide degree of variation in the level of management between the test sites), whereas Musa et al. (2001) measured a mean increase in chickpea yields of around 35% over two years in Bangladesh. Rashid et al. (2002) observed positive responses to seed priming for both crops in Pakistan.

Adequate Zn nutrition of plants depends on several factors besides the ability of the soil to supply this nutrient. Interactions occur between Zn and other plant nutrients and may take place in the soil or at the soil-root interface affecting Zn absorption by the plant. Antagonistic effects of some cations, especially copper (Cu) and Zn, on the uptake of each other have been demonstrated in crops such as wheat, maize, and rice (Chaudhry and Loneragan 1970; Kausar et al. 1976; Rashid et al. 1979; Tahir 1981). It seems likely that priming seeds with zinc solutions could minimise these external interactions, although antagonistic effects may also occur within the plant itself, affecting translocation, re-distribution, and assimilation of nutrients. In addition to phosphorous (P) and N interactions with Zn, other nutrients such as Zn, Cu, iron (Fe) and manganese (Mn) inhibit each other's uptake, possibly because of competition for the same carrier sites (Chaudhry and Loneragan 1970; Rashid et al. 1979). Further research is required to test whether zinc applied through seed priming has any negative effects on the uptake and use of other nutrients.

We conclude that, in NWFP, wheat and chickpeas respond positively to supplementary zinc supplied as zinc sulphate. In wheat, the degree of the response to the element itself is similar whether it is applied to the soil or by priming with an aqueous solution. However, in both wheat and chickpeas, significant additional yield benefits result from the priming process itself. This, together with the much smaller amounts of zinc sulphate required for application through priming, makes priming a very much more attractive option than soil application for resource-poor farmers growing crops on zinc-deficient soils. The positive results of the 22 participatory trials with farmers suggest that zinc priming is a practical option for farmers in NWFP.

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