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Factors affecting cadmium absorbed by pistachio kernel in calcareous soils, southeast of Iran

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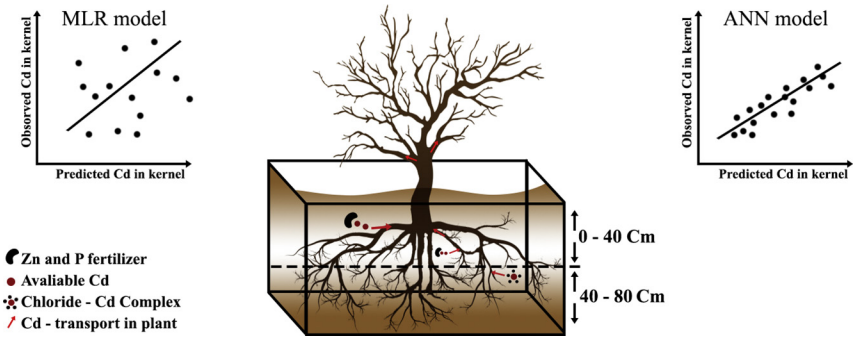
HIGHLIGHTS

- Soil available P, Zn and soil salinity were the most important factors affecting cadmium absorption in pistachio kernel.
- Modeling of Cd absorption by pistachio kernel using ANN model was more accurate compared to stepwise regression model.
- Cd-DTPA is not probably an appropriate indicator for determining plant available Cd in Saline-calcareous soils.
- Soil salinity in studied regions can increase the solubility and absorption of cadmium.

GRAPHICAL ABSTRACT



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ABSTRACT

Cadmium (Cd) which does not have a biological role is one of the most toxic heavy metals for organisms. This metal enters environment through industrial processes and fertilizers. The main objective of this study was to determine the relationships between absorbed Cd by pistachio kernel and some of soil physical and chemical characteristics using modeling by stepwise regression and Artificial Neural Network (ANN), in calcareous soils in Rafsanjan region, southeast of Iran. For these purposes, 220 pistachio orchards were selected, and soil samples were taken from two depths of 0–40 and 40–80 cm. Besides, fruit and leaf samples from branches with and without fruit were taken in each sampling point. The results showed that affecting factors on absorbed Cd by pistachio kernel which were obtained by regression method (pH and clay percent) were not interpretable, and considering unsuitable vales of determinant coefficient (R^2) and Root Mean Squares Error (RMSE), the model did not have sufficient validity. However, ANN modeling was highly accurate and reliable. Based on its results, soil available P and Zn and soil salinity were the most important factors affecting the concentration of Cd in pistachio kernel in pistachio growing areas of Rafsanjan.

1. Introduction

Heavy metal is a metal whose bulk density is >5.5 g cm^{-3}. Heavy metals are stable, non-degradable and toxic in high concentration (Kim et al., 2009). Among heavy metals, cadmium (Cd) has special importance due to long half-life in human and animal body and high toxicity. So this element has a role in liver, lung, bone, blood circulation,

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heart, kidney and brain failure, and also has a negative influence on people's mind (Gupta and Bhattacharyya, 2008). Furthermore, as soil pH increases, Cd solubility and availability for plant decreases (McBRIDE et al., 1997; McBride, 2002). The pH of calcareous soils is frequently 8 to 8.5 for the presence of abundant lime, so it is expected to have low available Cd. On the other hand, with an increase in soil salinity (soil solution ionic strength), soil pH tends towards the neutral pH and becomes <8. Moreover, chloride in saline soils together with Cd makes complex ion which increases solubility and consequently increases plant Cd availability (McLaughlin et al., 1997; Smolders et al., 1997; Weggler et al., 2004a). Increasing trend of heavy metal concentrations in environment has created serious environmental concerns. Heavy metals in soil and other components of environment may be originated from natural or anthropogenic sources. Actually, some of human activities such as release of waste in environment, usage of chemical fertilizers, pesticides and sewage sludge in agricultural lands, and also different industrial developments via atmospheric subsidence increase heavy metals concentration in soil (Yeganeh et al., 2010; Zheng et al., 2007). So, agricultural, industrial and urbanization activities have increased heavy metals accumulation possibility in crops and their entrance to human food chain (Jauslin et al., 2004). Toxic elements accumulation not only restrict plants growth but also affect their quality and food security. Furthermore, entrance of small amounts of these elements to human body can have harmful effects on health in long time (Kirchner et al., 2006).

Universal average of total Cd concentration in soil has been reported 0.06–1.1 mg kg^{-1} (Kabata-Pendias and Pendias, 2001). This concentration for soils of central Iran is 1.6 mg kg^{-1} (Amini et al., 2005), while the threshold value of total Cd in soil is 1–5 mg kg^{-1} (Cairney, 1995). The entrance of rare elements to agricultural lands is made possible via some important sources such as chemical fertilizers, manure, sewage sludge, industrial waste and pesticides. Some of heavy metals exist as impurity in different amounts in chemical fertilizers such as phosphate ones. Cd concentration range in macro, micro and phosphate fertilizers is 1.78–15.56, 1.11–170 (Afyuni et al., 2007) and 20–60 mg kg^{-1} P_2O_5 in different countries (Roberts, 2014), respectively.

Artificial Neural Network (ANN) is a simulation method which is modeled based on brain system and neural network of organisms and has a high capability for simulation and detection of complex and non-linear relationships. There is an input vector in ANN structure which includes the independent variables. And this structure also has one or some hidden layers each of which is composed of some processing elements called neurons. Input or independent variable, p, (like EC) is multiplied by w coefficient and wp quantity is produced before it enters the master core of the processing element or the neuron in the hidden layer. Another parameter of the neuron is the bias constant quantity, b, (generally considered 1) and is added to wp. All the neurons have a function called transfer function including sigmoid, linear, etc. The weighted input is entered into the function and produces the neuron output. The final network output, a, is produced after passing through the neuron output layer (Fig. 1). Actually, input vector is applied to neurons of hidden layers and then after reaching the output layer, output response is produced. Consequently, final output of the network (a) is produced after passing the output layer neuron. Final output is compared to its corresponding observed or actual quantity and their difference determines error. Then, the network changes its parameters based on an optimization algorithm so that in the next replication error quantity reduces (Dongare et al., 2012). Fig. 1 shows the structure of a neuron in ANN. The network may be composed of several layers and several neurons in each layer which has the capability of simulating very complex and non-linear relationships.

To the best of our knowledge, so far no study has been undertaken concerning the use of the ANN method to model the relationships between soil metals and pistachio plant uptake. There are also few studies undertaken in this respect regarding other plants. Of these rare studies we can name the study conducted by Hattab and Hambli (2014) on

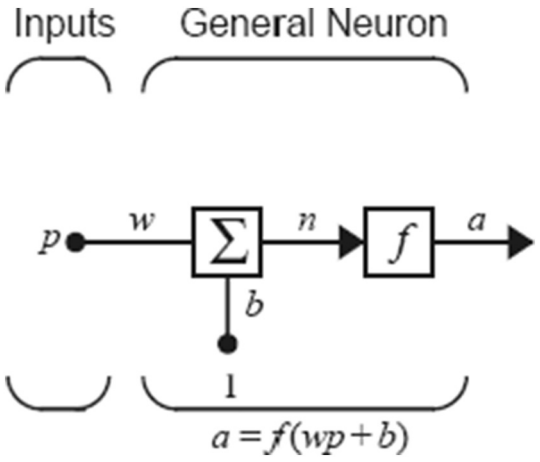

Fig. 1. Structure of a neuron in ANN (p = input vectors or input variables, w = weight, b = bias, n = wp + b, f = transfer function, a = final output).

prediction of copper and chromium concentrations in bean leaves based on an artificial neural network model.

Pistachio (*Pistacia vera* L.) is a sub-tropical plant belonging to the Anacardiaceae family (Hojat and Ghorbani, 2016). The world production of pistachio in 2014 achieved >638,000 tons (in shell basis), which has been grown 37% as compared to 2013, and 50% >2004. The top three pistachio producers are Iran, the USA, and Turkey with annual production of 230,000, 197,699 and 130,000 tons, respectively in 2014 (INC, 2015; Taghizadeh-Alisaraei et al., 2017). In Iran, pistachio is one of the most important horticultural products (Hojat and Ghorbani, 2016), and Rafsanjan region (southeast Iran) with >110 thousand hectares pistachio orchards is the main production center (Mirzaei Khalilabadi et al., 2014). Although high concentration of Cd has not yet been reported in soil and plant in pistachio growing areas of Rafsanjan, nowadays considering the increasing use of chemical fertilizers in pistachio orchards, there is the possibility of an increasing in Cd concentration in the soil and plant in this region. Also, pistachio orchards soils in Rafsanjan region are calcareous and are mostly saline whose anion is chloride (Hosseinifard et al., 2005). Thus, identifying the affecting factors on Cd absorption by plant, especially kernel which is widely consumed by human, is necessary to control Cd concentration increase in pistachio trees. To the best of our knowledge, no researches have yet been carried out in relation to the status of heavy metals such as Cd in pistachio orchards and affecting factors on this element absorption by plant and accumulation in pistachio trees. Therefore, the objectives of the current study were as follows. 1) Investigating this hypothesis that Cd absorption by pistachio trees can occur in calcareous and saline soils, 2) Determining the effective factors on Cd absorption by pistachio kernel, 3) Investigating this hypothesis that ANN models can be effectively used in modeling and identifying soil characteristics effective in Cd absorption by pistachio kernel and 4) Offering suggestions to reduce Cd absorption by pistachio trees.

2. Materials and methods

2.1. Study area and sampling

The areas under investigation were parts of pistachio orchards in Rafsanjan region, southeast of Iran. It is located between 30° 15′ 22″ and 31° 05′ 20″ N, and 55° 11′ 25″ and 56° 26′ 21″ E. The mean annual precipitation and temperature in the region are 81.2 mm and 11.7 °C, respectively. The mean altitude in the area is 1300 m a.s.l. Alluvial plain was the dominant landscape of the study area. Irrigated pistachio cultivation with the age of 20–40 years is the major land use in this area. Fig. 2 shows the location of the study area and sampling points. 220 pistachio orchards were considered randomly as the study points (Fig. 2). Soil samples at all the sampling sites were collected from depths

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