SUMMARY

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The study concerns the interactions between the element Zn and each of P, Fe, Cd, calcium carbonate and clay. Zn and Fe added in soluble sulphate form, Cd in soluble chloride form. The main considerations relate to implications on: (i) nutrient availability, and (ii) plant growth (wheat). The soil of the study was a non-calcareous sand collected from a sandy desert land about 40 km east of Cairo along the Cairo / Ismailia road.

Calcium carbonate source was in the form of limestone material applied in particle size of the following diameters: (1) 1.25-2.00 mm "D_1", (2) 0.60-1.25 mm "D_2", (3) 0.25-0.60 mm "D_3" and (4) less than 0.25 mm "D_4". The clay used in the study was as follows: (a) clay soil material "soil of 57 % clay" taken from a field of the farm of the Agricultural Research Center (ARC), Giza (used in one experiment); and (b) two clay minerals (montmorillonite and kaolinite) used in another experiment.

The experimental work involved 11 experiments (6 laboratory incubation experiments and 5 greenhouse pot ones).

The 6 incubation experiments were as follows: (1) Zn-P interaction; (2) Zn-Fe interaction; (3) Zn-Cd interaction; (4) Zn-$CaCO_3$ interaction; (5) Zn- clay- $CaCO_3$ interaction and (6) Zn-clay type- clay content interaction. Rates used were as follows: Zn: 0, 5, 10 and 20 $\mu g\ g^{-1}$; P: 0, 10, 20 and 30 $\mu g\ g^{-1}$; Fe: 0, 20, 40 and 60 $\mu g\ g^{-1}$; Cd: 0, 1, 2 and 4 $\mu g\ g^{-1}$; $CaCO_3$: 0, 5, 10 and 20 %; rates of clay addition (to the sand soil) were 0, 5, 10 and 20 %. Experiments design was a factorial randomized complete

block with 3 replicates.

The six laboratory incubation experiments involved the sand soil incubated for 8 weeks at ambient laboratory temperature (about 25 °C) with daily watering to 70 % of saturation percentage using distilled water.

The 5 greenhouse pot experiments were identical to those of experiments 1 to 5 of the incubation experiments and the soil was seeded to grow wheat (Triticum aestivum cv. Sakha) as a test plant. Soil portions were packed in polythene pots. At harvest, the aerial parts were cut 1-cm above the soil surface, oven-dried at 70 °C and kept for analysis.

Findings of the incubation experiments:

1. Available Zn was increased by application of Zn; and the increase progressed with increasing the rate of Zn whether Zn was applied solely or in combination with either of P, Fe, Cd, $CaCO_3$ or clay. However, available Zn decreased due to application of P; the decrease progressed with increased P.
2. Available P increased by application of P and the increase progressed with increasing the rate of P, and was not affected by applying Zn.
3. Available Zn or Fe increased when either was applied alone and continued increasing with the rise in its application; but decreased when the opposite nutrient was applied indicating an antagonism between them. The same pattern occurred to available Zn or Cd indicating an antagonism between Zn and Cd.

4. Available Zn decreased with the increase in $CaCO_3$ content as well as with the increase in the fineness of $CaCO_3$ particles; with the smallest size of < 0.25 mm Ø being the most effective in decreasing Zn extractability; thus reflecting the pronounced effect of increased specific surface area of lime particles in retaining available Zn by tight retention forces. The negative effect of $CaCO_3$ on availability of Zn indicates a tight adsorption of Zn on surface of $CaCO_3$ particles and/or a possible formation of Zn complexes with $CaCO_3$.

5. Presence of clay caused a decrease in extractable Zn; more pronounced with increased content of clay indicating tight adsorption of Zn on clay minerals. The decrease in Zn extractability progressed with the increase in reactive surface area; more pronounced with montmorillonite than with kaolinite; thus reflecting the influence of reactive surface area of soil mineral colloids.

6. Marked tendency of calcium carbonate to adsorb zinc is indicated.

<u>Findings of the greenhouse experiments:</u>

<u>(1) Zn / P</u>

Addition of Zn increased yields (grains and straw), Zn concentration and Zn uptake progressively with increasing the rate up to 10 µg Zn g^{-1} soil. Addition of P increased yields, P concentration and Zn as well as P uptake progressively with increasing the rate P up to 30 µg P g^{-1}, but P decreased Zn concentration.

(2) Zn / Fe

Either Zn or Fe application, up to 10 µg Zn g^{-1} or 40 µg Fe g^{-1}, increased yields progressively, after which a decrease occurred when 20 µg Zn g^{-1} or 60 µg Fe g^{-1} soil was applied. Either nutrient was associated with an increase in its contents in plant (concentration and uptake); the increases were progressive with increasing rates of application. Applying one of them caused a significant decrease in contents of the other indicating antagonism between them.

(3) Zn / Cd

Either Zn or Cd application, up to 10 µg Zn g^{-1} or 1 µg Cd g^{-1}, increased wheat yields and Zn in plant (concentration and uptake) but beyond 1 µg Cd g^{-1} or 10 µg Zn g^{-1}, yield decreased. Application of Zn decreased Cd concentration and Cd uptake indicating antagonism between Zn and Cd. There is an indication of Cd phytotoxicity.

Cd application increased the concentration and uptake of Cd as well as Zn, but did not affect Zn uptake.

(4) Zn / $CaCO_3$ diameter

Application of $CaCO_3$ decreased wheat yield and Zn uptake. Increasing fineness of $CaCO_3$ particles was associated with a progressive decrease in yield and Zn uptake; thus reflecting the increase in reactive surface area, which is directly linked to decreased availability of most nutrients in soil. Applying Zn solely or in combination with limestone caused a progressive increase in dry matter yield, Zn concentration and uptake in both grains and straw of wheat plants.

(5) Zn / clay

Application of Zn was associated with increases in yield, and Zn uptake. Addition of clay was also associated with progressive increase in yield and Zn uptake reflecting the positive effect of adding clay to such a sandy soil.

Interaction relationships concerning addition of Zn as related to addition of other elements and soil constituents:

A) Incubation experiments:

Zn extractability as affected by Zn/Fe interaction:

There was an interaction between Zn and Fe application with regard to Zn extractability. Treatments receiving no Zn showed little difference (or a slight non-significant decrease) in extracted Zn among soils receiving different rates of Fe. Under conditions of Zn application (particularly with high Zn rates), applying 60 μg Fe g^{-1} caused a considerable significant decrease in Zn extractability as compared with the rate of 40 $\mu g\ g^{-1}$; but no such significant decrease occurred where Zn was not added.

A similar pattern occurred regarding extractable Fe under conditions of different amounts of Zn present in the soil; i.e. a pattern of decreased extractability of Fe with increased presence of Zn in soil.

Cd extractability as affected by Zn/Cd interaction:

Decreased Cd extractability with increased Zn presence occurred only in treatments given Cd. In the treatment of no-Cd, increased presence of Zn showed no effect on Cd extractability; all soils had < 0.02 μg Cd g^{-1}. Soil given the highest Cd rate showed that increased application of Zn markedly decreased Cd extractability.

Zn extractability as affected by Zn/$CaCO_3$ interaction:

$CaCO_3$ decreased Zn extractability particularly when $CaCO_3$ particles are of the fine size. Decreased extractability of Zn due to decreased size of $CaCO_3$ particles occurred significantly only under conditions of added Zn, especially at the highest rate. Therefore, tight retention of Zn caused by increased fineness of $CaCO_3$ was most prominent where Zn was present in the soil at contents of 5 $\mu g\ g^{-1}$ or higher.

Zn extractability as affected by Zn/$CaCO_3$ interaction:

Decreased extractability of Zn caused by increased $CaCO_3$ addition occurred only in treatments supplied with added Zn. In treatments not receiving Zn, the effect was not significant. Therefore, involvement of added Zn sulphate with added $CaCO_3$ must have been prominent causing a decrease in Zn availability.

Zn extractability as affected by Zn/clay interaction:

Decreased Zn extractability caused by increased clay addition was most prominent under conditions of high addition of Zn. Under low rate of added Zn, such a decrease occurred only with high addition of clay.

Zn extractability as affected by Zn/ clay mineral interaction:

Application of either clay mineral (of montmorillonite or kaolinite) resulted in a significant decrease in the amount of extractable Zn. The decrease was progressive with increasing the rate of clay mineral application only under conditions of added Zn; since such a progressive decrease was not significant where no Zn was added. Therefore, for a progressive decrease of Zn extractability caused by increased presence of clay mineral, there should be high contents of Zn in the soil.

B) Greenhouse experiments:

Zn concentration in plant as affected by Zn/P interaction

There was an interaction between Zn and P on the concentration of Zn in grains. Under conditions of a very high presence of Zn (i.e. 20 µg Zn g^{-1}), the addition of 10 µg P g^{-1} (as well as the increase from 10 to 20 µg P g^{-1}) was associated with a decrease in Zn concentration. However, under conditions of no-addition of Zn or little Zn, the decreased Zn concentration due to applying 20 µg P in comparison with 10 µg P was not significant.

Zn uptake in plant as affected by Zn/P interaction

Zn uptake in grains was increased by applying P, but differences between different levels of added P were not significant except under presence of the highest dose of Zn when the increased addition of P was associated with increased uptake of Zn (only with grains).

Zn concentration in plant as affected by Zn/Fe interaction

Presence of high contents of iron in the root media antagonized the positive effect of increased increments of Zn preventing associated increases in Zn concentration in plants.

Also, progressive decrease in Zn concentration in straw due to the progressive increase in Fe application occurred particularly under conditions of Zn application. Under conditions of no-Zn, the decrement was not between the no-Fe and 20 or 40 μg Fe g^{-1}.

Zn uptake in plant as affected by Zn/Fe interaction

Increased Fe application was not always associated with progressive decrease in Zn-uptake in straw along the entire range of 0 to 40 μg Fe g^{-1}. Under 20 μg Zn g^{-1}, increased Fe addition from 40 to 60 μg g^{-1} showed no change in Zn uptake in straw; and 20 μg Fe g^{-1} decreased Zn uptake. Under no-Zn addition applying 20 μg Fe g^{-1} had no effect.

Fe uptake in plant as affected by Zn/Fe interaction

Application of Zn decreased Fe uptake; and the decrease progressed with increased Zn rate of application; but this occurred only under high rate (60 μg g^{-1}) of Fe. Under conditions of no-Fe or low to medium rate of 20 to 40 μg Fe g^{-1}, no difference occurred until adding 10 μg Zn g^{-1}. Antagonism between Zn and Fe on the uptake of Fe in plants required high Zn and high Fe in the root media.

Cd concentration in plant as affected by Zn/Cd interaction

Application of Zn decreased Cd concentration in plant only where Cd was present in the soil since with no Cd present in the soil, Cd in plant tissues was extremely low with no significant difference between plants receiving no-Zn or those receiving Zn.

Cd uptake in plant as affected by Zn/Cd interaction

The interaction between Zn and Cd occurred when application of Zn and its increased rates decreased Cd uptake only in presence of Cd; and caused no significant change in Cd uptake by plants, which had not received Cd. Under conditions of 4 µg Cd g^{-1}, the decreases were progressive and significant. Therefore, the positive effect of Zn application on preventing accumulation of Cd was most prominent under conditions of high Cd in the root zone.

Zn concentration in plant as affected by Zn/$CaCO_3$ fineness interaction

Calcium carbonate decreased Zn concentration, particularly with increased fineness. The significant interaction between $CaCO_3$ fineness and Zn occurred to Zn concentration in straw. Under conditions of no Zn or little Zn presence, the effect of increased fineness of $CaCO_3$ was not significant, whereas under high Zn rates, the negative effect of increased fineness of $CaCO_3$ was marked.

Zn uptake in plant as affected by Zn/ $CaCO_3$ fineness interaction

The progressive increase in Zn uptake due to the progressive application of Zn occurred where $CaCO_3$ was very coarse, coarse or fine, but with very fine $CaCO_3$, differences between the no-Zn and 5 µg Zn g^{-1} were not significant. Thus, very fine $CaCO_3$ caused no response to Zn except at the high Zn rates. This illustrates the marked fixation action of fine $CaCO_3$ particles as compared with coarse ones.

The significant interaction by Zn on the response to $CaCO_3$ fineness (concerning straw) show progressive negative effect by increased fineness only under high Zn application. Under low or no-Zn, the negative effect of $CaCO_3$ fineness was not always significant.