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Ailanthus Altissima (Mill.) Swingle, Bioacumulated Specie of Contaminated Soils

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Keywords: ailanthus altissima, soil contamination, heavy metals, bioconcentration, phytoremediation, fertility.

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Abstract- Ailanthus altissima (Mill.) Swingle) is one of the most widespread invasive alien species on a global scale. Its current distribution is clearly linked to anthropized environments, where concentrations of heavy metals or trace elements in their soils can reach levels of toxicity to other plant organisms. The present research carried out in environments of the Community of Madrid (Spain) focuses on the relationship between the presence in soil components such as arsenic (As), copper (Cu), chromium (Cr), boron (B), vanadium (V), cobalt (Co), etc., harmful to some plant organisms, and the existence of *Ailanthus altissima.* The results obtained identify that the species modifies the content of some minority elements, a fact that must be taken into account for future soil fertility studies. Secondly, ailanto is capable of absorbing toxic elements present in the soil environment, which shows its value as a phytoremediator of contaminated soils.

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I. Introduction

The last centuries are characterized by the increase in the quantity, typology and dangerousness of the waste that ends up being incorporated into the soil. The soil transformation of certain chemical compounds causes, on numerous occasions, its disturbance. This translates into a loss of quality and suitability for certain uses, unless the soil is subjected to phytoremediation treatments (Porta-Casanellas *et al.* 1999).

Among the chemical contaminants of the soil component, heavy metals such as copper (Cu), chromium (Cr), vanadium (V), cobalt (Co), among others, stand out. Although these elements are natural components, in high concentrations, they are potentially harmful to the natural environment. Without forgetting that the incorporation of contaminants into the soil implies an increase in the concentrations of trace elements that can be toxic and cause irreversible damage to plant organisms (Kumar, 2013; Kleckerova and Dočekalová, 2014).

In this context *Ailanthus altissima* (Mill.) Swingle could be used as an indicator species and bioaccumulator of harmful elements in disturbed environments. Hu *et al.* (2014) determines that in the city of Yan'an (Loess Plateau, China) ailanthus acts as a signifier bioaccumulating species of lead, copper and cadmium. In addition, it also has the capacity to store, in its aerial part, chromium and zinc.

Lin *et al.* (2017) establishes that, in different of Beijing, *A. altissima absorbs* a large number of toxic elements (highlighting metals) in its leaf surface.

In the same sense, recent research shows that the existence or degree of concentration of certain chemical substances in the soil is related to the proliferation of *Ailanthus altissima* (Corral, 2022).

These investigations identify the importance that the use of *Ailanthus altissima* as a remedying species of contaminated soils may have.

Considering the capacity of *Ailanthus altissima* to bioaccumulate toxic elements in its leaves, which will then be returned to the soil after the loss of the leaf surface, the present research has as a preliminary hypothesis the study of the soil composition modification in which this species develops. Previous research (Corral, 2021; Corral, 2022; Corral *et al.*, 2022) seem to indicate the importance of the existence of a significant number of specimens of *Ailanthus altissima* to be able to originate this modification.

Therefore, the objective of this article is to study the possible differences between soils with the presence and absence of *Ailanthus altissima* and to study the possible modifications into the soil due to the presence of this plant species.

II. *Ailanthus Altissima* as Bioaccumulating Species

Plant organisms play a major role as bioaccumulators of chemicals, transferring harmful elements from the abiotic environment to their plant tissues (Alcoba *et al.* 2014; Martínez-López *et al.* 2014). It is important to define the concept of bioaccumulator species as that organism that stores heavy metals or other environmental pollutants in its tissues. These pollutants are absorbed from the environment when species perform their biological functions.

Plant organisms present two adaptive strategies against soil contamination:

- On the one hand, exclusion strategies, which prevent the assimilation of the element, restrict its transport to the plant itself, produce exudates by the

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roots and/or reduce the concentration of the element taking advantage of the leaf fall.

- On the other hand, accumulation strategies that allow the plant to store toxic elements in different plant tissues (Baker & Walter, 1990; Verkleij & Schat, 1990). Positive relationships have been identified between the deposition of heavy metals in the soil and concentrations of the same in plants (Ugulu *et al*. 2012). Different plant species are able to absorb and accumulate significant amounts of potentially toxic substances (Piczak *et al*. 2003).

Thus, trees and shrubs play a significant role in removing heavy metals and other soil contaminants (McDonald *et al.* 2007, Dzierżanowski *et al.* 2011,). As well, different plant organisms are often used to measure environmental quality and possible environmental impacts (Piczak *et al.* 2003, Nowak *et al.* 2006).

In relation to the increase in chemical contaminants in soils, three types of plants have been differentiated:

- *Accumulative Plants:* those where the element (metal) is concentrated in the stem and leaves. Within this group, those that have the ability to grow in environments with high concentrations of toxic elements and, in addition, accumulate a large concentration of them in their tissues stand out. These plants are called hyperaccumulators.
- *Indicator Plants:* those where the absorption and transport of the chemical element are regulated in the way in which the concentrations in the plant are reflected in the aerial part of it (leaves, buds or fruits).
- *Exclusionary Plants:* in which the concentration of the element in the stem and leaves is constant, it happens as long as the concentration of the metal in the soil does not exceed the tolerance limits by the plant.

In this context, knowledge and use of plant species tolerant to anthropogenic environments are essential for the design of remedial measures to reduce soil pollution (Dzierżanowski *et al.* 2011).

Ailanthus altissima (Mill.) Swingle is one of the most widespread invasive alien species on a global scale. Its natural range is the geographical regions of Eastern China and Northern Vietnam. From these nuclei of origin, it has been progressively colonizing various spaces (natural and anthropized) of the rest of the continents (Köwarik & Säumel 2007).

In the regions of origin, *Ailanthus altissima* is considered as a colonizing species of habitats or spaces altered by anthropic actions, where ruderal vegetation or species associated with stages of substitution of natural formations prevail. In addition, it has been introduced ornamentally in green spaces of cities (Hu, 1979; Liu *et al.* 2015; Huang *et al.* 2015; Knüsel *et al.* 2019).

In relation to its area of distribution, Ailanthus altissima has colonized numerous and diverse territories between 35º and 60º latitude in the Northern Hemisphere and between 30º and 60º latitude in the South (Meusel & Jäger, 1992; Köwarik & Säumel, 2007; Gassó *et al.* 2012).

Its high adapting plasticity allows its growth in both anthropized and natural places. However, its secondary area of distribution is subject to spaces with some degree of disturbance; either anthropic (pollution, deterioration of urban and rural space, constructions, etc.), or natural disturbances that lead to the loss of tree cover (fires, thinning, phytosanitary diseases, among others) (Köwarik & Säumel, 2007).

In Europe, ailanto presents a wide dispersion in green areas, margins of communication routes, playhground or private gardens of the urban centers. This distribution is highly correlated with its introduction for ornamental purposes (Köwarik & Böcker, 1984; Kowarik & Säumel, 2007; Petrović *et al.* 2011; Maslo, 2016; Corral, 2021)

In the Community of Madrid (Spain) broadly speaking, the expansion of ailanto is radial and linear, following a distribution correlated with the main communication routes (Enríquez, 2020). Corral's research (2021) analyzes in different regions of the Community of Madrid the dispersion of *Ailanthus altissima*, corroborating the potential distribution in communication routes, but expanding to a detailed scale new colonized habitats highlighting significantly deteriorated environments such as dumps, landfills, abandoned plots or slopes, among others.

Table 1: Research determining A. altissima as a bioaccumulator and bioaccumulated compounds

Author/s and year	Element bioaccumulated by *Ailanthus altissima*
Porter (1968)	Fe, Cu, Zn, Ti, K, Cl
Hu *et al.* (2014)	Pb, Cu, Cr, Zn,
Filippou et al,. (2014)	SnO
Ranieri & Gikas (2014).	Cr
Lin *et al.* (2017)	suspended particles (PM1, PM2,5, PM10)
Ashraf *et al.* (2017)	Cr
Abbaslou & Bakhtiari (2017)	Cu, Mn, Fe, Zn, Cd, Pb
Nabi *et al.* (2019)	NO, SnO
Roy *et al.* (2020)	Cd, Cr, Cu, Mn, Ni, Pb, Zn
Corral (2022)	Ni, Cu, MgO, Sr, B, CaO, Sn

In addition to the ability to bioaccumulate these substances, *Ailanthus altissima* returns to the soil the toxic components it absorbs, serving as a favorable strategy for their proliferation.

With all the above, it is evident that the existence or degree of concentration of certain chemical

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compounds in soils is closely related to the proliferation of *Ailanthus altissima*.

III. Methodology

This research was carried out in different habitats of the Community of Madrid (Spain). The variability of physical-environmental components of the region forced to define an area large enough and with differentiated features that would allow reaching the objectives set. Regions with different physiography, lithology, soil science, altitude, thermo-rainfall regime and uses and uses of the territory were selected.

The successive field campaigns were carried out between March to October of the years 2019 and 2020. These months were chosen for the optimal state of foliar growth and flowering of the species; ending just before the onset of autumn and leaf loss (Sæbø *et al.* 2012). Samples were taken in four different environments with the presence of *A. altissima* (dump, natural space, communication route and urban green area).

a) Sampling and Laboratory Analysis

250.0 g of soil were collected with an auger at a depth between 0.5 cm to 0.5 m. Subsequently, the sample was dried at room temperature for 7 days (drying at room temperature has been used because the increase in drying speed limits changes due to microbial activity). Once the sample was dry, 2.0 g of soil was separated for the calcination of organic matter in laboratory muffle at 300ºC for 12 hours (this temperature and scale time have been used to avoid the destruction of clay minerals in the soil).

The sample (previously treated in the oven) was then ground in agate mortar to a fine size (<20μm). After soil treatment, values for pH, electrical conductivity (EC), organic matter, texture and mineralogical composition were obtained.

For the study of the content of the chemical elements, an elementary semi-quantitative analysis of the samples was carried out, which encompasses the vast majority of the periodic table, except of noble gases and other elements such as carbon (C), hydrogen (H) and several halides. The chemical determination was by Mass Spectroscopy with Inductively Coupled Plasma (ICP-MS) with argon flame. The spectrometer used has been ICP-MS Elan 6000 Perkin Elmer Sciex with AS91 autosampler.

To perform the calibration curve, the values 0.1, 1 and 10 mg/l are taken, except for the Na, Mg and Ca in which values 0.1, 1, 10 and 100 will be used. The measurement of Na and K has been made by emission flame photometry, with Perkin Elmer 2280 equipment.

b) Statistical Analysis

With the chemical data of the soil, a statistical studywas done with the statistical program SPSS version 27. A discriminant study has been carried out with the content of minority elements.

The initial hypothesis of the research is that invasive species such as this plant can change soil fertility and nutrient cycles (Gutiérrez López, *et al.* 2014, Medina-Villar *et al.* 2015, 2016), so this statistical study can provide very valuable information about the influence of the plant on the soils analyzed.

Complementary to this analysis, the coefficients of bioaccumulation or bioconcentration factor (FBC = concentration of metal in the root/concentration of metal in the soil) have been calculated. The coefficient determines the transfer of metal from the soil to the plant. A value, >1, means that there are mechanisms that concentrate the element in the leaves. On the other hand, the transfer factor FT= (metal concentration in the leaf/metal concentration in the root) was calculated to indicate the type of response (accumulation, indicator, exclusion) of the plant to the metal (Abreu *et al.* 2012).

The coefficient establishes that, if the ratio <1, there is a restriction of metal transport between root and leaf. If it is >1, the metal is transferred to the aerial part of the plant organism.

IV. Results

The analysis has established that the presence of minority elements in the soil samples is related to the number of specimens of *Ailanthus altissima*. In this way, the samples are grouped in the statistical study according to the number of existing specimens. So, the existence of this plant species can alter the content of minority elements of the soil.

Figure 1 shows the result of the statistical study of discriminant with the minor concentration of the minority elements and in which the samples have been grouped, initially, according to the number of plants that appeared at each sampling point in an area of 1m^2.

The following initial groups were made for this study: soils without plant, soils with 1 to 50 individuals, soils with 51-150 individuals and soils with more than 150 individuals (see figure 1).

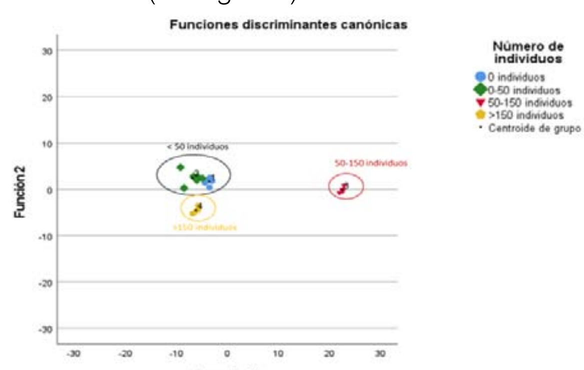

Fig. 1: Statistical analysis of the discriminant according to the number of individuals and their content in minority elements

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A grouping of the samples in the following subgroups has been obtained according to their content in the following minority elements:

- *Samples from 0 to 50 individuals* present similar contents of Be, Cr, Cu, Cr and S.
- *Samples from 51 to 150 individuals* present similar contents of As, B, Co and V.
- *Samples from > 150 individuals* present similar contents of Be, Cr, Cu, V, As and B.

In view of these results, a second statistical study of the discriminant was carried out, in order to study in more detail the samples that presented up to 50 individuals in an area of 1m2 (Figure 2).

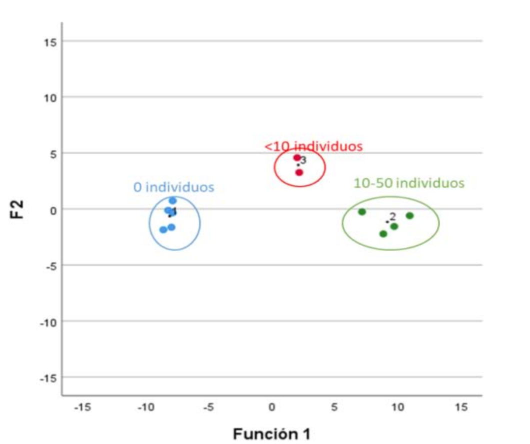

Fig. 2: Result of the statistical analysis of the discriminant of soils with less than 50 individuals based on their content in minority elements.

The samples are grouped into the following subgroups.

- *Soil samples without plants:* Similar contents of Cr, B and Li.
- *Soil samples with less than 10 individuals:* Similar contents of Be, V, P and S.
- *Soil samples with 10 to 50 individuals:* Similar contents of Cr, B, Li, Be, P and V.

According to the bioaccumulation capacity of *Ailanthus altissima*, B, Cu, Sn and Sr are the elements that can be considered bioaccumulated by the leaves of *A. altissima* since its bioconcentration factor (FBC) is higher than the unit (FBC ≥1). In addition to the aforementioned elements, other compounds such as Cu and Ni can be considered to have a certain cumulative character, since their bioconcentration factor is ≥0.5 (Table 2).

Table 2: Bioconcentration factor values (FBC).

Element	Average concentration in leaves (ppm)	Average concentration in soil (ppm)	FBC
Sn	41	8	5,06
B	174	148	1,18
Sr	108	92	1,17
Cu	22	24	0,92
Ni	6	12	0,51
Mn	102	213	0,48
Zn	31	70	0,45
Cr	4	11	0,34
Ce	4	16	0,25
Sc	1	3	0,25
Zr	7	39	0,18
As	1	8	0,12
Ba	40	375	0,11
V	3	30	0,11
Ga	1	14	0,09
Rb	10	127	0,08
Li	3	51	0,07
Pb	2	39	0,06

They have differentiated:

- *Elements not accumulated in the leaves:* They have bioconcentration factor less than 0.5 (FBC ≤ 0.5). Among these elements are As, Ba, Ce, Cr, Ga, Li, Mn, Pb, Rb, Sc, Zn and Zr.
- *Possible bioaccumulated elements:* These are those that present a bioconcentration factor (FBC ≥ 0.5). Cu and Ni.
- *Bioaccumulated elements:* Those whose bioconcentration factor is equal to or greater than the unit (FBC ≥ 1), B and Sr.
- *Potentially accumulated elements:* Those elements whose concentration in the leaves is significantly higher than in soils. In research, the only element with this characteristic is the Sn (FBC >5).

V. Discusion

The processes of industrialization, urban development, change in land uses and other anthropic actions contribute to the increase in the concentration of chemical substances (heavy metals or trace elements) that can be harmful to plant organisms.

The toxicity of metals in plants depends on the tolerance of each species tolerance, the chemical element in question and/or the physicochemical characteristics of the soil. Thus, certain metals are considered essential for the growth and development of plant organisms, such as Cu and Zn that activate enzymatic reactions and participate in the Redox reactions of plants. Or the Cu that acts in the photosynthetic process (Mahmood & Islam, 2006; Chatterjee *et al.* 2006). Zn is essential for ribosomes. Co is an indispensable element for vitamin B12 (Nagajyoti *et al.* 2010).

In the soil of anthropized environments it is common to find non-essential elements that are considered toxic to plant organisms such as Hg, Ag, Pb, Ni. In addition, in anthropized spaces, trace elements such as Fe, Cu, Zn, Mn or Co, among others, usually occur in high concentrations, harmful to the development of most plant species (Nagajyoti *et al.* 2010). However, species such as *Ailanthus altissima* have the ability to develop in soils with toxic concentrations of these metal elements (Corral, 2022).

This species shows a clear and marked expansion in habitats significantly disturbed by anthropic actions. Thus, the species has been considered one of the most tolerant to air pollution, being highly resistant to SO2 and other compounds harmful to most plant organisms, being highly resistant to SO2 and other compounds harmful to most plant organisms. This tolerance is due, among other characters, to the high antioxidant capacity of its leaves. In addition, it has a great capacity for detoxification (Kovacs *et al.* 1982).

According to the results *Ailanthus altissima* has the ability to bioaccumulate in its plant tissues elements such as B, Cu, Sn and Sr (Table 2), which will be returned to the soil surface with the loss of the leaf surface.

The loss of the leaves implies that *Ailanthus altissima* has modified the content of minority elements of the soils studied. This change is related to the number of individuals existing in the same soil surface.

This fact is important when studying soil fertility, since there are changes in the phosphorus content of the soil. Before this study, changes in soil fertility have been observed due to the presence of *Ailanthus altissima* (Gutiérrez López *et al.* 2014, Medina-Villar *et al.* 2015, 2016), so this fact should be consider in future work, since there is very little research on the influence of the plant on soil fertility.

It has been observed that the samples are grouped according to the number of individuals and their content in some toxic elements and soil contaminants such as Cr, V, As, Co and Cu (Figures 1 and 2).

These results are of crucial importance, since such elements have been considered as toxic, according to the list of toxic substances made by the Agency for Toxic Substances and disease Registry (ATSDR) in 2019, where the Ace, ranks first.

There are studies about the ability of the plant to reduce the concentration of heavy metals in soils (phytoremediation). In these cases, *ailanthus* retain toxic elements of the soil, such as heavy metals, in its roots and leaves (Hu *et al.* 2014; Ranieri *et al.* 2016; Abbaslou and Bakhtiari, 2017; Ashraf *et al.* 2017; Lin *et al.* 2017; Popoviciu and Negreanu-Pîrjol, 2017) who demonstrated the effectiveness of ailanto as a phytoremediation plant to extract Cr, among other metals.

A recent study (Lebrun *et al.* 2020) has shown that *Ailanthus altissima* remove As and Pb from the soil, in such a way that the As is absorbed, mainly, in the roots due to its similarity with P, with very low amounts in the leaves, while Pb is restricted only to the root surface. More recently, the success of the plant in remedying a soil with Pb and Ni contamination has been demonstrated, this efficiency being clearer when the soils were treated with organic amendments and the plant (Mohebzadeh *et al.* 2021).

In a short period of time, *Ailanthus altissima* has the ability to retain these minority elements of the soils, an also, to changeits concentration in the soil. The statistical study has demonstrated its capacity as a phytoremediator. Thus, this should be considered in future works, taking into account that currently in the European Union it is estimated that there may be up to 2.8 million places where polluting activities are developed or have been developed (Payá Pérez & Rodríguez Eugenio, 2018).

VI. Conclusions

Ailanthus altissima presents a clear and marked expansion in habitats significantly disturbed by anthropic actions. Thus, the species has been considered one of the most tolerant to air and soil pollution. Being highly resistant to SO2, heavy metals and other compounds harmful to most plant organisms It has been shown that the existence or degree of concentration of certain chemical substances in soils is closely related to the proliferation of *Ailanthus altissima*.

According to our initial hypothesis and the specific objective of this research, the results of the statistical study conclude that *Ailanthus altissima* produces a change in the content of minor elements content, a fact that must be consider for future studies of soil fertility and heavy metal contamination.

Therefore, it is interesting to study those plant organisms that have high tolerance and ability to absorb harmful components of urban soils, in order to manage green areas. In addition, it is important to consider that those species are capable of surviving and growing without constant irrigation and they are sustainable and disturb natural spaces as little as possible and use species without risk of future Invasions.

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