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Lactuca sativa growth in compacted and non-compacted semi-arid alkaline soil under phosphate fertilizer treatment and cadmium contamination

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ABSTRACT

Soil compaction is known to drastically modify soil properties and hence to affect both plant growth and metal distribution in the soil. Phosphate amendment is generally used to improve plant production but unfortunately it also gives rise to higher metal contamination in soils and plants. In this work, we aimed to study the effects of soil density, phosphate fertilization and cadmium contamination on the growth of *Lactuca sativa*. In particular, the migration of cadmium in the soil columns, its accumulation and translocation in lettuce were also examined. *Lactuca sativa* was selected as a model plant because it is widely cultivated in alkaline clay soils of eastern Mediterranean countries. Two levels of soil compaction (1.2 and 1.4 $g\,cm^{-3}$), two rates of P amendment (0 and 109 $mg\,P\,kg^{-1}$), and two levels of Cd contamination (0 and 84 $mg\,Cd\,kg^{-1}$) were used in 24 model columns with a factorial randomized block experimental design. Soil compaction increased considerably both leaf area and dry weight of roots and shoots, whereas both chlorophyll content and NRA decreased. For the two soil bulk densities, the phosphate fertilizer improved lettuce growth characterized by plant height, dry matter, leaf number and NRA, whereas Cd contamination altered those parameters and increased the chlorophyll content. In soils contaminated with cadmium, the combination of compaction and phosphate fertilization resulted in a significant decrease in Cd migration along the soil columns. Cd uptake by plants increased in Cd treated soils; its accumulation was found to be more important than in plants grown in P-Cd treated soil where Cd uptake was clearly reduced in shoots and roots.

1. Introduction

Mechanization of agriculture and addition of mineral fertilizers have been the typical responses to increase crop yields and to improve soil fertility. However, such approaches have led to significant soil compaction and soil structure deterioration. According to the literature, soil compaction is one of the main factors that influences soil physical, microbial and biochemical properties and processes (Barzegar et al., 2006; Rosolem et al., 2002). Soil compaction increases soil bulk density, soil mechanical resistance, and surface runoff; it also reduces soil porosity and modifies the pore size distribution in the soil profile (Kulli et al., 2003; Zhang et al., 2006). The increase in soil compaction strongly influences plant productivity and crop growth rate by reducing root growth and penetration into the soil, thus reducing water and air availability as well as ion transfer to roots and nutrients uptake (Barzegar et al., 2000; Chen et al., 2014; Głąb, 2014; Kuncoro et al., 2014; Miransari et al., 2009).

If porosity reduction by compaction is a common problem encountered in ploughed soils (Kuncoro et al., 2014; Lipiec et al., 2012), soil amendment with mineral fertilizers has represented the

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main practice to improve the agriculture productivity. Thus, leaf surface area, leaf mass ratio and leaf area ratio of an Oleaceae species (*Fraxinus angustifolia* Vahl.) cultivated in a loamy soil were increased in a compacted soil as a result of increased amount of nutrients per volume unit (Alameda and Villar 2009, 2012; Arvidsson, 1999). Unfortunately, intensive phosphate fertilization has led to the accumulation of trace metals such as zinc, cadmium, and lead in cultivated soils (Jiao et al., 2012; Lavado et al., 2001; Azzi et al., 2016). Metallic contaminants are transferred to cropland and subsequently along the food chain, which represents a critical environmental issue (Giuffré et al., 1997; Jiao et al., 2012; Nicholson et al., 2003; Luo et al., 2009). Soil compaction has been shown to inhibit nutrients transfer to plants; it thus limits the availability and the uptake of major nutrients (N, P, K, Ca, Mg and S) and micronutrients (Mn, Fe, Zn and Cu) (Barzegar et al., 2006; Lipiec and Stępniewski, 1995; Miransari et al., 2009; Zhao et al., 2007). Obviously, soil compaction also affects trace metals bioavailability (Basta et al., 2001; Qiu et al., 2011). In the case of *Trifolium alexandrimum*, soil compaction reduced both P and Zn uptake (Barzegar et al., 2006). In addition, high levels of phosphorus in soil may also slow down the uptake of trace contaminants by plants, as illustrated by *Pteris vittata* in presence of arsenic (Bolan et al., 2003a; Huang et al., 2007; Qiu et al., 2011; Yu and Zhou, 2009).

Cadmium has been identified as the most common toxic element that readily reaches the food chain because of its great bioavailability. It accumulates in large amounts in plant tissues without showing any noticeable toxic signs (Grant and Bailey, 1997; Renella et al., 2004). Previous studies of phosphate interaction with cadmium in cultivated soils evidenced antagonistic results. Pot cultivation with various crops revealed that cadmium uptake by plants was inhibited in presence of phosphate (He and Singh, 1994; Naidu et al., 1994; Yu and Zhou, 2009). Unexpectedly, soil Cd phytoextractability and Cd uptake by *Raphanus sativa L.* were found to be increased with superphosphate use in the field (Hong et al., 2008). Cadmium bioavailability depends on soil pH, organic matter content, clays and iron oxide/hydroxide contents (François et al., 2009; Grant et al., 2010; Williams and David, 1976). However, little attention has been given to the influence of soil compaction and phosphate fertilization on the cadmium behavior in soil and its influence on plant growth.

The main goal of this study is to investigate the effects of soil compaction on *Lactuca sativa* growth in presence of phosphate fertilizer and cadmium. *Lactuca sativa* is the main leafy vegetable in Mediterranean cooking and is intensively cultivated in Eastern Mediterranean countries. In the Beqaa valley, around 1500 ha are annually cultivated with *Lactuca sativa* (Karam et al., 2002). The accumulation and translocation of Cd in plants and its distribution in compacted and non-compacted soil columns were simultaneously investigated to provide evidences of physiological and morphological modifications in the plants.

2. Experimental section

2.1. Soil sampling

A typical Mediterranean terra rosa soil was selected for this study. Soil samples were collected in the Ammik plain, a semi-arid region located in the western Beqaa valley in Lebanon (Lat. 33° 44′ 17.2″ N, Long. 35° 46′ 49.8″ E). No anthropogenic activity (agriculture and industry) has been reported for this sampling site. An approximate mass of 750 kg of soil was collected over an area of 50 m^2 and at a depth between 0 and 50 cm. It was then air-dried at ambient room temperature, crushed and sieved through a 7 mm mesh sieve to remove coarse fragments, and finally homogenized.

The main physical and chemical properties of the soil were determined following standard methods listed in Table 1. To determine the trace metals content, soil samples were mineralized and digested using an aqua regia digestion (HNO_3: $HCl_{v/v}$ 1:3). The concentrations of Cd, Zn, Cu, Pb, Ca, Al and Fe in the digested soil solutions were determined by Atomic Absorption Spectrometry (AAS) using a Rayleigh WXF-210 AA Spectrophotometer and WF-10A Autosampler. All reagents were of analytical grade and each value reported is the average of triplicate determinations.

2.2. Experiment design

Two soil bulk densities, 1.2 and 1.4 g cm^{-3}, were selected to assess the effects of soil compaction on *Lactuca sativa* growth in the presence of phosphate fertilizer and cadmium contaminant. A $2 \times 2 \times 2$ factorial randomized block experimental design was used with three replicate columns per treatment. Eight treatments were prepared by combining two soil bulk densities, two rates of P_2O_5 amendment and two Cd concentrations. The 1.2 g cm^{-3} bulk density is representative of the density of a clay soil. The 1.4 g cm^{-3} bulk density is selected to evaluate the effect of an increased compaction on plant growth since a 1.39 g cm^{-3} density affects root growth according the USDA (2001). A single superphosphate (18% P_2O_5), graciously provided by the 'Lebanon Chemicals Company-LCC,' was used as fertilizer. It was added to provide two phosphorus levels (0 and 109 mg P kg^{-1} of soil). Cadmium was added to the soil

Table 1
Physical and chemical parameters of the sampled soil.

Soil parameters	Standard methods		Amount
Soil texture (%)	Bouyoucous hydrometer method (Thien and Graveel, 2003)	Sand	26.9
		Silt	20.1
		Clay	53
Total calcareous (%)	EN ISO 10693 (2014)		1.39 ± 0.17
Cation exchange capacity (meq 100 g^{-1} soil)	NF-X 31-108 (2002)		19.23 ± 1.16
Conductivity (μS cm^{-1})	X 31-113 (NF ISO 11265, 1995)		1157 ± 23
pH	X 31-117 (NF ISO 10390, 2005)		8.21 ± 0.01
Organic matter (%)	ASTM D 2974 (2007)		2.08 ± 0.02
Trace metals concentrations (mg kg^{-1})	ISO 11466: 1995	Cd	1.52 ± 0.05
		Ca	818 ± 33
		Zn	98.6 ± 8.9
		Fe	33230 ± 925
		Al	37100 ± 1178
		Cu	26.1 ± 0.6
		Pb	27.05 ± 0.51