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Effect of tire rubber ash and zinc sulfate on yield and grain zinc and cadmium concentrations of different zinc-deficiency tolerance wheat cultivars under field conditions

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ABSTRACT

The aims of these field experiments were to investigate the effectiveness of soil application of rubber tire ash in comparison with soil and foliar applications of zinc (Zn) sulfate to increase Zn and decrease cadmium (Cd) concentrations in wheat grain. A two-year field experiment was conducted during the 2007–2008 and 2007–2008 growing seasons at Isfahan research field, Iran. Ten different Zn-efficiency bread wheat cultivars (*Triticum aestivum* L.) commonly cultivated in different parts of Iran were subjected to no Zn fertilizer addition (control), soil application of 40 kg ha^{-1} $ZnSO_4$, soil application of 100 (for the first year) and 250 (for the second year) kg ha^{-1} waste rubber tire ash, foliar application of Zn at the mid tillering stage, and foliar application of Zn at the early anthesis stage. In the foliar application, $ZnSO_4$ was sprayed at a rate of 0.66 kg Zn/ha. Foliar spray of zinc sulfate at early anthesis, in general, had no significant effect on the yield and grain Cd while significantly increased grain Zn concentrations of most cultivars. On average, the foliar Zn treatment at the mid tillering stage (0.66 kg Zn/ha), decreased the mean grain Cd concentration from 0.032 mg kg^{-1} in the control treatment to 0.024 mg kg^{-1}. While the grain Zn concentrations of some cultivars increased with soil application of Zn sulfate, they were not affected or even decreased in other cultivars. For most studied wheat cultivars, pre-planting application of rubber tire ash in soil resulted in a significant decrease of grain Cd concentrations. The results show that the effectiveness of soil and foliar application of Zn on yield and grain Zn and Cd concentrations greatly depends on the cultivar. The currently recommended rates of soil applications of Zn to ameliorate Zn deficiency are sufficient to increase grain Zn and decrease grain Cd concentrations in some wheat cultivars, while they do not in the others. In this study, soil application of 250 kg rubber tire ash/ha and foliar spray of 0.66 kg Zn/ha at tillering stage were the most effective treatments to ameliorate Zn deficiency and to increase Zn and decrease Cd concentration in grains of most wheat cultivars.

1. Introduction

Many soils are calcareous and thus low in phytoavailable zinc (Zn) in central Iran (Afyuni et al., 2007). Soil application of Zn sulfate before sowing is the most common approach to correct Zn deficiency in crops. But foliar Zn applications of Zn are also used, usually at the mid tillering or at early anthesis stages of growth (the latter in particular when also elevated grain Zn density is the target) (Brennan, 1991; Cakmak et al., 2010). Foliar application of Zn seems to be an effective method of ameliorating Zn plant deficiency as well as a useful method for increasing Zn and decreasing cadmium (Cd) concentrations of grain; although the effectiveness of this method of Zn application is not always high. For example, Choudhary et al. (1994) found soil-applied Zn decreased the Cd concentrations in durum wheat grain but foliar applications of Zn at the 4-leaf stage had no effect on grain Cd concentration when applied to wheat grown in the glasshouse. One reason for the controversy of the results may be the large differential responses of wheat cultivars to Zn application treatments (Wagner, 1993).

The beneficial and adverse effects of trace element levels in crop foods that make up major proportion of dietary intake on human health are particularly important (Grant et al., 2008). Agronomic and genetic practices can be important tools to both increase the concentration of desirable trace elements such as Zn and reduce that of potentially harmful trace elements such as Cd. While soil Cd concentrations are relatively low in most wheat growing areas

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in Iran, some agricultural lands are contaminated with Cd due to excessive application of low-quality phosphate-fertilizers containing Cd as impurities (Afyuni et al., 2007). In some cases the concentrations of Cd in wheat grains have increased to levels above the maximum permissible limit of 0.2 ppm (Codex, 2008).

Because P fertilizers contain a significant amount of Cd as impurity, application of P fertilizers at high cumulative amounts is considered as a factor in crop plants Cd accumulation. Elevated Cd concentrations in wheat grain have been reported following long term application of P fertilizers containing 70–150 mg Cd per kg P (Andersson and Simon, 1991; Roberts et al., 1994).

Zinc status of soils and plants plays an important role in Cd accumulation by crop plants (Hart et al., 2002). Increasing phytoavailable soil Zn concentration was found to reduce Cd accumulation in potato tubers (McLaughlin et al., 1994). Oliver et al. (1994) showed that Zn applications on marginally and severely Zn-deficient soils in South Australia significantly decreased wheat grain Cd concentration. Similarly, Zn applications reduced Cd accumulation in flaxseed (Grant and Bailey, 1997) and durum wheat grain (Choudhary et al., 1994).

Tire rubber is rich in zinc (1–2%) and might be applied as an effective and safe fertilizer source for supplying this nutrient element with no risk of Cd contamination (Chaney, 2007; Taheri et al., 2011). There are some reports showing that ground tire rubber and rubber ash were very effective amendments to increase the DTPA-extractable Zn in a calcareous Zn-deficient soil (Taheri et al., 2011). Rubber ash was a fast release source of Zn in soil, showing results similar to laboratory grade zinc sulphate in increasing the DTPA-extractable soil Zn (Taheri et al., 2011). The ground rubber could also increase the DTPA-extractable soil Zn more than the commercial fertilizer and the control but with an initial slow rate of release to the soil because the Zn is within the rubber particles (Taheri et al., 2011).

Natural variation occurs in the uptake and distribution of essential and nonessential trace elements among crop species and among cultivars within species. Such variation can be responsible for differential responses of wheat cultivars to Zn application treatments, which in turn can affect the quality of food.

Zinc deficiency has become a limiting factor for crop productivity in many agricultural soils. In order to obtain the genetic potential yields of crops, correcting Zn deficiency is necessary (Khoshgoftarmanesh et al., 2010). On the other hand, the need for selection programs for reduced Cd and enhanced Zn content of wheat cultivars are recently considered. Increasing Zn/Cd ratio in wheat grain via Zn fertilizer application can be useful to reduce the risk of Cd accumulation in humans. An important aim in agronomic and genetic biofortification is to improve crop quality by increasing grain concentration of desirable trace elements and reducing these of potentially harmful trace elements such as Cd (Welch and Graham, 2004). This study aimed to assess the usefulness of various Zn fertilizer treatments to increase yield and grain Zn and decrease Cd concentrations of a variety of wheat cultivars with different Zn-efficiency under field conditions.

2. Materials and methods

2.1. Experimental site and soil properties

A two-year field experiment was conducted during the 2006–2007 and 2007–2008 growing seasons at Isfahan research field (32°30′ N, 52°9′ E, altitude = 1500 m). The mean temperature was 15.9 and 16.4 °C for the first and second years, respectively. The average annual rainfall was 117 mm in the first year and 126 mm in the second year. The rainy season ranged from November to May, and the summer precipitation was negligible.

Table 1
Selected soil properties in different experimental locations.

Characteristics	Unit	Trial 1	
		First year	Second year
pH	–	7.7	7.7
EC	dS/m	8.6	6.8
$CaCO_3$	%	15	10
Sand	%	15.0	14.8
Clay	%	37.5	37.3
Organic C	g/kg soil	3.3	4.1
$NaHCO_3$—P	mg kg^{-1}	15	15
DTPA-Zn	mg kg^{-1}	0.65	0.81
DTPA-Cd	mg kg^{-1}	0.14	0.15
Total-Cd	mg kg^{-1}	2.11	1.89

Before planting, soil samples (0–30 cm) from the experimental site were collected, air-dried, and crushed to pass a 2-mm sieve. Soil pH was measured in 1:2.5 soil:water suspension with a digital pH meter (Model 691, Metrohm AG Herisau Switzerland) (Thomas, 1996). Electrical conductivity (EC) was measured with an EC meter in soil saturation extracts (Model Ohm-644, Metrohm AG Herisau Switzerland) (Rhoades, 1996). The $CaCO_3$ equivalent was determined by neutralizing with HCl and back titration with NaOH (Black et al., 1965). Available-P content in the soil was extracted from the soil with 0.5 M $NaHCO_3$ (Olsen and Sommers, 1990) and determined by a colorimetric method (Black et al., 1965). Available-Zn was extracted with DTPA and determined on a graphite furnace-atomic absorption spectrophotometer (GF-AAS) (Lindsay and Norvell, 1978). Available and total-Cd was extracted with DTPA and HNO_3, respectively and determined on a GF-AAS (Chapman and Pratt, 1961).

Compared to the critical deficiency level for DTPA-extractable soil Zn in Iranian soils (2 mg kg^{-1}) (Milani et al., 1998), the soil was severely deficient in available Zn. Selected properties of the experimental soils are shown in Table 1. The soils were classified as Fine-Loamy, Mixed, Thermic, Typic, Haplocambids (Soil Survey Staff, 1999).

2.2. Plant material, experimental design, and experiment performance

Ten bread wheat cultivars (*Triticum aestivum* L.) commonly cultivated in different parts of Iran were studied. These wheat cultivars were largely different in Zn-efficiency (Khoshgoftarmanesh et al., 2010). All wheat cultivars were selected from the germplasm collection at the Iranian Institute of Seed and Plant Improvement Institute (SPII).

The experimental location was chisel-plowed in October and then was cultivated by disk harrow. Nitrogen, P, K, and Fe fertilizers were applied based on the soil testing and Iranian Soil and Water Institute (ISWI) recommendation model (Milani et al., 1998). Phosphorus was applied as triple superphosphate (40% P) at planting (80 kg P ha^{-1}) and N as urea (45%N) in two applications (95 kg N ha^{-1} at planting and 95 kg N ha^{-1} at tillering stage). Soil available K was higher than its critical level (280 mg kg^{-1}) reported for wheat in the studied region. Wheat was planted on 1 December and 4 November in the first and second years, respectively. Plant density was 350 m^{-2}. Plot area was 3 × 2 m^2 with 20-cm row spacing. Irrigation water (from wells) had an EC of 6.0 dS m^{-1}. During the growth period, the basin irrigation method was used based on cumulative evapotranspiration rates collected from Rudasht weather station and soil moisture was kept approximately 70% of field capacity. Herbicides were applied as needed. The first irrigation was done using river waters with an EC of 2.0 dS m^{-1}.

The following 5 Zn treatments were applied: (1) no Zn fertilizer addition (control), (2) soil application of 40 kg $ZnSO_4$ ha^{-1}, (3)