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Mixed cropping promotes the ability of wheat and lentil to increase rhizosphere micronutrients availability in calcareous soil

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Abstract

Micronutrient deficiencies are common almost in all Iraqi soils. Field experiment included six treatments was conducted in order to study the effects of mixed cropping practices on micronutrient availability in the rhizosphere and bulk soils. At different plant ages (50 and100 days and at harvest time) concentration of DTPA-extractable Zn, Cu, Mn and Fe were determined and soil pH was also measured. The results showed that the concentrations of the plant available micronutrients (Fe, Zn, Cu and Mn) were generally increased in the rhizosphere and bulk soils in response to mixed cropping system and different plant ages as compared to that of the monocropping soils of wheat and lentil. The results also showed that micronutrient concentrations (Zn, Cu and Mn) in the rhizosphere of wheat and lentil were lower than that of the bulk soil in the mixed cropping system.

Keywords: Lentil; Micronutrients; Mixed Cropping; Rhizosphere; Wheat

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1. Introduction

soils in northern part of Iraq (includes Nineveh province) are usually known as calcareous soils which characterized by low organic matter, high pH (7.6–8.2) and high levels of calcium carbonate (Buringh, 1960; Al-Nuaimi, 1977), in addition to heavy soil texture and low soil moisture (Arid and semiarid land farming). The combination of these factors is the main reason that lowering micronutrients availability in soil solution and reducing cereal productivity in many agricultural areas in this part of Iraq (Barwary, 2012).

Soil amendment, nutrient supply in calcareous soil and foliar application is not always easy to overcome the nutrients deficiency, but it is only a coasty and time consuming. Therefore, there is considerable interest in devising practical approaches for the correction or avoidance of micronutrients deficiencies in cereals. Using intercropping system (cereal with legume) which defines growing two or more species or cultivars on the same piece of land during the same season known to increase yield through the effective utilization of natural resources (Snaydon and Harris 1981; Shackle and Hall 1984; Donald 1985,Hauggaard–Nielsen et al., 2006; Li et al.,1999 and 2001; Zhang and Li., 2003) and monetary returns to the farmers (Ofori and Stern, 1987) and improve soil fertility through the addition of nitrogen by fixation and extraction from the component legume (Hauggaard-Nielsen et al., 2001) compared to mono cropping system.

Root and soil interactions during plant growth induce changes that make rhizosphere soil to differ from bulk soil (Wang and Zabowski, 1998). These changes are caused by root uptake of nutrients, microbial activity, and/or components of root exudates (Marschner, 1995; Hinsinger, 2001; Dakora and Phillips, 2002). It is well known that lentil and wheat have distinctly different response mechanisms to micro nutrients deficiency stress. Lentil is a ‘strategy I’ plant, while wheat belongs to the ‘strategy II’ group. Strategy II plants are characterized by a higher micronutrient acquisition efficiency in soils with high pH and, in particular, high bicarbonate content through the excretion of phytosiderophores (PS) into the rhizosphere (Römheld and Marschner 1986) . However, this mechanism still remains to be properly understood. Although we have recently gained considerable insights into nutrient dynamics in the rhizosphere, little is known about the mineral concentrations of plant rhizosphere, especially when grown in different cropping systems and/or plant densities. This study was carried out to investigate the micronutrients status in the bulk and rhizosphere soils of mixed wheat and lentil crops at various plant ages and mixing ratios.

2. Materials and methods

2.1. Crop management and experimental design

Field experiment was conducted during 2012 in a private farm in Al-Shalalat village [(43º.12'03''.64 E) and (36º.28'04''.40 N)], Mosul city, Nineveh province of Iraq. The topsoil (0–0.3 m) of the experimental field (table-1) which classified within the order Aridisols and Calciorthid great group was a clay loam. The pH of the soil was 7.83 and contained 370 g kg^{-1} $CaCO_3$.The experiment was arranged as a factorial based on randomized complete block design (split plot) with three replications. The following treatments were used:

T1: Sole wheat (100 kg ha^{-1})
T2: Wheat (100 kg ha^{-1}) + (20 kg ha^{-1}) Lentil
T3: Wheat (100 kg ha^{-1}) + (40 kg ha^{-1}) Lentil
T4: Wheat (100 kg ha^{-1}) + (60 kg ha^{-1}) Lentil
T5: Wheat (100 kg ha^{-1}) + (80 kg ha^{-1}) Lentil
T6: Sole Lentil (80 kg ha^{-1})

The treatment unites were as strips (each strip contains 3 replicates) with area 3.6 m×100 m involving 20 rows with inter–row spacing of 18cm and inter-strip spacing of 1.5m. Zero tillage system was used and supplementary irrigation water was provided when needed by using sprinkler irrigation.

2.2. Soil collection and analysis

In order to evaluate the effects of mixed cropping performance in mixture and sole crop on pH and micronutrients available concentrations on bulk and rhizosphere soils, soil was collected from the bulk and rhizosphere soils of the field study after 50,100 days of plant age in the field and at harvest time (168 days). The rhizosphere soil collected as followed by (Gobran and Clegg, 1996; Rengel, 1997), the roots were held by the stem base and gently have been shaken, the soil that remained adhering to the roots was defined as rhizosphere soil and the soil which easily removed from the roots defined as bulk soil. The soil samples were air-dried, passed through a 4-mm sieve and the pH was measured by pH meter in 1:1 soil suspension after shaking for 30 minutes according to Ryan et al. (2001). Plant available concentration of the micronutrients (Fe, Zn, Cu and Mn) in soil were determined according to the method stated by Ryan et al. (2001) by extraction with DTPA using a soil solution ratio of 1:2 and shaking time of two hours. Micronutrient extracted was determined by Inductively Coupled Plasma- Optical Emission Spectrometry (ICP-OES).

2.3. Statistical analysis

A randomized complete block design (split plot) was used for the statistical analysis of the data. The treatment means were compared by determining the least significant difference (LSD) at 5% level of probability (P =0.05) using statistical analysis software SAS (2002).

3. Results and discussion

3.1. Physicochemical characteristic of soil

Physical and chemical properties of soil are presented in table (1). Soil had high pH (7.83) and was calcareous, which contains about 370 g kg^{-1} $CaCO_3$. The organic matter content was 20.4 g Kg^{-1} soil. Soil had a clay loam texture, where the clay fraction was almost that of silt. In soil sample concentration of DTPA-extractable Fe was 2.80 mg kg^{-1} which was less than the adequate amount of Fe in calcareous soils (4 mg kg^{-1}) as stated by Soltanpour and Schwab (1977), and it was marginal with the critical level for calcareous soils

(2.5 mg kg^{-1}) obtained by (Sims and Johnson, 1991). While the DTPA- extractable Zn in soil (0.6 $mgkg^{-1}$ soil) was marginal with the adequate amount of Zn in calcareous soil (0.5 $mgkg^{-1}$ soil) as stated by (Sims and Johnson, 1991) and it was less than the adequate amount of Zn in calcareous soils (> 1.0 $mgkg^{-1}$ soil) as stated by Soltanpour and Schwab (1977). The high pH and the high concentrations of $CaCO_3$ and clay in soil together with low annual precipitation may considered to be the major factors causing deficiency of the most nutrients specially micronutrients in plant grown in the north part of Iraq.

Table 1. Physiochemical properties of top soil sample (0 – 0.3m)

1	Electrical conductivity EC (ds m^{-1}) from 1:1 extract	0.57
2	Soil pH from 1:1 soil suspension	7.83
3	Total Calcium carbonate(g kg^{-1})	370
4	Organic matter (g Kg^{-1})	20.4
5	Sand (g Kg^{-1})	98
6	Silt (g Kg^{-1})	450
7	Clay (g Kg^{-1})	452
8	Soil texture	Clay loam
Micronutrients (DTPA)		
9	Available Fe (mg Kg^{-1} soil)	2.8
10	Available Zn (mg Kg^{-1} soil)	0.6
11	Available Mn (mg Kg^{-1} soil)	5.0
12	Available Cu (mg Kg^{-1} soil)	3.0
Macronutrients		
13	Available Nitrogen (mg Kg^{-1})	56
14	Available phosphorous (mg Kg^{-1})	4.6
15	Available Potassium (mg Kg^{-1})	355.6

Nutrients move to plant root in soils is limited largely by diffusion and mass flow in the soil solution (O'Connor et al., 1971, Chaney, 1984, Marschner, 1993), and thus absorption is highly dependent on soil water status and root growth (Mengel and Kirkby, 2001). Micronutrients nutrition of plants is often threatened in arid soils having low plant available concentration of Fe and Zn. Diffusion of micronutrients in soil is also greatly affected by soil pH. In calcareous soils, diffusion coefficient for micronutrients is lower than in acid soils (Melton et al., 1973). O'Connor et al. (1971) stated that at neutral to basic soil pH, inorganic Fe levels available for transport to the plant roots by both mass flow and diffusion are below the plant requirements. Fe^{2+} decreases in solubility 100-fold for every unit increase in pH (Crowley et al., 1987).

3.2. Rhizosphere and bulk soils micronutrient concentration

The data (Tables 2 and 3) showed that the concentration of the plant available micronutrients (Fe, Zn, Cu and Mn) were generally increased in the rhizosphere and bulk soils in response to mixed cropping system as compared to that of the mono cropping soils of wheat or lentil under the effect of different field plant ages (50,100 days and at harvest time). This result was expected because the mixed cropping system is more efficient in exploring a larger total soil volume if component crops have different rooting habits, in particular depth of rooting (Willey, 1979). Rotting patterns differ greatly between cereals and legumes (Anil et al., 1998) and this may be one reason for the commonly observed advantage of cereal-legume mixed crops in increasing available micronutrients in soil .The other reason that cereal–legume mixed cropping can promote the availability of micronutrients in soil especially in low micronutrients soils (calcareous soils) is by its root-induced pH changes. In our study the mixed crop bulk and rhizosphere soils at different plant ages and at harvest time were acidified as compared to that of sole cropping soils of both crops (Table 4). This small acidification might be due to that in neutral and alkaline soils legumes are assumed to increase micronutrients availability by rhizosphere acidification due to N_2 fixation process. Ae et al., (1990) and Marschner (1995) stated that, due to dependency on N_2 fixation, legumes (N_2 fixing plants) is known to take up higher amounts of mineral elements from their rhizosphere as they are required for plant growth and N_2 fixation compared with non-legume plant which is a non N_2-fixing plant. Consequently, their rhizosphere will acidified which is not only enhanced by the release of H^+ but also by the change in cation/anion ratio (Tang et al., 1997, 2001), a process which could lead to variation in micronutrients concentration in the rhizosphere compared with the bulk soil (Wang and Zabowski, 1998; Wang et al., 2001; Dakora and Phillips, 2002; Cornu et al., 2007). Similar result was reported by Haynes (1983) who found that the growth of legumes which are fixing atmospheric N_2 involves the excess uptake of nutrient cations over anions from soil solution which results in the net efflux of H_3O^+ ions from plant roots into the rhizosphere. This processes leading to legume-induced soil acidification. Also lentil belong to Strategy I plants which is a micronutrients acquisition mechanism used by all higher plants except the grasses (Römheld et al., 1984) such as wheat. Under micronutrient-deficient conditions, strategy I plants increase the solubility of micronutrient in the rhizosphere to enhance micronutrient availability to plants by H^+ exudation, which lowers the rhizosphere pH and increases solubility of Fe (Römheld et al., 1984), the release of organic reductants from plant roots that promote the reduction of micronutrient such as Fe(III) to Fe(II) (Chaney et al., 1972) and root exudation of micronutrient-chelating agents (phenolic) that increase the solubility of micronutrient (Schmidt, 1999).

The results also showed that micronutrient concentrations (Zn, Cu and Mn) in the rhizosphere of wheat and lentil were lower than that of the bulk soil in mixed cropping system (Tables 2 and 3) suggesting greater root uptake rates that would have exceeded their replacement through the soil solution by mass flow and diffusion processes. Similar results were found by Yanai et al. (2003) when they studied the differences in nutrient concentrations between rhizosphere and bulk soil in a Norway spruce stand. Likewise, the use of different crops in cropping systems in this study created variation in mineral elements demand from their rhizosphere. As a result, the surrounding rhizosphere was strategically modified through root exudation and uptake of micronutrients.

From the results, no clear differences were found between the mineral concentration in the rhizosphere of sole wheat and sole lentil (Table 2); it was not reduced more in lentil compared with wheat. This result differ than the finding of (Delhaize *et al.*, 1993; Dakora and Phillips, 2002, Hinsinger et al., 2003) who stated that higher demand of mineral elements from the rhizosphere by legumes for growth and N_2 fixation and the species-to-species competition for growth factors suggest reduced mineral elements concentration in the rhizosphere of legumes compared with cereal species.

In conclusion, our results suggest that different agronomic practices may lead to significant variation in the concentration of mineral element in the rhizosphere.

Table 2. Effect of wheat-lentil mixed cropping on the micronutrients concentration (g kg^{-1}) in the rhizosphere soil

Treatments	Fe		Zn		Cu		Mn	
	50 d.	100 d.	50 d.	100 d.	50 d.	100 d.	50 d.	100 d.
Sole lentil	3.22	6.82	0.37	0.36	1.26	0.59	9.76	11.68
Sole wheat	3.48	6.46	0.34	0.39	1.27	0.62	7.30	14.52
Mixed crop	3.66	6.84	0.40	0.45	1.39	0.70	9.50	15.10
LSD (0.05)	0.37	0.44	0.09	0.07	1.15	0.08	0.94	0.90

Table 3. Effect of wheat-lentil mixed cropping on the micronutrients concentration (g kg^{-1}) in the bulk soil

Treatments	Fe			Zn			Cu			Mn		
	50d.	100d.	harvest	50d.	100d.	harvest	50d.	100d.	harvest	50d.	100d.	harvest
Sole lentil	2.80	3.76	3.18	0.47	0.49	0.30	0.97	0.75	0.20	9.53	14.35	12.97
Sole wheat	3.97	5.62	2.22	0.46	0.47	0.16	1.54	0.68	0.23	9.82	13.56	7.28
Mixed crop	3.62	5.76	2.88	0.53	0.53	0.19	1.50	0.78	0.23	12.57	15.21	15.52
LSD(0.05)	0.65	0.53	0.28	0.09	0.07	0.22	0.13	0.18	0.02	1.65	1.00	1.36

Table 4. Effect of wheat-lentil mixed cropping on the pH of both bulk and rhizosphere soil

Treatments	bulk soil			rhizosphere	
	50 d.	100 d.	Harvest	50 d.	100 d.
Sole lentil	7.95	7.56	7.35	8.00	7.49
Sole wheat	7.96	7.59	7.49	8.06	7.55
Mixed crop	7.89	7.54	7.29	7.90	7.48
LSD (0.05)	0.09	0.04	0.12	0.54	0.04
Age (mixed crop)	7.89	7.54	7.29	7.90	7.48
LSD (0.05)	0.05			0.03	

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