Iran Agricultural Research, Vol. 32, No. 2, 2013
Printed in the Islamic Republic of Iran
Shiraz University

The Effects of Zinc Sulphate and Monocalcium Phosphate Fertilizers on Extractable Zn and Fe under Different Soil Moisture Conditions

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Received 19 October 2013, Accepted 4 February 2013, Available Online 1 June 2014

ABSTRACT- To evaluate effects of different soil moisture conditions namely, phosphorus (P) and zinc (Zn) application, on extractable Zn and Fe, two experiments were conducted in laboratory conditions based on a completely randomized design with a factorial arrangement of treatments with two replications. The first experiment was performed with the following factors; incubation time at four levels (1, 10, 30 and 60 days), soil moisture at two levels (0.6 FC and FC), P fertilizer at two levels (0 and 60 mg P per kg of soil) and Zn fertilizer at two levels (0, and 20 mg Zn per kg of soil). The second experiment was conducted with two Zn levels (0 and 20 mg Zn per kg of soil), two P levels (0 and 60 mg P per kg of soil) and three wetting-drying cycles (1, 10 and 20 cycles). The results showed that the extractable Zn and Fe decreased by time. The application of Zn fertilizer under FC conditions resulted in higher amounts of extractable Zn in all incubation times. The application of P reduced the extractable Zn and Fe in most incubation times and moisture conditions. By increasing the number of wetting-drying cycles and the duration of incubation time, the extractable Zn decreased significantly. There were no significant differences between constant moisture and wetting-drying cycles on the extractable Zn, except for the application of 60 mg P and 20 mg Zn per kg of soil under 0.6 FC conditions.

Keywords: Extractable, Phosphorus, Soil moisture, Wetting-drying, Zinc

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INTRODUCTION

Zinc is an exceptional micronutrient in plant physiology. It is the only trace metal appearing in all types of enzymes (3, 9, 11). Zn affects wider essential cellular functions and metabolic pathways, including the function and structural stability of proteins, the integrity of membranes and protection against reactive oxygen species (10). About 2800 proteins require Zn for their activity and structural stability in biological systems (2, 11). Nearly 30 percent of the soils in world, most of which being calcareous, suffer from Zn deficiency as a major limiting factor for crop growth (14, 60). In these areas, Zn deficiency is often caused by lower levels of soil total Zn and/or its bioavailability (4, 14). Zn is present in soil in a number of chemical forms with varying solubility (39, 54) It is either water soluble, adsorbed on exchange sites, related to soil organic matter, precipitated with secondary minerals and sesquioxides or present in the structure of primary minerals (3, 54, 59). Soil chemical properties i.e. pH, redox potential, soil organic matter, pedogenic oxides, soil sulfur contents (3, 4, 54) exchange capacity (CEC), the type and amount of clay, Fe, Al and Mn oxides, and calcite (43), macronutrients content (especially P) and the soil moisture status have strong influence on Zn reactions and play a critical role in its solubility and fractionation in soils (4). In addition, Zn may be strongly adsorbed on free $CaCO_3$ or $MgCO_3$ in calcareous soils (24, 70).

Soil moisture plays an important role in the extractability of Fe and Zn (57). Changes in soil moisture content can regulate the nutrients' availability and plant species' distribution by changing soil solution chemistry (41). Soil moisture regimes control the entry and escaping tendency of oxygen in the soil. Thus, different soil moistures change physico-chemical and electrochemical properties of soils such as pH, Eh, electrical conductivity (EC), calcite content, and oxides of Fe and Mn (17, 36, 43). Khan and Banwart (26) showed that moist incubation gave lower extractable Fe and Zn values than air dry soils. They obtained similar results with sterilized soils and concluded that the effects were non-microbial.

In a pot study with five genotypes, three soil pHs (5.0, 6.5 and 7.5) and two soil moisture contents (flooded and aerobic), it was shown that aerobic genotypes had high Zn uptake and the effect of soil moisture on Zn uptake and concentration was more significant at high soil pH (64).

Chatterjee and Mandal (12) showed that after 75 days of soil incubation with different soil moistures and organic matter levels, about 35% and 20% of the added Zn as ZnEDTA and $ZnSO_4.7H_2O$ was found in the DTPA extractable form, respectively. They concluded that the low recovery of added Zn, when applied as $ZnSO_4.7H_2O$ relative to ZnEDTA, may be attributed to the rapid dissociation of Zn^{2+} from $ZnSO_4.7H_2O$ and its subsequent precipitation as $ZnCO_3$, $Zn(OH)_2$ and $Zn_5(CO_3)_2(OH)_2$. They concluded that the recovery of Zn^{2+} from $ZnSO_4.7H_2O$ was lower in flooded conditions compared with the saturated moisture regime.

Many researchers have reported contrary results on the effect of P on the availability of micronutrients in the soil, hence necessitating a more careful investigation of the problem. It is expected that P fertilizers alter the micronutrients' concentrations in soil solutions by influencing their capacity factor (52). It is important to note that higher application of a P fertilizer increases the intensity of Zn deficiency in soils, especially in the low or marginal available Zn (47, 58). High P levels can affect soil properties such as (1) a shift in pH due to the dissolution of the fertilizer in the soil solution or reaction of both the phosphate and the associated cation with the soil component, (2) changes in surface charge due to the adsorption of phosphate anion on the colloids surface (37, 58); and (3) increase in negative charges on surfaces of Fe and Al oxides due to P sorption (37).

Mandal and Mandal (37) compared the effect of a P fertilizer on variations of native and applied Zn under flooded and non-flooded regimes in glasshouse conditions. The application of P encouraged the transformation of the applied Zn in the soil to sesquioxides bound forms, whereas it reduced Zn transformation to the water soluble plus exchangeable and organically complex forms. This effect is generally more intensified under flooded moisture regimes.

Wetting-drying is one of the most common and widespread phenomena that occurs in soils (8). Soils are subjected to wetting-drying cycles in the field, depending on climate, topography (42) and type of irrigation. The periodic irrigation of soils in arid and semiarid regions with high temperatures subjects soils to wetting-drying cycles during the growing season. The effects of wetting-drying on soil characteristics and plant nutrient availability have been evaluated by different studies (19, 49). Wetting-drying affects microbial activity and nutrient cycling in the soil. This enhances chemical properties of soil such as ionic equilibria, and influences decomposition and oxidation processes. Factors such as degree, rate, duration and frequency of wetting-drying alter the nutrients' availability (7, 8).

Knowing the fate of added fertilizer to the soil can be effective in improving fertilizer recovery and plant nutrition. The extractability of added fertilizer varies in different soil moisture conditions. In most studies, constant moisture is used for nutrient extractability, while in periodic irrigated conditions, soils undergo different wetting-drying cycles. Despite this, the interactive effect of P and Zn was found to be antagonistic and varying with experimental conditions. Nevertheless, this interaction has not been studied extensively under aerobic or wetting-drying conditions (54). The present research was therefore conducted to evaluate the extractability of Zn and Fe in different soil moisture conditions and different times after Zn and P application to the soil. Another purpose of this study was to apply wetting-drying cycles to simulate conditions that soils would experience when subjected to periodic irrigation in arid and semiarid regions.

MATERIALS AND METHODS

This research was designed in two experiments during 2012 at the University of Tabriz, Iran. The first was arranged as a factorial experiment based on a completely randomized design with four factors; Zn at two levels (0 and 20 mg Zn per kg of soil as $ZnSO_4.7H_2O$ from AppliChem Co.), P at two levels (0 and 60 mg P per kg of soil as $Ca(H_2PO_4)_2.H_2O$ (monocalcium phosphate) from SIGMA-ALDRICH Co.), soil moisture at two levels (0.6FC and FC) and incubation time at four levels (1, 10, 30, and 60 days) with two replications. The second study was carried out as a factorial experiment on the basis of a completely randomized design with two Zn levels (0 and 20 mg Zn per kg of soil as $ZnSO_4.7H_2O$), two P levels (0 and 60 mg P per kg of soil $Ca(H_2PO_4)_2.H_2O$), three wetting-drying cycles (1, 10 and 20 cycles), replicated two times. Zn levels were selected based on the results of Koleli et al. (30), Tavallali et al. (66), Gunes and Bagci (16) and Peck and Mcdonald (50), and P levels were based on the reports from Nelson and Safir (45), Rodriguez and Goudriaan (55) and Jin et al. (22). At first, a calcareous non-saline soil (EC=0.47 dS m^{-1}) low in available P and Zn (Olsen-P=8.7 and DTPA-Zn=0.5 mg kg^{-1}) was selected (3, 23). The soil was taken from Espiran village in the northwest of Tabriz, Iran, (latitude 38° 15' 57" N and longitude 46° 19' 53" E from depth of 0-25 cm). After air drying and sieving (2 mm in diameter), the soil physical and chemical properties such as available-P (Olsen (23) method), available-Zn, Mn, Fe and Cu (Lindsay and Norvell (32) method), soil texture (hydrometric (15) method), organic carbon (wet oxidation method (46)), available-K (1 N acetate ammonium extraction method (28)), pH in a 1:1 soil/water ratio suspension (40) and EC in a 1:1 soil/water solution (23) were measured. Moisture of field capacity (FC) at 300 kPa was determined by the pressure plate method (27).

Each sample contained 10 g air dried soil in a 50 mL plastic container. P and Zn were added as solutions. Incubated samples were brought to FC by adding deionized water. Moisture contents were controlled throughout the experiment by adding known amounts of deionized water every day. For each wetting-drying cycle (wet/dry) treatments, soil water content was brought to FC by adding deionized water and allowed to dry for 3 days. All treatments were kept in an incubator at a temperature of 25°C.

At the end of each incubation period, Zn and Fe were extracted by ammonium bicarbonate-DTPA extractant (62) and measured by an atomic absorption spectrometer (Shimadzu AA-6300, Shimadzu Corporation). The data were subjected to analysis of variance using MSTATC software. LSD test at the p≤ 0.05 probability level was applied to compare the means of measured attributes. Excel software was used to draw Fig.s.

RESULTS AND DISCUSSION

Some of the physical and chemical properties of the soil used in this experiment are shown in Table 1. On the basis of the analyses made before the trials, the experimental soil had clay loam texture and high CCE without any salinity and sodicity problems. FC moisture content was approximately 18.5%. Available P and Zn values of the soil were lower than the critical levels (3, 23).

Table 1. Some physical and chemical properties of soil

Texture	CCE	SP	FC	OC	pH (1:1)	EC (1:1)	P	K	Fe	Zn	Mn	Cu
	(%)					(dS m^{-1})	(mg kg^{-1})					
Clay loam	15.25	44.4	18.5	0.5	7	0.47	8.7	556	3.98	0.52	7.01	2.2

CCE: calcium carbonate equivalent; OC: organic carbon;

Extractable-Zn

The analysis of variance showed that the main effects and two, three and four way interactions of the factors on the extractable Zn were significant, except for the two way interaction of cycle×P and the three way interactions of time×moisture×P, moisture×Zn×P, time×Zn×P and wetting-drying cycle×Zn×P, (Tables 2 and 3).

Table 2. Summary of analysis of variance (mean squares) for the extractable Zn and Fe in the first experiment

Source of variation	df	Zn	Fe
Time	3	25.610^{***}	8.302^{***}
Moisture	1	28.382^{**}	9.075^{***}
Time × Moisture	3	8.097^{*}	4.733^{***}
Zn	1	2429.258^{***}	5.476^{**}
Time × Zn	3	29.547^{***}	2.152^{*}
Moisture × Zn	1	48.372^{***}	0.226^{ns}
Time × Moisture × Zn	3	5.431^{ns}	0.302^{ns}
P	1	31.444^{**}	1.626^{ns}
Time × P	3	10.554^{*}	0.226^{ns}
Moisture × P	1	26.112^{**}	1.850^{ns}
Time × Moisture × P	3	5.804^{ns}	0.293^{ns}
Zn × P	1	13.95^{*}	9.136^{***}
Time × Zn × P	3	2.504^{ns}	4.794^{***}
Moisture × Zn × P	1	6.138^{ns}	0.035^{ns}
Time × Moisture × Zn × P	3	12.301^{**}	0.770^{ns}
Error	32	2.827	1.407

Table 3. Summary of analysis of variance (mean squares) for the extractable Zn and Fe in the second experiment

Source of variation	df	Zn	Fe
Cycle	2	1.204^{**}	3.959^{ns}
Zn	1	1335.489^{***}	0.059^{ns}
Cycle × Zn	2	2.535^{***}	0.712^{ns}
P	1	3.089^{***}	1.354^{ns}
Cycle × P	2	0.057^{ns}	1.447^{ns}
Zn × P	1	2.35^{**}	0.416^{ns}
Cycle × Zn × P	2	0.022^{ns}	0.352^{ns}
Error	12	0.157	1.236

Fig. 1 shows that the extractable Zn decreased during the time of incubation in 20 mg Zn per kg soil level, while a reverse result was observed in the control level and during the incubation time the extractable Zn mostly increased. In 20 mg Zn per kg of soil level, there was a rapid fall in the extractable Zn during the early period of incubation (up to 30 days), but thereafter it decreased slowly.

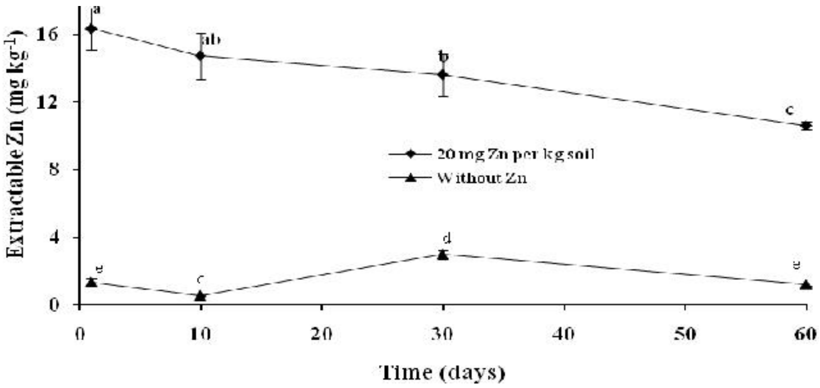

Fig. 1. Effects of Zn fertilizer and incubation time on the extractable Zn

The three way interaction of soil moisture×Zn×incubation time showed (Fig. 2) that in treatments with 20 mg Zn per kg of soil, the availability of Zn at FC condition was greater than the 0.6 FC, and the difference was significant in the first 10 days of incubation. However, the extractable Zn was statistically similar after the 10th day of incubation in both moisture levels. According to Fig. 2, a reverse trend was observed with no Zn fertilizer conditions so that the extractable Zn was higher at the 0.6 FC condition compared to the FC level. In soil treatments of 20 mg Zn per kg, the extractable Zn decreased to 66% and 40% at FC and 0.6 FC conditions, respectively. The results also showed that unlike the treatment with 20 mg Zn per kg of soil, the extractable Zn did not increase in any Zn treatment with time for the two moisture regimes.

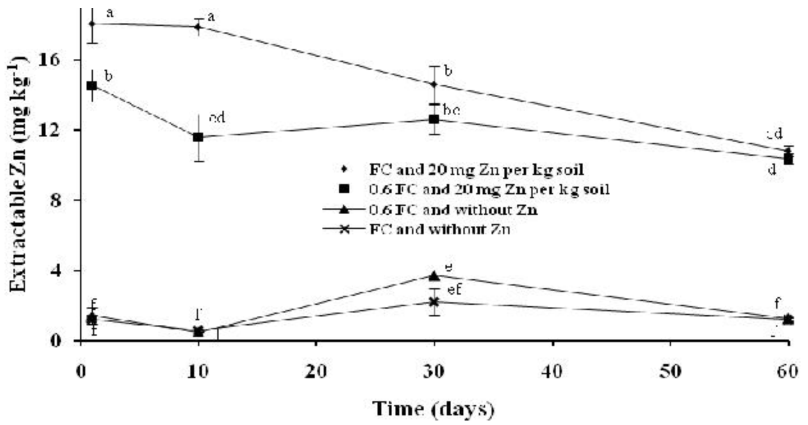

Fig. 2. Effects of soil moisture and Zn fertilizer during incubation time on extractable Zn

The application of 60 mg P per kg of soil under FC condition and without P under 0.6 FC condition significantly decreased the extractable Zn during incubation time (Fig. 3), while with no P addition under FC condition, the extractable Zn remained constant up to the 30th day of incubation, significantly decreasing between the 30th and 60th days of incubation. At the 0.6 FC and 60 mg P per kg of the soil treatment, the extractable Zn of the soil was not affected significantly by incubation time (Fig. 3). At each incubation time, the application of 60 mg P per kg of soil under 0.6 FC resulted in diminishing the availability of Zn in the soil comparing with other treatments. It can be revealed from Fig. 4 that the application of P resulted in diminishing the extractable Zn in both Zn levels. It can also be mentioned that the reduction of the extractable Zn by P application was more pronounced at 20 mg Zn per kg of the soil level (Fig. 4). The effect of incubation time on the extractable Zn at the application of 60 mg P per kg of the soil under 0.6 FC was not significant, but there was a significant relationship between incubation time (T) and the extractable Zn (Extrat-Zn) under the above-mentioned conditions ($\text{Extrat-Zn} = 0.3411(\ln T)^2 - 1.6 \ln T + 6.7161$, $R^2=0.992^{**}$).

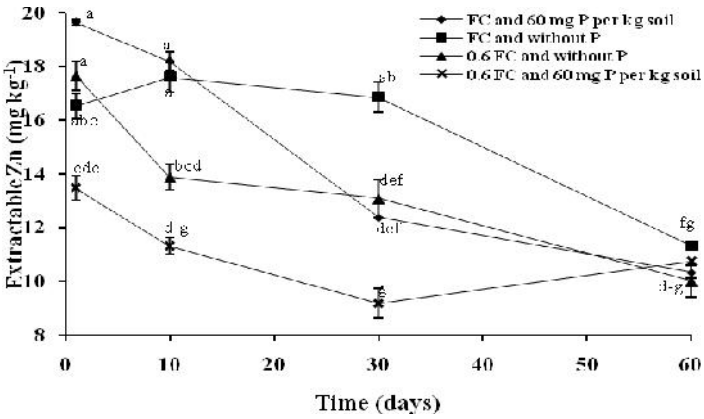

Fig. 3. Effects of soil moisture and P fertilizer under Zn application conditions on the extractable Zn during incubation time

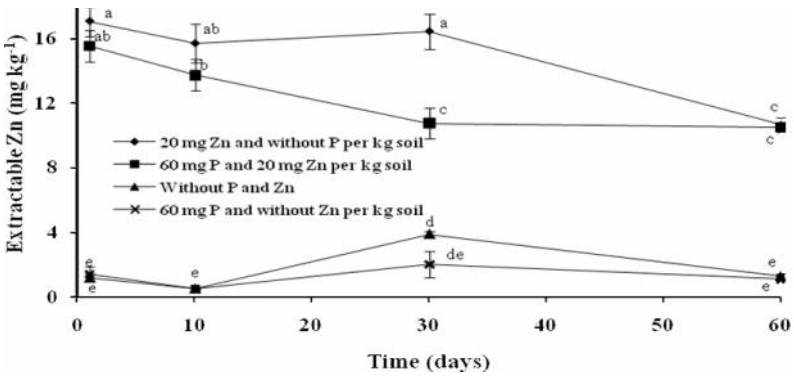

Fig. 4. Effects of Zn and P fertilizers on the extractable Zn during incubation time

According to Fig. 5, at 20 mg Zn per kg soil, the extractable Zn under FC conditions was significantly higher than that of the 0.6 FC conditions. P application sharply reduced the extractable soil Zn at 0.6 FC, while with native soil Zn (no Zn application) contrary results were found.

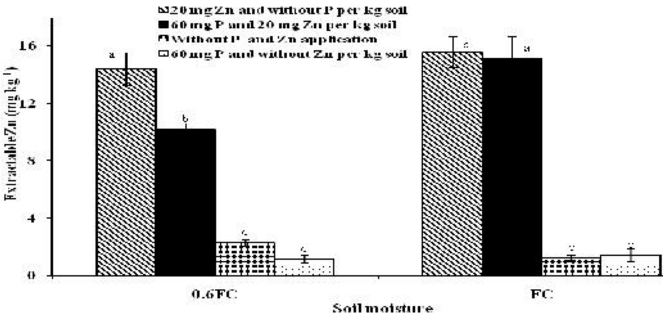

Fig. 5. Effects of Zn, P and soil moisture combined treatments on extractable Zn

In Zn application conditions, wetting-drying cycles significantly decreased the extractable Zn, while the addition of P had no significant effect on the extractable Zn during wetting-drying cycles (Fig. 6). It can also be revealed from Fig. 6 that in no Zn application conditions, wetting-drying cycles and P fertilizer had any significant effect on the extractable Zn, and the same Zn content was found in all P and wetting-drying levels. The Zn extractability was not significantly affected by different moisture levels or wetting-drying cycles (Fig. 7). But the extractable Zn content of the soil under wetting-drying conditions was greater than that of constantly moist soil.

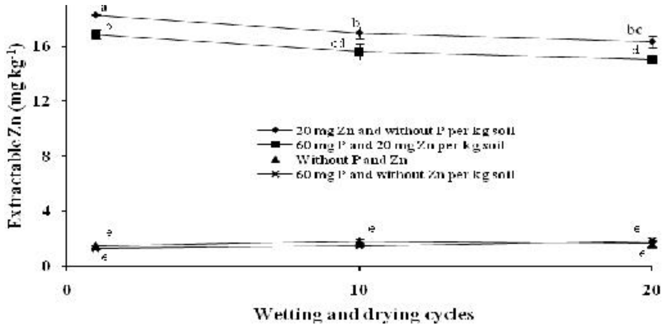

Fig. 6. Effects of soil wetting-drying cycles and Zn and P fertilizers on extractable Zn

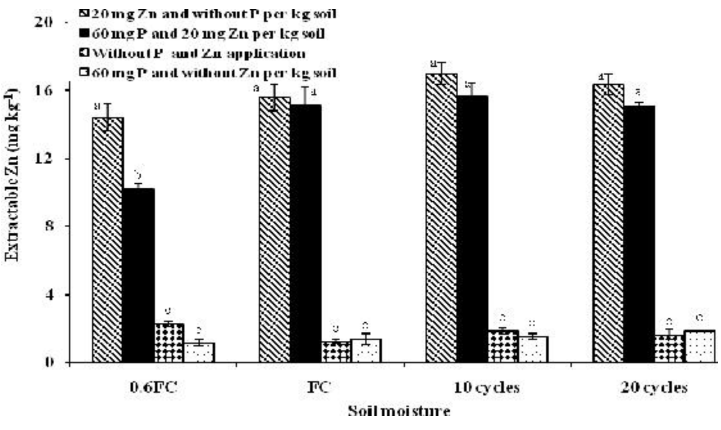

Fig. 7. Effects of Zn and P fertilizers on extractable Zn under different soil moisture levels and wetting-drying cycles

Based on the results of this study, the sharp decrease in the extractable Zn at early periods of incubation (Fig. 1) may be due to the precipitation of Zn with SO_4^{2-} and CO_3^{2-} (12), adsorption of Zn on hydrous oxides of Fe and Mn (21), and calcite and poorly crystalline sesquioxide surfaces with a high affinity for Zn (38). Other researchers such as Adam and Anderson (1), Armour et al. (5), Ma and Uren (34), Towfighi and Najafi (67), and Naik and Das (43) have reported extractable Zn decrease after Zn application during incubation time. The increase of the extractable Zn without Zn application levels might be attributed to the release of Zn from insoluble Zn minerals such as franklinite (18) and the increase of microorganism activities in constant moisture incubation conditions that might have led to higher organic bounded Zn and its availability (69).

The higher amount of extractable Zn at FC conditions under the application of Zn (Fig. 2) might be due to the higher solubility of Zn because of the additional water (57), higher levels of microorganism activity (1, 57), additional reduction of soil pH (12) and lower adsorption of Zn on hydrous oxides (68). Water deficit increases soil Eh and therefore, makes Fe oxides less soluble (33, 35) and as a result Zn is adsorbed onto these oxides. Higher amounts of extractable Zn in FC moisture levels were in agreement with the findings of Katyl and Sharma (25) but against those of Misra and Tyler (42). According to Fig. 5, the sharp reduction of the extractable Zn at 0.6 FC as compared to the FC after P application might be due to the higher precipitation of Zn with phosphate anions in drier soils (31).

The significant decrease in the extractable Zn with P addition (Fig. 3 and 4) might be due to the enhanced adsorption of Zn to the surfaces (31), which might be caused by the increased surface-negative charge (or reduced surface-positive charge) after P-sorption, or the formation of new adsorbing sites of Fe-phosphates precipitated on the surfaces of the oxides (37) resulting in higher precipitation of Zn-phosphates (31). Zahedifar et al. (71) showed that desorption of Zn was reduced by the application of P fertilizers.

The reduction of Zn availability in wetting-drying incubation conditions (Fig. 6) might be due to the fixation process as a result of precipitation, physical entrapment in clay lattice wedge zones, and/or strong adsorption at the exchange sites (53). Naik and Das (43) showed that the wetting-drying of soil (drying from saturated to FC) in both conditions (with and without Zn application) reduced the availability of Zn. Our results at 20 mg Zn per kg of soil (Fig. 6) were in agreement with those of Nambiar (44) and Naik and Das (43). Adam and Anderson (1) showed that in soil wetting-drying conditions, Zn availability reduced by increasing the incubation time. Higher extractable Zn under wetting-drying conditions comparing with continues soil moisture conditions (Fig. 7) might be caused by the organic compound solubilization due to the physical disruption of the soil structure and organic compound desorption from surfaces, higher microbial mobility and the diffusion of soluble organic compounds (8, 51). The higher amount of extractable Zn at wetting-drying cycles as compared to the continuous soil moisture condition (Fig. 7) could also occur by physicochemical mechanisms such as adsorption-precipitation (13). These results were in contrast with the findings of Ryan and Hariq (56). In this regard, Khan and Banwart (26) have suggested that the decrease in the extractable Fe, Zn, and Cu upon soil incubation at FC is non-microbial in nature (1). Mandal et al. (36) showed that under alternate wetting-drying conditions Zn was released more than the control and constant flooding conditions. This process might be attributed to the higher solubility of Zn minerals resulting from drying (43).

Extractable Fe

According to the analysis of variance (Table 2, and 3), the main effects of incubation time, moisture condition and Zn fertilizer, two way interactions of time×moisture, time×Zn and Zn×P and the three way interaction of time×Zn×P on the extractable Fe were significant.

Fig. 8 shows the effect of soil moisture × Zn fertilizer interaction on the extractable Fe during the incubation time. The extractable Fe reduced by increasing incubation time up to 10 days and this trend continued more or less between the 10th and 60th days of incubation (Fig. 8).

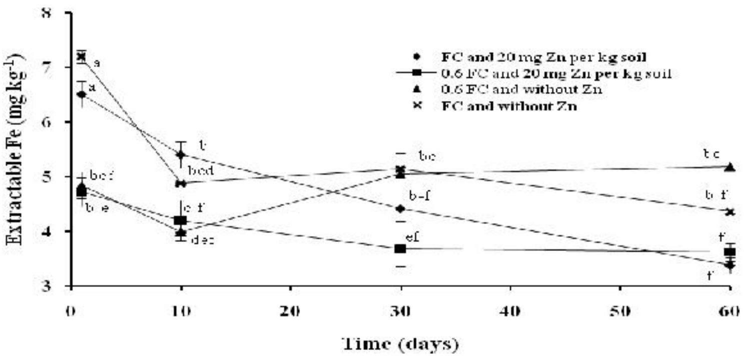

Fig. 8. Effects of Zn fertilizer and soil moisture levels on extractable Fe during time lapses

The extractable Fe was reduced with time by the application of P and Zn fertilizers to the soil (Fig. 9). The application of P or Zn fertilizers decreased the extractable Fe; the reduction being more pronounced during the last days of incubation. In no Zn and P fertilizer treatments, not only the extractable Fe did not decrease, but also increased with incubation time. The highest extractable Fe under the mentioned conditions was found between the 30th and 60th days of the incubation time. It can be mentioned that on the 10th day of incubation, there were no significant differences between the control and the application of P or Zn condition. However, in the next days, the extractable Fe decreased significantly by the application of P or Zn fertilizers to the soil.

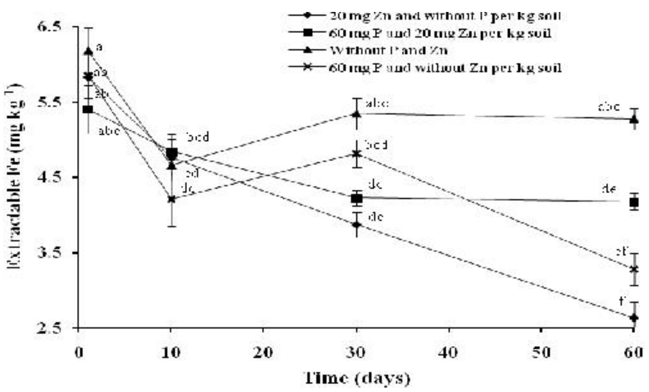

Fig. 9. Effects of the application of Zn and P fertilizers to soil on extractable Fe during incubation time

According to Fig. 10, wetting-drying of soil increased extractable Fe in all P and Zn fertilizer treatments compared to constant moisture conditions. In all soil moisture conditions, higher amounts of extractable Fe were observed in no P and Zn fertilizer treatments and the amounts significantly decreased by the application of Zn and P fertilizers to the soil.

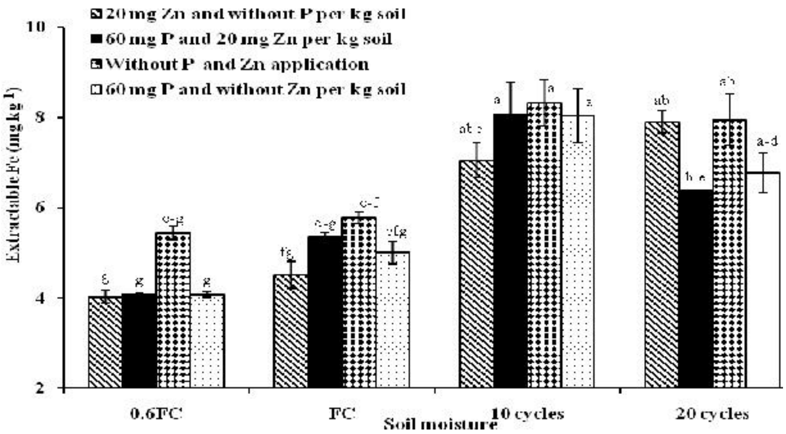

Fig. 10. Effects of Zn and P fertilizers on extractable Fe under different soil moisture levels and wetting-drying cycles

The possible formation of insoluble Fe compounds by the oxidation process (1) may have reduced the extractability of Fe during incubation time (Fig. 8). It can also be speculated that the sharp reduction of available Fe might be caused by the activities of microorganisms and the immobilization processed that might have reached equilibria after the mentioned day. The higher extractability of Fe in FC conditions may also be related to this process.

Higher concentrations of Zn were shown to have induced lower Fe extractability (Fig. 9) through the replacement of Fe in soil chelates and phytosiderophores (63). Phosphorus is universally known to form insoluble Fe phosphates (52). Moreover, phosphorus reacts with Fe to co-precipitate as $Fe(OH)_2H_2PO_4$ (20) which reduces their availability (Fig. 9). It is expected that P fertilizers change the micronutrients' concentration in the soil solution and influence their capacity factor (52). Additionally, phosphorus fertilizers may encounter transformations of Fe soluble forms to insoluble forms (36). The reduction of extractable Fe by P application was previously shown by Singh and Dahiya, (61), Ohki (48) and Kochain (29).

The increase of the extractable Fe in wetting-drying conditions (Fig. 10) may be due to microbial effects (1). Drying a soil increases the solubility of soil organic matter (6). By re-moistening dried soil, higher activity of soil microorganisms occur which might cause temporary anaerobiosis (65, 72) and immobilization of Fe. The higher solubility of organic matter and modified pH (6) caused by the remoistening of the dried soil, can mostly explain the increased levels of the extractable Fe in the soil solution.

CONCLUSION

The results showed that in constant moisture conditions, time lapse reduced the extractable Zn and Fe and the higher decline rate obtained in the first 30 days of incubation. The application of Zn fertilizer to the soil increased extractable Zn in all studied conditions, but decreased the extractable Fe. The application of P fertilizer to the soil declined the extractable Zn and Fe, the decrease being more visible in the 0.6 FC condition and the presence of Zn fertilizer. Incubation of soils in FC moisture conditions resulted in higher amounts of extractable Zn and Fe and this trend continued in most incubation times.

The extractable Zn declined by increasing the wetting and drying cycles but the extractable Fe was not significantly affected by these. Most of the reduction in the extractable Zn happened in the Zn application condition, but without Zn application, wetting and drying cycles did not alter Zn availability and the same results emerged in different wetting and drying cycles.

Except for the treatment of 60 mg P and 20 mg Zn per kg of soil under 0.6 FC, extractable Zn was not significantly different between constant moisture and wetting and drying cycles, while the extractable Fe increased significantly in wetting and drying conditions compared to those with constant moisture. The results also revealed that wetting and drying cycles and the application of Zn and P fertilizers to soils with the mentioned conditions had no effect on the extractable Fe.

ACKNOWLEDGMENTS

The authors would like to thank the Vice Chancellor of Research and Technology of the University of Tabriz for financial support of this project. We are also grateful to the reviewers for their perceptive comments and corrections on the manuscript.

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تأثیر کودهای سولفات روی و منوکلسیم فسفات بر روی و آهن قابل-استخراج در شرایط مختلف رطوبت خاک

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چکیده- به‌منظور بررسی تأثیر شرایط مختلف رطوبت خاک و کودهای روی و فسفر بر روی و آهن قابل‌استخراج خاک دو آزمایش به‌صورت فاکتوریل و در قالب طرح کاملاً تصادفی و با دو تکرار در شرایط آزمایشگاهی انجام شد. آزمایش اول با فاکتورهای زمان انکوباسیون در چهار سطح (۱، ۱۰، ۳۰ و ۶۰ روز)، رطوبت خاک در دو سطح (FC و ۰/۶FC)، کود فسفر در دو سطح (صفر و ۶۰ میلی‌گرم P بر کیلوگرم خاک) و کود روی در دو سطح (صفر و ۲۰ میلی‌گرم Zn بر کیلوگرم خاک) انجام شد. آزمایش دوم با فاکتورهای کود روی در دو سطح (صفر و ۲۰ میلی‌گرم Zn بر کیلوگرم خاک)، کود فسفر در دو سطح (صفر و ۶۰ میلی‌گرم P بر کیلوگرم خاک) و چرخه‌های مرطوب و خشک شدن در سه سطح (۱، ۱۰ و ۲۰ چرخه) اجرا شد. نتایج نشان داد که با افزایش زمان انکوباسیون روی و آهن قابل‌استخراج کاهش یافت. مصرف روی در شرایط رطوبت خاک FC باعث افزایش روی قابل‌استخراج در تمام زمان‌های انکوباسیون شد. مصرف فسفر باعث کاهش روی و آهن قابل‌استخراج در اکثر زمان‌های انکوباسیون و رطوبت خاک شد. با افزایش تعداد چرخه‌های مرطوب و خشک شدن و افزایش زمان انکوباسیون روی قابل‌استخراج کاهش یافت. به‌جز مصرف ۲۰ میلی-گرم روی و ۶۰ میلی‌گرم فسفر بر کیلوگرم خاک در شرایط رطوبت خاک ۰/۶FC، تفاوت معنی‌داری بین رطوبت ثابت و چرخه‌های مرطوب و خشک شدن از نظر روی قابل‌استخراج وجود نداشت.

واژه های کلیدی: رطوبت خاک، روی، خشک شدن، فسفر، قابل‌استخراج و مرطوب

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