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ScienceDirect
Field Crops Research 102 (2007) 119–127
Field Crops Research
www.elsevier.com/locate/fcr

'On-farm' seed priming with zinc sulphate solution—A cost-effective way to increase the maize yields of resource-poor farmers

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Received 5 December 2006; received in revised form 9 February 2007; accepted 8 March 2007

Abstract

The effect of adding zinc sulphate ($ZnSO_4$) to maize (*Zea mays* L.) growing on calcareous, Zn deficient soils in the North West Frontier Province of Pakistan was assessed *in vitro*, on-station and in on-farm trials. The zinc sulphate was added either as a powder to the soil or by soaking seeds for 16 h in dilute solutions prior to sowing. For the first time in maize, we separated the benefits of priming simply with water from those provided by added zinc.

In four trials, the soil application of 2.75 kg Zn ha^{-1} significantly increased mean maize grain yield by 720 kg ha^{-1} (25%) total dry matter, number of cobs and cob weight. Adding 5.50 kg Zn ha^{-1} was the same as adding 2.75 kg Zn ha^{-1} for TDM and cob yield but worse for cob number and grain yield.

Preliminary experiments established that maize seeds could be primed safely and effectively for 16 h with 1% Zn solutions. Such priming increased seed Zn content initially from 15 mg kg^{-1} to 560 mg kg^{-1} but this was reduced to 220 mg kg^{-1} by rinsing the seed surface with distilled water. Non-rinsed seeds were used in all field trials. Seedlings from seeds primed with either 1% or 2% Zn were significantly heavier and taller than seedlings from non-primed seeds. The Zn concentration of seedlings was unaffected by priming with water alone but was increased significantly by both Zn priming treatments. The amount of Zn per plant was further increased because priming and Zn supply produced bigger plants.

In seven further trials, mean grain yield was significantly increased from 3.0 t ha^{-1} in crops from non-primed seed to 3.4 t ha^{-1} (14%) in crops from seeds primed with water alone and to 3.8 t ha^{-1} (27%, a similar response to that following soil application) using seeds primed with 1% Zn. Hence, the contribution of water alone and zinc contributed about equally to the overall increase. Total dry matter, stover dry matter, cob yield, individual cob weight, grain number per cob, cob number and 1000-grain weight showed similar responses to that of mean grain yield. Plant population density and shelling percentage were unaffected by either treatment. Grain Zn concentration was 15.4 mg kg^{-1} in a non-primed crop and was significantly higher in a crop grown from seeds primed with water (16.5 mg kg^{-1}) and with 1% Zn (18.3 mg kg^{-1}). The apparent recovery of added Zn in the grain was much higher for seed priming (at around 80%) than the less than 1% for soil fertilisation.

Monetary returns to use of $ZnSO_4$ were high, with a benefit to cost ratio for soil application of 15. However, the ratio was much higher, at 236, when a 1% Zn solution was used to prime seeds before sowing. This was due to the small amounts of $ZnSO_4$ used per hectare and hence low cost. Since priming maize seeds with water increased yield by 14% at no extra cost and adding small amounts of $ZnSO_4$ to the priming water doubled that yield gain, priming with 1% Zn represents an attractive option for resource-poor maize farmers in Zn-deficient areas in Pakistan and elsewhere.

Keywords: Zn deficiency; Pakistan; Micronutrients; Benefit cost ratio; Field trials; Tissue concentration; Seed priming

1. Introduction

More maize is produced worldwide than any other cereal grain and it is of huge importance to subsistence farmers and commercial farmers alike (FAO, 2004a). In Pakistan, it is the third most important cereal grain crop after wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) and is used as a staple food for humans, as feed for livestock and as raw material for industry. During 2004, it was planted on 0.98 million hectares in Pakistan, with total production of almost 2.8 million tonnes. In the North West Frontier Province (NWFP), maize was sown on around 0.5 million hectares with production of nearly 0.9

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0378-4290/$ – see front matter
doi:10.1016/j.fcr.2007.03.005

million tons and an average yield of only 1.8 t ha^{-1} reflecting the high proportion of rainfed cropping in the province (Government of Pakistan, 2005). There are two seasons of maize production; the spring season crop is sown from mid-February to the end of March and the main summer crop from June to mid-July. Both seasons' crops have durations of about 3–4 months. Mostly open-pollinated maize cultivars are sown.

Zinc deficiency, particularly in calcareous soils, is a worldwide problem (Takkar and Walker, 1993; White and Zasoski, 1999). Global studies initiated by FAO (Sillanpa, 1982) revealed that 50% of soil samples collected from 25 countries were deficient in Zn. Zinc deficiency in Pakistan soils was first recognized by Yoshida and Tanaka (1969) and later research established the incidence of widespread Zn deficiency in all rice growing areas (Kausar et al., 1976; Nawaz et al., 2004; Alam, 2004). Kausar et al. (1976) also indicated that 86% of soil 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 rising to nearly 100% of the loess soils of the Peshawar valley. It has been estimated that about 70% of the cultivated area of the country is Zn deficient and that Zn deficiency is the third most serious crop nutrition problem in NWFP province after N and P deficiency (Rashid, 1996).

Zinc deficiency has been reported in maize (Rashid et al., 1979; Shah et al., 1985; Rizvi et al., 1987; Azim et al., 1994; Tariq et al., 2002) and other crops (Kausar et al., 1976; Khattak and Parveen, 1986a; Tahir et al., 1987; Alam, 2004; Singh et al., 2005). Soil fertilization with Zn as $ZnSO_4$ is widely recommended but its use as a soil additive is not a common practice of farmers in NWFP. Fewer than 5% of farmers in Pakistan use zinc fertilizer (FAO, 2004b). In this paper, we first test the hypothesis that maize responds to additional Zn under NWFP conditions, then we determine the technical and economic feasibility of an alternative to soil amelioration. This alternative approach involves soaking seeds in dilute solutions of Zn before sowing. It is already well established that 'on-farm' seed priming with water alone is effective in substantially increasing yields of maize (Harris et al., 1999, 2002, 2004; Rashid et al., 2002) in South Asia. Since it is well documented (e.g., Welch, 1986; Rengel and Graham, 1995a,b; Yilmaz et al., 1998) that use of seeds with elevated micronutrient content can improve seedling vigour and increase yield, we attempt here to use seed priming to deliver Zn to seeds. There may be several advantages to this approach: the effects of uneven application of Zn to the soil are avoided as each seed is exposed to the nutrient; initial uptake is guaranteed; the nutrient is available early in the life of the plant; the amounts required are likely to be orders of magnitude less, and thus less costly, than for soil application. Conversely, optimal use of micronutrients added to seeds depends on the mobility of the element once inside the seed, and risk of toxicity may be increased by priming.

In this paper we report the results from a combination of *in vitro*, on-station and on-farm trials in which the growth and yield responses to soil-added Zn were determined for maize, and seed priming with water and with aqueous $ZnSO_4$ solution were compared with soil amelioration.

2. Materials and methods

2.1. Experimental sites

In vitro, miniplot and research station trials were all implemented at the NWFP Agricultural University research station, Peshawar (AUP-Farm), whereas farmers' fields in the Risalpur area of Nowshera District were used for FArmer-Managed PARticipatory (FAMPAR) trials (Tables 2 and 3).

Peshawar has a warm to hot, semi-arid, sub-tropical, continental climate with mean annual rainfall of about 360 mm. Summer (May–September) has a mean maximum temperature of 40 °C and mean minimum temperature of 25 °C. Winter (December to the end of March) has mean minimum temperature of 4 °C and a maximum of 18.4 °C. The average winter rainfall is higher than that of summer. The highest winter rainfall has been recorded in March, while the highest summer rainfall is in August. AUP-Farm soils have developed in piedmont alluvium and are Peshawar silty clay loams (fine, silty, mixed calcareous, hyperthermic Udic Haplustalf). Risalpur also has a semi-arid, hot, subtropical, continental climate with mean annual rainfall less than 550 mm, with the same temperature regime except that the mean highest summer temperature is 4 °C more than in Peshawar. Risalpur soils (Missa Series) have developed in water-redeposited loess material and are coarse silty, mixed, calcareous, hyperthermic Typic Ustochrepts.

Soils of both experimental areas are deficient in N, P and available Zn, but have adequate K. Canal water is available for irrigation. Selected mean soil properties of sites are given in Table 1.

2.2. Seed priming and seed imbibition

For trials involving priming, the appropriate amount (equivalent to a rate of 40 kg ha^{-1}) of seed per treatment was sealed in perforated plastic bags and the bags were soaked for 16 h in either fresh water or in the required aqueous solution

Table 1
Physico-chemical properties of test soils

Soil property	AUP research station	Risalpur area
Sand (%)	8.7	27.1
Silt (%)	51.3	52.3
Clay (%)	40.0	20.1
Textural class	Silty clay loam	Silt loam
Organic matter (g kg^{-1})	0.845	0.92
Total N (g kg^{-1})	0.04	0.05
$CaCO_3$ (%)	14.4	8.8
pH 1:1 water	8.02	7.7
Elect. conduct. 1:1 (dS m^{-1})	0.87	0.92
AB-DTPA extractible nutrients		
P (mg kg^{-1})	3.80	4.20
K (mg kg^{-1})	105	126
Zn (mg kg^{-1})	0.68	0.78

Data from Bhatti (2002) and Tariq et al. (2002) for AUP-Farm and from Khattak and Parveen (1986b) and Munawar (1990) for Risalpur.