Federal Republic of Iraq
Kurdistan Regional Government
Ministry of Higher Education and Scientific Research
Koya University

Effect of Magnetic Water on Growth and some Physiological Characteristics of *Paulownia tomentosa* Plants under Cadmium Stress conditions

A Thesis Submitted to the Faculty of Science and Health at Koya University as Partial Fulfillment for the Degree of Master's of Science In Biology

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(2011)

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August 2023

أَعُوذُ بِاللَّهِ مِنَ الشَّيْطَانِ الرَّجِيمِ

صَدَقَ اللَّهُ العَظِيمُ

سورة طه

الايـة 114

Dedication

Dedicated to:

- My parents for their endless love, support and encouragement
- My lovely husband who infinitely supports me with all my love.
- My daughters (Maily& Malin) who opened my heart to life.
- My dear friends, with best wishes to them.
- All my teachers who taught me even with a letter.
- All staff in the Department of Biology, Faculty of Science and Health, Koya University.

Ara

Supervisor's Approval

Hereby I (Prof. Dr. Ikbal Muhammed-Gharib Albarzinji) state that this thesis entitled (Effect of Magnetic Water on Growth and some Physiological Characteristics of *Paulownia tomentosa* Plants under Cadmium Stress) was prepared under my supervision at the department of Biology, the Faculty of Science and Health at Koya University by (Ara Abdullah Fattah) as partial fulfillment for the degree of Master of Science (MSc) in (Plant Physiology).

I have read and reviewed this work and I confirm that it is an original work to the best of my knowledge.

Name and signature of the supervising

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Viva Examining Committee Approval

We, (the examining committee) confirm that we have read this thesis entitled (Effect of Magnetic Water on Growth and Some Physiological Characteristics of *Paulownia tomentosa* Plants under Cadmium Stress conditions). We have examined the student (Ara Abdullah Fattah) in all aspects of this thesis. In our opinion, it meets the standards of a thesis for the degree of Master of Science in Biology.

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List of Abbreviations and Symbols

Symbol Abbreviation	Description
A.A	Ascorbic Acid
APX	Ascorbate Peroxidase
ASA	Ascorbate
ATP	Adenosine triphosphate
CA	Carbonic Anhydrase
CAT	Catalase
CCC	Certain Compensatory Criteria
Chl.	Chlorophyll
Cm	Centimeter
CNCC	Certain Non-Compensatory Criteria
CRD	Complete Randomized Design
Cu	Copper
DEA	Data Enveloped Analysis
DNA	Deoxy Ribonucleic Acid
EC	Electrical Conductivity
FW	Fresh Weight
G, g	Gauss
Ga	Gallium
GA_3	Gibberellic Acid
GPX	Glutathione Peroxidase
GR	Glutathione Reductase
GSH	Glutathione
H_2O_2	Hydrogen Peroxide
H_2SO_4	Sulfuric Acid
H_3PO_4	Phosphoric Acid
Hf	Hafnium
HM_S	Heavy Metals
M	Mole

M	Meter
MDA	Malondialdehyde
MFs	Magnetic Fields
MFTW	Magnetic Field Treated Water
Mg	Milligram
Mm	Millimeter
Mm	Millimole
mµ	Micro Mole
MTNS	Magnetically Treated Nutrient Solution
MW	Magnetic Water
NADPH	Nicotinamide Adenine Dinucleotide Phosphate
NO_2	Nitrogen Dioxide
O_2^-	Superoxide Anions
PEP	Phosphoenolpyruvate
Ph	Potential of Hydrogen
POD	Peroxidases
PSII	Photosystem Two
ROS	Reactive Oxygen Species
RuBP case	Ribulose-1,5-Biphosphate Carboxylase
SMF	Static Magnetic Field
SOD	Superoxide Dismutase
SWHC	Soil Water Holding Capacity
TBARS	Thiobarbiturice Acid Reactive Substances
TC	Total Carotenoids
TCHO	Total Carbohydrate Content
Ti	Titanium
UCC	Uncertain Compensatory Criteria
W	Tungsten
XRF	X-ray Fluorescence Spectrometry
Y	Yttrium

Acknowledgments

I would like to thank (Allah) for the blessing that enabled me to complete and conduct this study successfully, the lord of the universe, a blessing on the prophet Muhammad (peace and prayer upon him).

I would also want to thank Koya University and the Dean of the Faculty of Science and Health **Professor Dr. Zrar Salim Marzani,** and head of department of Biology **Dr. Hiwa Ramadhan Fatah** for their patient and scientific advices throughout this study.

My sincere and deepest gratitude to my supervisor Prof. **Dr. IKbal Muhammed-Gharib Albarzinji** for her supervision, help, valuable scientific suggestion, and continuous guidance throughout the research.

I also wish to express thanks to the staff members of the Science and Health Research center at Koya University especially **Mr. Hiwa Abdulrahman.**

I wish to express my appreciation to my family for their help and for providing all the facilities and encouragement to complete this study.

Finally, my thanks should go to all friends who helped me in most parts of thesis.

Summary

Paulownia (*Paulownia tomentosa*) is considered as one of the world's fastest-growing species of trees and most widely used for commercial. In koya city, Erbil, Iraq, this study was carried out as a factorial experiment (CRD), during 2021-2022 to examine the effects of magnetic water (MW) at (0 (not treated with magnetic field), 500,1000, 1500 and 2000) gauss and cadmium chloride (Cd) at (0, 3.33, 6.66 and 10 mg Cd. Kg^{-1}soil) on some growth, physiological and biochemical properties of this plant. The results demonstrate that MW had non-significant differ regarding the survived and the velocity of cutting outgrowth compare to using control, whereas Cd application increased the velocity of cuttings outgrowth. At least one of MW powers increased significantly each of plant leaf-area, stem diameter, shoot and root fresh weight and dry matter content, all Cd concentrations increased the plants leaves number, leaf-area, stem diameter. Cd had more effects on roots than plant shoots, where it has non-significant effects on shoot high or dry matter, whereas it increased each of shoot and root fresh weight significantly compared to the control treatment.

Low power MW (500 and 1000 gausses) performed better than high powers (1500 and 2000 gausses) in increasing the content of photosynthesis pigments. Utilizing magnetic water greatly enhanced total carotenoids and chlorophyll a, b, and regardless of device power. High Cd concentrations resulted in significant decreases of both chlorophylls a and b, however it was significantly increased by low concentrations as compared to other treatments. High power MW decreased significantly peroxidase enzyme activity and proline content whereas it decreased the percent of total carbohydrate compared to other treatments. Cd application decreased each of peroxidase enzyme activity and percent of total carbohydrate content and increased ascorbic acid and proline significantly in compared to the control.

At the same time, G1500 had increased significantly macro element of paulownia soil, while at tap water and G2000 increased essential micro element in soil, with application increased power of magnetic water significantly increased heavy metal in soil. While with application high power of magnetic water in G2000, increased significantly other element in soil such as (Ta, Hf, Re, Au and Sn).

Low concentration of Cd increased significantly essential macro element in soil like (N, P and S), but in macro element in soil increased at increased concentration of Cd (Cd6.66 and Cd10) mg Cd. Kg^{-1} soil treatments, whereas increased concentration of Cd at Cd10 mg Cd. Kg^{-1} soil treatments, increased heavy metal and other element in soil while Cd non-significantly effected in w element.

Regardless the device power, using MW increased macro element in root significantly, while G 1500 increased significantly (essential micro element, non-essential heavy metal and other elements) in root. Cd application does not affect in macro element in root. Also Cd application of Cd3.33 mg Cd. Kg^{-1} soil treatments, increased micro element and other element in root compared to the other elements, but using Cd10 mg Cd. Kg^{-1} soil treatments, caused significantly increasing of heavy metal in soil.

MW increased macro element content in stem significantly compared to tap water, whereas the power of magnetic water in G1500 increased the micro element and heavy metal in paulownia stem. With increasing Cd concentration, the majority of elements content in paulownia stem increased. While the magnetic water powers of G1000 and Cd3.33 mg Cd. Kg^{-1} soil increased the most elements content in the leaves.

Chapter One

1. Introduction

Paulownia (*Paulownia tomentosa* Thunb.) is a genus containing nine native Chinese species and a few natural hybrids in the genus (Paulowniaceae previously the family Scrophulariaceae) (Yadav *et al*., 2013). A hardwood tree known by a variety of names, including Kiri tree, Princess tree, Phoenix tree, Royal tree, Dragon tree, Empress tree, and Tree of Adam, is the paulownia. Currently, six species (*P. tomentosa, P. fargesii, P. glabrata, P. elongate, P. fortune, and P. taiwaniana*) are recognized (Sabir and Hamad, 2022). Paulownia is referred to as "magic" because of its rapid growth and the large amount of wood it produces in a short length of time (Icka *et al*., 2016). They are deciduous trees that are among the world's fastest-growing and most developed in terms of commercial wood output. They also serve additional afforestation goals such as establishing forests and farms and protecting smaller tree species from severe winds (Barbu *et al*., 2022).

Paulownia can be planted from seed, stem and root explants and cuttings. Compared to cuttings grown from stem and root explants, the development of seeds takes more time, has a slower rate of germination, is more sensitive to disease and pest problems, and has slow growth (Yaycili and Alikamanoglu, 2005). The best type of cuttings can be used successfully for reproduction depending on the species, genotype and season of collection. The results of Mahmood et al. (2017) study, found that *Paulownia tomentosa* basal cuttings gave a higher survival percentage compared to intermediate and apical cuttings which was 48.52%, while the lowest survival percentage 31.19% was found with apical cuttings. For increasing and enhancing paulownia plantations, many applications were applied such as; silviculture, fertilizer, nutrition, plant growth regulators, magnetic fields, and many other applications (Hamad *et al.*, 2020).

Magnetic water (MW) is that water flows through a magnetic device, where some of the water's chemical and physical characteristics are changed, such as viscosity, dielectric stability, the formation of clustering structures, polarization, conductive electricity, and salt dissolution, the formation of hydrogen bonds, conductivity, activation energy, surface tension, size of water molecules, evaporation, mobility of salts and dissolved gases. The structural regularity all of them are distinct from those of normal water (Chang and Weng, 2008). da Silva and Dobránszki (2014), demonstrated that irrigation with MW enhance both the quantitative and qualitative growth and development of plants. It can enhance seed germination and seedlings' early vegetative growth, length of the plant, fresh weight, and shoot development.

The impacts of MFs produce changes in cell membrane characteristics at the tissue, cellular, and subcellular levels as well as the mineral content of plants. They also result in increases in proliferation, gene expression, and protein production (Othman *et al*., 2019, Çelik *et al*., 2008). Positive impact of a magnetic field on the fresh weight, length, number of leaves, and chlorophyll content of *P. tomentosa* and *P. fortunei* node explants was observed by Yaycili and Alikamanoglu (2005).

When used in agriculture, magnetically treated water increases water solubility, leaches salts from the soil, and increases the activity of nutrients including nitrogen, phosphorus, and potassium (Abdulraheem and Jameel, 2021). It is believed that MWT increased both of the Moringa species' assimilation, transpiration rate, stomatal conductance, water use efficiency, and vapour pressure deficit (Hasan *et al.*, 2019).

The effects of heavy metal stress on plant development, yield, and productivity are negative. One of the most familiar heavy metals is cadmium (Cd), Cd is released into the environment by the use of phosphate-based fertilizers, urban composts, the irrigation of wastewater, and the metalworking industries. When plants are grown in soil that contains high Cd, their roots take up the heavy metal, which accumulates in various organs and eventually slows down plant development (Bruno *et al*., 2017). When *Paulownia tomentosa* is exposed to varying concentrations of Cd, Pb, and Zn, the total dry biomass, leaf area, stomatal conductance, and transpiration rate all decrease significantly, whereas the leaf area ratio, net photosynthetic rate, and water usage all increase significantly (Miladinova *et al*., 2014).

Through the production of superoxide anions (O_2), hydrogen peroxide (H_2O_2), malondialdehyde (MDA), and reactive oxygen species, the accumulation of Cd in plant tissues causes oxidative stress. Thus, exposure to Cd can affect the antioxidative defense mechanism, cause lipid peroxidation, affect the composition and fluidity of the cell membrane, degrade protein and nucleic acid structures, and affect the levels of endogenous phytohormones (Liu *et al*., 2022). Plants have different enzymatic and non-enzymatic antioxidant molecules such as ascorbate, glutathione, α-tocopherol, superoxide dismutase (SOD), peroxidase (POD) and catalase (CAT), proline, carotenoids which keep them against oxidative damage, these antioxidants play a significant function in the defense system created by plants to respond with heavy metal stress (Ahmad *et al*., 2017). For example, in maize (*Zea mays*) under Cd stress, magnetic water increased SOD and CAT activity, which decreased oxidative stress in this plant.

P. tomentosa tree exported to Iraqi Kurdistan Region last decay, several paulownia plantations are existing in Kurdistan Region-Iraq for wood production. However, very little studies were conducted in Iraq and Kurdistan region on *P. tomentosa* in general, and any about magnetic water's effects and Cd element. As a result, the focus of this work is on how *P. tomentosa* plants that grow in soil that has been contaminated with cadmium respond physiologically to magnetic water.

Chapter Two

2. Literature Review

2.1. Botanical Description of Paulownia Plants

Paulownia formerly belonged to the Paulowniaceae family, but recently it belongs to the Scrophulariaceae, that are deciduous trees. The Paulownia tree can achieve a height of 20 to 30 meters with age, and its diameter can reach 2 meters, which makes it an excellent source of timber. The mature tree's leaves may reach 15–30 centimeters in length and 10–12 centimeters in width, with weaving and smooth sides, the leaves are spiral (Yadav *et al*., 2013) and (Sabir and Hamad, 2022). The leaves have long petioles and are arranged oppositely; juvenile leaves may reach 80 cm in length and have a serrate margin, while mature leaves are smaller and have a smooth, wavy margin. The underside of the leaves is densely covered with fine filaments. The inflorescence is a pedunculate or subsessile cyme with two to five aromatic purple-white flowers that have a large, two-lipped corolla with two lobes on the upper lip and three lobes on the lower lip. Paulownia is entomophilous and, through cross-pollination, can produce numerous small, ellipsoid, membranous seeds with striate wings (El-Showk and El-Showk, 2003).

While flowers are pedicellate with 2–5 subsessile or stem-based flowers situated apically, they are pedicellate. The fruits have containers (2.5–4 2.5 cm) that contain numerous 1.5–3 mm-sized seeds. The number of seeds in the fruit can reach up to 2,000 (Yadav *et al*., 2013). Paulownia is a deciduous hardwood with lenticellate gray-brown bark. Paulownias have a deep, well-developed root system that creates multiple branches and typically extends to depths of 2 meters. There are documented instances of root systems that are nearly three times wider than the crown (Jakubowski, 2022).

2.2. Economical Values

Paulownia is one of the world's fastest-growing species, with minimal concentrations of ash, sulphur, and nitrogen in its wood and a high calorific value. It is regarded as a productive crop suitable for the production of solid biocarburants and bioethanol. The cultivation of Paulownia, which absorbs a large amount of carbon dioxide from the atmosphere in order to sustain rapid biomass growth, is regarded as an effective method for mitigating climate change. When the plant's cultivation is focused on the production of biomass, it is also considered appropriate for rehabilitating abandoned land. The species of the paulownia genus (Scrophulariaceae) are native

to China and East Asia (Icka *et al*., 2016). From the size of its foliage, a paulownia tree can absorb 22 kg of carbon dioxide and release 6 kg of oxygen per year. Depending on environmental conditions, Paulownia can reach a height of 30 meters (Dubova *et al*., 2019). However, because of their high nutritional value, their leaves have been utilized for nourishing ruminants, non-ruminants, and poultry. In addition, they are known for their medicinal and antibacterial qualities (Alagawany *et al*., 2022).

Paulownia tree leaves contain calcium (2.1%), zinc (0.9%), phosphorus (0.6%), and iron (0.6%) in high concentrations (El-Showk and El-Showk, 2003). In addition, it is known that Paulownia leaves contain 8.8% protein and 15.1% cellulose (Koleva *et al*., 2011). Additional macro- and microelements such as glutamic amino acids (16.04%), asparagine acid (11.30%), and essential amino acids are also abundant. Researchers enumerated Paulownia's uses as a short-rotation woody crop plant, afforestation, mine site reclamation, ornamental use, the bark has been used in Chinese herbal medicine as a component remedy for some infectious diseases, used to make furniture, musical instruments, and flooring, and the wood is soft, lightweight, and has excellent machining and finishing properties. *Paulownia tomentosa* exhibits cytotoxic activity against a number of human cancer cell lines and inhibits the effects of human cholinesterase, butyrylcholinesterase, and bacterial neuraminidases (Hussien, 2020).

Tomentosa has been used to treat or prevent numerous diseases, including hemorrhoids, carbuncles, inflammatory bronchitis, gonorrhea, upper respiratory tract infection, parotitis, asthma, traumatic bleeding, erysipelas, bacterial diarrhea, swelling, bronchopneumonia, enteritis, conjunctivitis, hypertension, and tonsillitis. The foliage, wood, and fruits of *P. tomentosa* have been used historically to treat tonsillitis, bronchitis, asthmatic attacks, and bacterial infections such as enteritis and dysentery. Paulownia may also have wound-healing properties, as frostbite and leg ulcers have been treated with its leaves. Leaves, fruits, and flowers are the most vital plant elements used in traditional herbal medicine. In China, mashed Paulownia flowers are used to treat acne vulgaris, while the decoction is used to treat fungal infections on the sole of the foot and between the toenails. Additionally, flowers are used to cure first- and second-degree empyrosis (He *et al*., 2016).

Under favorable conditions, their robust and swiftly growing root systems can also penetrate to greater depths and can be used, for instance, to stabilize landslides (Jakubowski, 2022). The objectives of Paulownia cultivation are site reclamation, the utilization of animal waste, rapid biomass production, and pulpwood for paper production (Langowski *et al.*, 2019).

2.3. Climatic Requirement

Paulownia is able to thrive between latitudes 40°N and 40°S and at altitudes up to 2,000 meters. Even though the tree can withstand temperatures between -20°C and +40°C, it grows best at temperatures between 24°C and 29°C. Young trees should be wrapped in grass during the winter (to protect the bark from frost damage) and painted during the summer (to prevent sunscald). Young Paulownia trees are very tall but may not yet have an extensive root system to provide anchorage; strong winds can cause stem fracture or crookedness, necessitating straightening, propping, and mounding (El-Showk and El-Showk, 2003) , as a result of its high carbon absorption rate and classification as a rapid-growing energy crop with C_4 photosynthesis, simple processing capability, and excellent fire resistance (Barbu *et al.*, 2022). These conditions, particularly light levels and have an effect on photosynthesis, which is beneficial to paulownia growth under favorable conditions but inhibits growth under unfavorable conditions. For optimal growth, this tree requires light intensities between 20,000 and 30,000 lux. Paulownias execute photosynthesis using C_4-cycle enzymes, as opposed to the C_3-cycle used by the majority of plants (Jakubowski, 2022).

The greater photosynthetic efficiency of paulownias under optimal conditions enables them to gain weight rapidly in a brief period of time. Despite the presence of C_4 mechanisms in paulownias, hybrid lines tend to manifest C_3 activity (Ivanova *et al.*, 2016). The activity of C_4 cycle enzymes is highly variable and frequently limited. Paulownias are significantly impacted by their growth and development conditions, particularly the stress brought on by drought or salinity (Wang *et al*., 2019). Through these mechanisms, paulownias can demonstrate exceptional adaptation to environmental duress. However, their rapid growth necessitates a substantial amount of water—1,000 to 2,000 L per seedling in the first growing season (García-Morote *et al*., 2014). Paulownias require permeable soil with a pH above 5 (5–8.9) in order to thrive. However, researchers have noted that mass production is highly dependent on soil quality (Tu *et al*., 2017).

2.4. Cultivation of Paulownia

Paulownias reproduce generatively and vegetative; however, under industrial conditions, reproduction is nearly exclusively vegetative. Root-splitting, which is also utilized by natural species, was the earliest method of reproduction in history. Root-splitting at an early developmental stage, also referred to as the mini-cuttings technique, or activating the rooting process in green cuttings have also been utilized (Jakubowski, 2022).

2.5. Water as a Source of Life

Water is one of the most vital natural resources for life continuation. In a variety of ecosystems, particularly in arid and semi-arid regions such as Iraq, potable water is a source of life. Rivers are the most significant supply of fresh water, which is the primary source of water for human consumption, agriculture, and industry. Due to the rapid growth of industries, agriculture, and urbanization over the past decade, pervasive water quality degradation in inland water systems has been documented (Al-Aboodi *et al.*, 2018). The soil's water content is crucial because it influences its moisture, the amount of nutrients available to plants, and the soil's aeration. Depending on the functions of the soil, soil water can be gravitational water, capillary water, or hygroscopic water (Gavrilescu, 2021). Water is the most prevalent molecule in all living tissue and the universal solvent. Growing plants consume and lose water continuously. In the transpiration stream, water is absorbed by the roots and evaporates through the stomatal apertures of the leaves. On a hot arid day, a leaf may exchange all of its water in one hour. Long-distance water transport occurs in the vascular tissues, xylem and phloem, where water is transported by bulk flow and membrane barriers are absent in the majority of cases. In contrast, short-distance and non-vascular tissue transport frequently involves transport across membranes (Johansson *et al*., 2000). A sufficient water supply is one of the most essential resources for plant growth and function. Due to the undeniable significance of water conditions for plant growth, considerable effort has been expended in an attempt to quantify the quantity of water a plant needs. Under normal conditions, the quantity of water within a plant is determined by the equilibrium between the rate of water absorption by the roots and the rate of transpiration by the leaves. If the water saturation, that is, the amount of water per unit volume of soil, falls below a level known as the 'permanent wilting point,' absorption ceases and the plant wilts (Roose and Fowler, 2004).

2.5.1. Water Structure

Water is necessary for maintaining a sufficient food supply and a productive environment for humans and all other animals, plants, and microorganisms on Earth. As human populations and economies expand, the global demand for freshwater has increased rapidly (Pimentel *et al*., 2004). The water molecule is composed of two types of atoms, oxygen and hydrogen, which are connected by hydrogen bonds (Al-Bayar *et al*., 2020), recently,

the commonly held belief that each molecule of liquid water is, on average, 4-fold coordinated by accepting and donating two H-bonds has been refuted (Paesani and Voth, 2009). Water molecules

interact closely with biological macromolecules (Figure 2.1), and hydration shell waters have substantially different properties than bulk waters. The effects of interactions with surfaces are typically limited to one or two hydration shells in the water (Raschke, 2006). Management and consumption of water resources are governed by a dynamic, complex system composed of subsystems that can be roughly classified as ecological, engineering, economic, and organizational (Wang *et al*., 2009a).

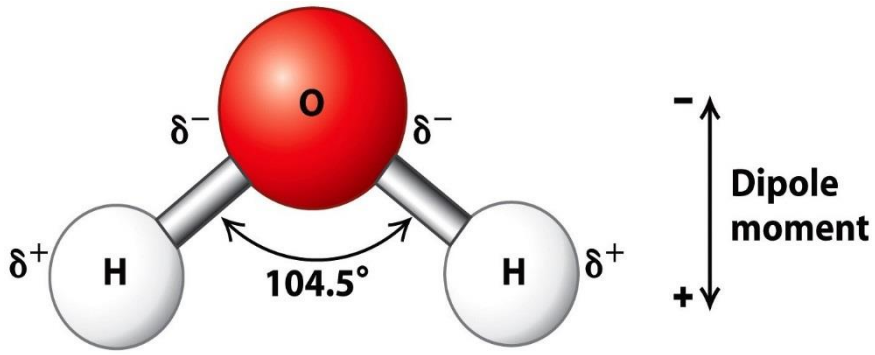

Figure 2.1.*The chemical Structure of Water Molecule* Board *et al.* (2023)

2.5.2. Physical and Chemical Properties of Water

Epoxy compounds that absorb water and various types of colorants are soluble in water. These solutions are absorbed by the composite material, leading to chemical decomposition and surface erosion (Hilal, 2022). Researchers agree that water is a highly structured liquid because of its extensive network of hydrogen bonds. However, there is no consensus on how the structure should be defined and how the extent of hydrogen bonding should be measured or calculated (Marcus, 2009). Two hydrogen atoms covalently bonded to an oxygen atom form the water molecule. A water molecule is polar, which means that one end is negatively charged (around oxygen atoms) and the other end is positively charged (around two hydrogen atoms). When water molecules are connected, the positively charged end of one molecule (hydrogen atom) is connected to the negatively charged end (oxygen atom) of another water molecule via a hydrogen bond (Filipović, 2020).

In addition to surface tension, cohesion and adhesion forces played a significant role in water transportation. Adhesion causes water molecules to adhere to another solid (such as a cell wall), whereas cohesion describes the attraction between two water molecules (Pevalek-Kozlina, 2003).

The results of natural processes include the weathering of bedrock minerals, leaching of organic matter and nutrients from soil, atmospheric processes of evapotranspiration and the deposition of dust and salt by wind, hydrological factors that lead to runoff, and biological processes within the aquatic environment that can result in a change in the physicochemical properties of water (Al-Ani *et al*., 2019).

2.5.3. Functions of Water in Plants

Water is a vital part of every plant's existence, enabling them to carry out fundamental metabolic processes such as nutrient acquisition (via photosynthesis), growth (cell division, mitosis), respiration (cellular respiration), and turgidity (up standing form). Water helps plants maintain their structure by transporting water, dissolved nutrients, amino acids, and other osmotically active substances from the soil to the plant's aboveground parts. Photosynthesis, the most essential process for plants, is aided by water (Filipović, 2020). Water reaches plant roots through soil, leaves through plant stems, then diffuses from leaf stomata to the static air layer, and finally participates in the turbulent transformation of the atmosphere to form a unified, dynamic, and continuous system with mutual feedback (Gao *et al.,* 2022).

In addition to being the substrate that must be conveyed by this water oxidation enzyme, water is obviously crucial for the operation of Photosystem II (PSII), Water is also essential for the transport of protons to and from the enzyme's catalytic center, as well as for the transport of other important cofactors and key residues (Linke and Ho, 2014). It is well established that stomatal mechanisms that modulate transpiration are the primary determinants of water relations at the shoot level (Rane *et al*., 2021).

2.6. Magnetic Waters

Magnetic field treated water (MFTW) or (MW) is water that has been passed through a magnetic field of a certain strength (Jain *et al*., 2017). Due to magnetization, the optical and infrared absorption properties of water are altered (Ramalingam *et al*., 2022). Exposure to a magnetic field can alter the biophysical, physicochemical, chemical, and physical properties of water (Alattar *et al.*, 2021). Throughout history, magnetically treated water has been referred to as marvelous water, magic water, environmental friend, etc., while others have referred to it as living water, which is defined as water that is more beneficial to living organisms than regular water. A different moniker, such as healing water or activated water, may be discovered due to the water's ability to repair

damaged cell membranes and in some cases DNA. It was also known as functional water due to its ability to stimulate the circulation properties within the body (Al-Bayar *et al*., 2020).

Three mechanisms of action of a MF on water, the first hypothesis assumes that the formation and decay of colloidal complexes of metal cations in MW accelerates their subsequent sedimentation, the second hypothesis is the polarization of dissolved ions in water and deformation of their hydration shells by the MF, and the third hypothesis states that the MF directly influences the structure of water due to the dipole polarization of water molecules (Esmaeilnezhad *et al*., 2017).

2.6.1. Physical and Chemical Properties of Magnetic Water

In fact, magnetized water undergoes some physical and chemical alterations due to the breaking of hydrogen bonds in clusters (Emamdadi *et al.,* 2020). Water can be magnetized by applying a magnetic field, according to research and practice. Magnetization of water induces favorable alterations in its micro and macro physical and chemical properties. Clearly, the activity of magnetized water (i.e., the water's capacity to interact with other substances, such as solubility, reaction rate, etc.) is enhanced, which is extremely important for enhancing water availability and crop stress resistance (Zhang *et al*., 2022).

Numerous experiments demonstrate that water can be magnetized by a magnetic field, although the effect is minor. When water is exposed to a magnetic field, the so-called magnetization of water refers to its changes in properties such as optics, electromagnetism, thermodynamics, and mechanics, such as the changes in the dielectric constant, viscosity, surface tension force, solidifying and boiling point, and electric conductivity, relative to those of pure water (Pang and Deng, 2008). Due to magnetization, water particles become charged and the number of molecules within a cluster of water drops from 13 to 5 or 6, thereby decreasing the water's hardness (Ramalingam *et al*., 2022). The effects of magnetic treatment on irrigation water are an increase in crystallization centers and a change in the amount of free gas. Both effects enhance irrigation water quality. Flow rate through the apparatus and certain chemical parameters of water, namely a carbonate water hardness of more than 50 mg/L and a concentration of hydrogenous ions in water with a pH>7.2, are crucial for effective magnetic treatment. The conductivity and pH of magnetic water are 71.4% and 7.14 % higher than those of conventional water, while the density and surface tension are 4.4% and 4.6% lower (Alwediyani *et al*., 2015).

Water is diamagnetic and composed of microscopic particles known as molecules. Each drop of water is composed of millions of molecules, and each molecule is made up of even smaller particles known as atoms. Every water molecule is composed of three atoms held together by a covalent bond; two hydrogen atoms are connected to one oxygen atom at a 105-degree angle, as depicted in Figure 2.2.

The final configuration of the water molecule will resemble a magnetic pole in that the oxygen will be slightly negative and the hydrogen will be slightly positive. In consequence, water molecules will attract one another at the opposite end, forming a covalent bond. It is believed that when water is exposed to a strong magnetic field, the water molecules will align in one direction, as depicted in Figure 2.2. The bond angle will diminish to less than 105 degrees as the magnetic field squeezes the bond pairs together. This change in the composition of water molecules may result in a modification of certain physical and chemical properties. Therefore, magnetized water refers to water that has been treated by a magnetic field, which has been found to alter certain properties of water (Alwediyani *et al.*, 2015). Moreover, magnetization significantly modifies the physiochemical properties of the MW. For example, the conductivity of water increases while the surface tension decreases. Furthermore, the frictional coefficient of MW is less than that of normal water (NW) (Ramalingam *et al.*, 2022). Furthermore, magnetic fields have been shown to affect dipole polarization, the permeability of cell membranes, ion activity, and related functions, thereby disrupting the intracellular ion concentration balance and modifying intracellular pH (Matwijczuk *et al*., 2012).

The intensity of MW's UV absorption, which is greater than that of untreated water, increases exponentially with increasing magnetization period and decreasing UV light wavelength. As a direct consequence of the magnetic treatment, these changes are related to molecule clustering, atomic polarization, and changes in the transition dipolemoment of electrons within molecules (da Silva and Dobránszki, 2014). Based on the experiments of Pang and Deng (2008), in comparison to untreated water, treated water's clustering structure and increased polarized effect diminish the surface tension force of MW and its hydrophobicity. In addition, magnetized water has a higher shear viscosity, and the magnetic field inhibits the formation of scales (Esmaeilnezhad *et al*., 2017).

An externally applied MF causes changes in the atomic, molecular, and electronic structure of treated water, including modifications to its solidifying and boiling point, viscosity, and dielectric constant, the formation of clustering structures from linear and ring hydrogen-bound chains of

molecules, the magnetic interaction between these clustering structures, and the enhancement of the polarization effects of water molecules (Pang and Deng, 2008). An experiment revealed that the presence of a relatively faint magnetic influence (field) increased the viscosity of water, resulting in the formation of stronger hydrogen bonds (Mostafazadeh-Fard *et al*., 2011).

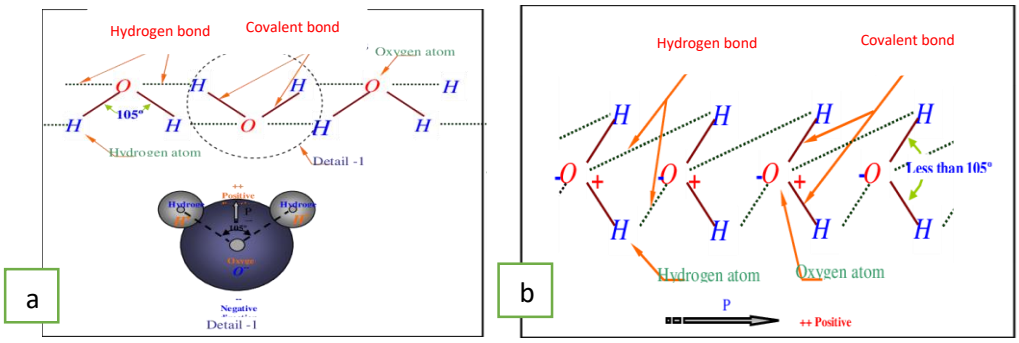

Figure 2.2. *The Directional Arrangement of Water Molecule (a) for Ordinary Molecules (b) Under the Effect of Magnetization* (Ahmed, 2009)

2.6.2. Effects of Magnetic Water on some Growth Parameters of Plants

It was discovered that the magnetic field affects various growth-related aspects and functions of plants, including shoot and root growth, seed germination, different yield parameters, reproduction, productivity, photosynthesis pigment contents, meristem cell growth and development, protein biosynthesis mRNA quality, enzyme activities, and gene expression (Alattar *et al*., 2021). Irrigation with magnetic water can increase both the quantity and quality of plant growth and development. It can also improve seed germination, early seedling growth, and the mineral content of seeds and products. Therefore, MW could be one of the most viable methods of applying a magnetic field (MF) in the future to enhance agricultural production in a sustainable manner. The effect of MW, which is dependent on the water's quality and ion concentration as well as the type of magnetization, is highly species- and genotype-specific (da Silva and Dobránszki, 2014).

Using magnetized irrigation water (i.e., MW), the germination rate of seeds increased by 13.3%, but magnetic treatments of seeds had no effect on the germination rate. Although the length of shoots (9.14 cm to 8.4 and 8.6 cm at 3 and 6 water passages, respectively) and roots (12.65 cm to 11.3 and 10.16 cm at 3 and 6 water passages, respectively) decreased as the number of water

passages increased, the dry weight of 7-day-old seedlings was increased by treatments with MW, and the effect was dependent on the amount of water passed through the device. Four and six passes through the device resulted in the highest seedling dry weight (0.57 g) compared to the control (0.52 g). However, direct magnetization of seeds produced inconsistent results (da Silva and Dobránszki, 2014).

The results revealed that corn plants irrigated with magnetized water had longer shoots than those irrigated with regular tap water. Compared to non-magnetized plants, corn plants grown in magnetized water had a significant increase in dry weight. The results indicated that magnetizing water with six magnets had the greatest impact on increasing plant length (194.10 cm, 66.74 cm) and dried weight (52.22 g, 12.3 g). However, magnetized water did not have a significant effect on root length, stem thickness, or fresh weight. The impact of magnetized water is proportional to the number of magnets used to magnetize it (Alattar *et al*., 2021). The stimulatory effect of magnetic water is attributable to increased plant growth (plant height, leaf area, leaves, stems, and roots fresh and desiccated weights) and yield production, which enhances nutrient absorption and utilization. It appears that irrigation with magnetic water could be viewed as a promising method for enhancing the growth and hydration of broad bean plants (El Sayed, 2014).

It can enhance germination of seeds and early vegetative growth of seedlings (da Silva and Dobránszki, 2014). Four crops' seeds were magnetized through a magnetized funnel with a magnetic field strength of 400 gauss for one hour and then irrigated with magnetic water. After seven, ten, and fifteen days, their germination percentage was compared to the control treatment (non-magnetized water or seeds). In general, the results indicate that there was a significant difference between the germination percentages of magnetized water and seeds at 7, 10, and 15 days after germination and those of non-magnetized water and non-magnetized seeds (Shahin *et al.*, 2016a).

It was discovered that the magnetic field stimulated the development of maize shoots, leading to an increase in germinating energy, fresh weight, and stalk length (Aladjadjiyan, 2002). The effect of a static electromagnetic field on the root growth and number of root hairs of radish seedlings. Although the static electromagnetic field had no effect on root length, a significant increase in the number of root filaments was observed (Nasher, 2008). Magnetoprimed seeds increased plant height, leaf area, fresh weight, midrib density, and minor veins. In a similar fashion, magnetopriming of the seeds increased the chlorophyll and carotenoid contents, the efficiency of

PSII, the quantum yield of electron transport, the stomatal conductance, and the activities of carbonic anhydrase (CA), Rubisco, and PEP-carboxylase enzymes (Sarraf *et al*., 2021).

2.6.3. Effects of Magnetic Water on the Photosynthesis Process and Photosynthetic Pigments

Photosynthesis contrabutes life on Earth by removing carbon dioxide from the atmosphere and releasing oxygen (Maurino and Weber, 2013). MF could affect metabolic substances such as the photosynthetic compounds of plants. It has been discovered that chemical reactions of plants increase in the presence of MF, which has a positive impact on photochemical activity, respiration ratio, and enzyme activity (Dhawi and Al-Khayri, 2009). Thus, magnetized water treatment increases plant photosynthesis and water uptake. The magnetically treated water, particularly at (50 and 30% soil water holding capacity (SWHC)) treatments, has a greater effect on photosynthetic pigments than the untreated water (Al-Khazan *et al*., 2011). MFs are known to promote biochemical changes and could be used to stimulate growth and responses, including the production of photosynthetic compounds like chlorophyll and carotenoids (Taimourya *et al.*, 2018).

In addition, it has been demonstrated that magnetically treated water increases the synthesis of photosynthetic pigments, the photosynthetic rate, and the translocation of photoassimilates, as well as the plant height, spike length/weight, straw yield, and grains yield. It has been demonstrated that magnetically treated water accelerates the emergence of wheat seedlings compared to conventionally irrigated wheat (Alkhatib *et al*., 2020). Chlorophylls are essential pigments that absorb a substantial quantity of light energy and facilitate photosynthetic reactions in plants. Another observation revealed that extended MF exposure time of an static magnetic field (SMF) (100 mT for 360 minutes) treatment substantially increased the amount of photosynthetic pigments in date palm (Dhawi and Al-Khayri, 2009).

Compared to plants grown in normal nutrient solution, the photosynthetic pigments (chlorophyll a and b) in strawberry and tomato plants cultivated in magnetically treated culture medium increased dramatically. The strawberry and tomato plant chlorophyll a content increased by 345.4% and 99.1%, respectively, when compared to the control plants. In comparison to the controls, the percentage of chlorophyll b in strawberry and tomato plants increased by 255.9% and 108.4%, respectively (Taimourya *et al*., 2017). Additionally, magnetized water promotes crop root

development, photosynthesis, and enzyme activity (Zhou *et al*., 2021). In addition, (El Sayed, 2014) found that Compared to the control, the gibberellic acid (GA3) and kinetin contents of broad bean plants irrigated with magnetically treated nutrient solution (MTNS) were significantly elevated. Figure 2.3 presents a comprehensive summary of MFs and their function in photosynthetic pigments.

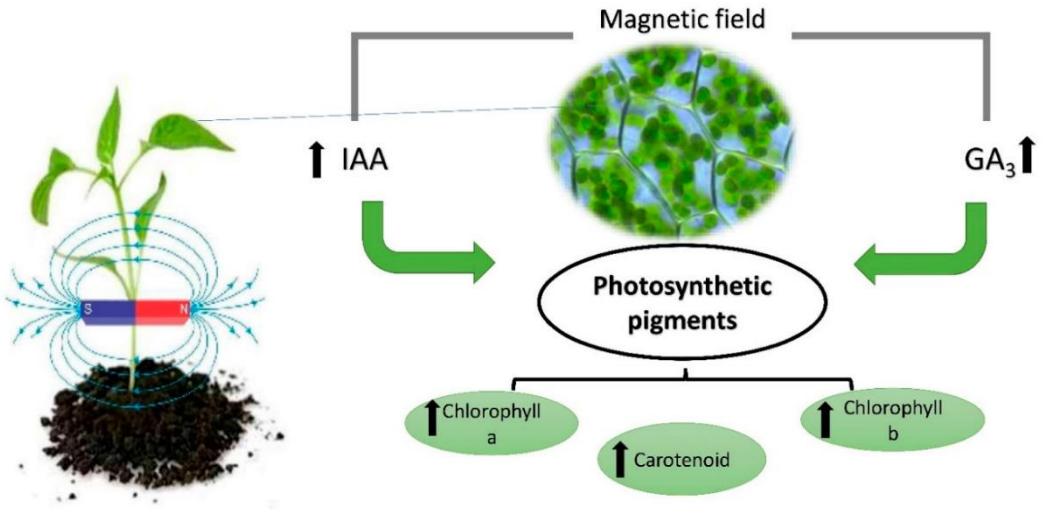

Figure 2.3. *The performance of photosynthetic pigments under the influence of magnetic field* (Sarraf *et al*., 2021).

2.6.4. Effects of Magnetic Water on some Enzymatic and Non-Enzymatic Anti-oxidant

Plants possess enzymatic systems that protect them from H_2O_2 and other reactive oxygen species (ROS) that are toxic. Included in these enzymatic systems are superoxide dismutase (SOD) and catalase (CAT). CAT converts H_2O_2 to water and oxygen, while SOD converts superoxide radicals to hydrogen peroxide. Plants contain non-enzymatic ROS-scavengers, such as ascorbate, tocopherols, phenolic acids, and flavonoids, which are localized in various cellular compartments (Çelik *et al*., 2009). ROS can affect leaf guard cell functions in Arabidopsis (*Arabidopsis thaliana*), bean (*Phaseolus sp.*), and pea *(Pisum sativum*) plants (Rane *et al*., 2021). After 24 hours of soaking in distilled water, germination-related enzymes in magnetically exposed and unexposed germinating cumin seeds were measured (Samani *et al.*, 2013). In addition, the antioxidant enzymes (catalase, peroxidase, and superoxide dismutase) in the magnetized plants are more active

than in the control plants (Moussa, 2011). Additionally, magnetized water irrigation increased the antioxidant enzyme activities in plant foliage, thereby reducing oxidative damage (Hu *et al*., 2022). By increasing magnetic field intensities, ascorbate peroxidase (APX) activity increased in both root and stem, and superoxide dismutase (SOD) activity increased in the root of pretreated plants (Shabrangi and Majd, 2009).

As an abundant component of plants, ascorbic acid functions as an antioxidant and an enzyme cofactor. It is involved in numerous processes, such as photosynthesis, cell wall growth and cell expansion, resistance to environmental stresses, and synthesis of ethylene, gibberellins, anthocyanine, and hydroxyl proline (Hashem and Hegab, 2018a). The antioxidant enzymes (catalase, peroxidase, and superoxide dismutase) in the magnetized plants are more active than in the control plants (Moussa, 2011). In comparison to the control (0 mT), magnetic water irrigation substantially increased the activity of (SOD), peroxidase (POD), and proline content in cotton (*Gossypium herbaceum*) seedlings (Gao *et al*., 2017). Clearly, SOD is an essential enzyme family for sustaining normal physiological conditions in living cells and the most powerful antioxidant enzymes in soybean roots (*Glycine max*) (Çelik *et al*., 2009).

2.6.5. Effects of Magnetic Water on Some Plants Content of Elements

Plants irrigated with water treated by a magnetic field readily absorb mineral salt from the soil, and there is no surface sedimentation. This results in higher crop yields and enhanced agricultural product quality (Nasher, 2008). Magnetically purified water is the most effective irrigation method for soils with a high sodium carbonate content (Ali *et al*., 2014). Recent research indicates that magnetically treated water irrigation substantially accelerates soil water infiltration and soil salt leaching. As water molecules (polymers) travel through a given magnetic field intensity, the large aggregate water cluster breaks down into smaller particles, making water and nutrients more available to plants (Gao *et al*., 2017). By using magnetic-water irrigation, soil salt ions such as Cl^{-}, Na^{+} and HCO^{3-} are significantly leached from the cultivation layer (Mostafazadeh-Fard *et al*., 2011).

The nutrient uptake, assimilation, and mobilization facilitated by magnetically treated water enhanced plant productivity (Maheshwari and Grewal, 2009). Regarding Fe_2^{+}, magnetic field induces the transformation of Fe from ferric (Fe_3^{+}) to ferrous (Fe_2^{+}), thereby facilitating the transfer of Fe_2^{+} from roots to leaves. Consequently, the magnetic solution could influence the physiological

and biochemical characteristics of grape (*vitis vinifera*) by affecting the Fe^{2+} content. It has been reported that magnetic water increases the Fe^{2+} content of snow pea (*Pisum sativum*) seedlings and lettuce (*Lactuca sativa L.*) plants (Zareei *et al*., 2021). Some elements in buck wheat straw (*Fagopyrum esculentum Moench*) (P, Ca, K, Zn) were more abundant in seeds that were exposed to a magnetic field, and the results of (Moussa, 2011). When the seeds were magnetically treated, an increase in the iron content of buck wheat chaff was observed (Ismail *et al.*, 2020). Similar results were obtained by Ibrahim and Mohsen (2013), where using magnetized water led to an increase in soluble soil K, Mg^{2+}, and Ca^{2+}.

2.7. Heavy Metals Definitions and Sources

The term "heavy metal" has generated considerable controversy in the scientific community and has various definitions and interpretations in various scientific disciplines, such as chemistry and plant sciences. Based on these definitions, the group of chemical elements with metallic properties, such as Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se, and Zn, is commonly referred to as the heavy metals (HMs) (Figure 2.4). However, it appears that the classification based on density (3.5–7 g/cm^3) or atomic number (greater than 20) has been supplanted with a definition based on the mode of action in plant sciences (Jócsák *et al*., 2022). Mercury (Hg), lead (Pb), cadmium (Cd), and manganese (Mn) are some of the heavy metals associated with gold mining (Aendo *et al*., 2022). More than sixty elements are classified as heavy metals, and a significant portion of the periodic table known as "transition elements" contains these elements (HocaoĞLu-ÖZyİĞİT and GenÇ, 2020). In excess of permissible limits, their concentration in soil is deleterious to plants, either by inducing oxidative stress via free radicals or by interfering with the function of enzymes by replacing essential metals and nutrients (Shah *et al*., 2010). HMs negatively affected the structure and activity of microbial communities in polluted soils (Jarosławiecka and Piotrowska-Seget, 2022).

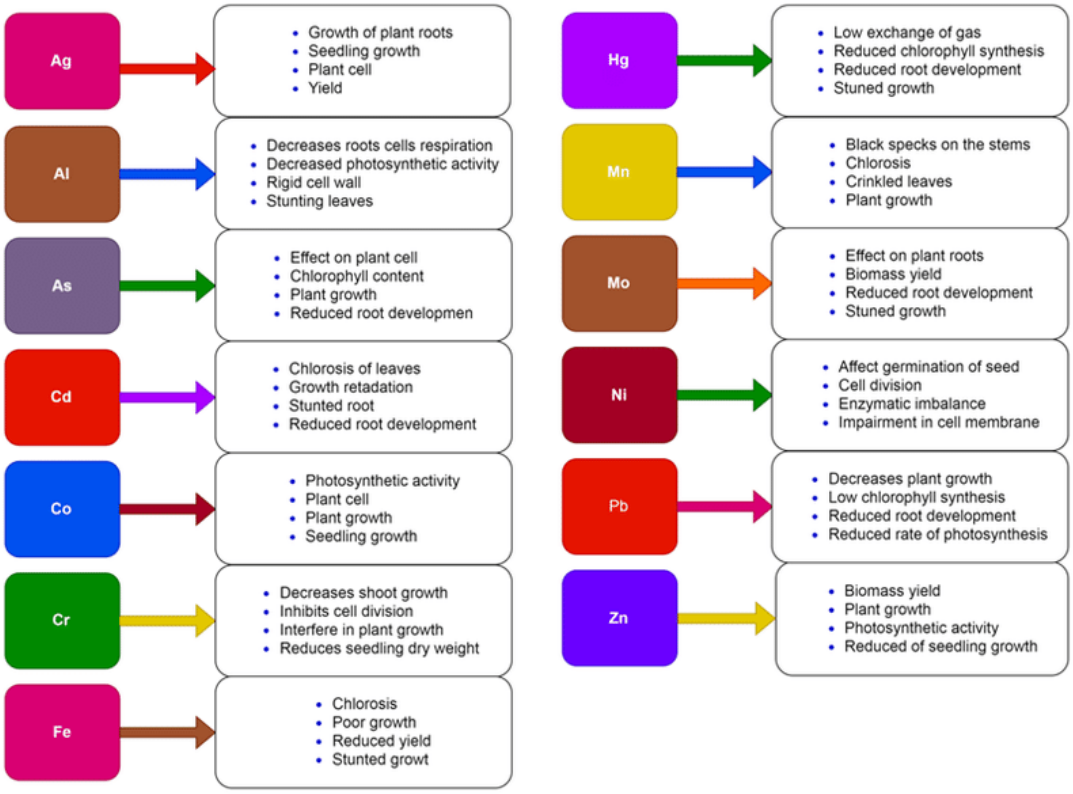

Figure 2.4. *Heavy Metal Toxicity Symptoms in Plants* (Kumar and Aery, 2016)

2.7.1. Cadmium as a Heavy Metal

Cadmium is a non-essential element and the fourth most toxic metal to vegetation (Herath *et al.*, 2015). Although Cd is a non-essential element for crop plants, it is readily absorbed by plants growing in Cd-supplemented or Cd-contaminated soils, causing harm to plant and human health by entering the food chain (Nazar *et al*., 2012).

2.7.2. Factors Affecting Cd Availability to Plants

Principal sources of cadmium include contaminated sewage sludge and waste water, sewage effluents, and agricultural runoffs (Huang *et al*., 2020). Cadmium is a highly toxic trace metal that can originate from geological or anthropogenic sources, such as minerals, phosphate fertilizers, and combustion emissions. Due to its low sorption affinity relative to that of other heavy metals, Cd is readily mobilized, which may result in elevated Cd concentrations in groundwater (Kubier *et al*., 2020). The availability of Cd is affected by soil pH, root exudates, organic matter, plant age, micro and macronutrients, and plant genotypes, but soil pH is regarded as the most influential factor

(Haider *et al*., 2021). As it inhibits seed germination, cell growth, plant growth, and nutrient absorption, its presence ultimately retards growth and productivity (Mobin and Khan, 2007).

2.7.3. Effects of Cadmium on some Growth Parameters in Plants

The accumulation of cadmium in agricultural soil can be hazardous to crops. When plants are flourishing in a Cd-polluted environment, Cd is readily absorbed by plant roots and translocated into the leaves of many plant species (Herath *et al.*, 2015). The visible symptoms of Cd toxicity are stunted growth, leaf chlorosis and necrosis, stomatal closure, an imbalance in water uptake, and damage to the photosynthetic apparatus (Dobrikova *et al*., 2021). Cadmium (Cd) is one of the heavy metals and one of the most significant environmental pollutants that is readily transported in plants, distributed to all plant organs, and transmitted to the food chain. To date, no positive effects of Cd on living organisms have been documented (HocaoĞLu-ÖZyİĞİT and GenÇ, 2020). Cadmium's toxicity slows down the germination process. It also inhibits seedling development following germination. Additionally, it inhibits the morphological and physiological development and function of plants, as well as their metabolism (Jócsák *et al.*, 2022).

Cd has also been demonstrated to induce oxidative stress, genotoxicity, inhibition of photosynthetic function, and inhibition of root metabolism (Andresen and Küpper, 2013). Reduced leaf surface area, chlorosis, necrotic spot formation, leaf growth inhibition, and leaf rolling are observed in plants exposed to toxic levels of Cd (Benavides *et al*., 2005). Typical Cd toxicity symptoms in rice plants include wilted leaves, growth inhibition, progressive chlorosis in certain leaves and leaf sheaths, and browned root systems, particularly at the root extremities (Shah *et al.*, 2010).

Cadmium disrupts chloroplast function by accumulating to high levels in aerial plant parts. Ribulose-1, 5-biphosphate carboxylase (RUBPCase) and phosphoenol pyruvate carboxylase (PEPCase), enzymes required for chlorophyll biosynthesis and carbon dioxide fixation, are inhibited (Noor *et al.*, 2018). Cd toxicity results in oxidative DNA damage, DNA strand breaks, DNA protein cross-links, chromosomal aberrations, dysregulation of gene expression leading to an increase in proliferation, a decrease in apoptosis, and altered DNA repair (Nazar *et al.*, 2012). Reduction in *Thespesia populnea* seed germination provided evidence that an element like Cd, when present in excess, is responsible for producing toxic effects that limit plant growth and development (Kabir *et al.*, 2008). A greater concentration of cadmium reduced the leaf area of plants, most likely due to a restriction of cell division and expansion. Also, the outcome was similar

to that of Mohammadi et al. (2019) Cd had an impact on the fresh weight of *Lemna polyrhiza*. The diminution of growth in *L. polyrrhiza* may also be attributable to the inhibition of the elongation growth rate of cells by Cd's irreversible inhibition of the proton pump responsible for the process (John *et al.*, 2008).

Due to Cd toxicity, the main root becomes rigid, contorted, and brown, and the formation of lateral roots is inhibited (Krantev *et al*., 2008). The reduction in root length was more pronounced in *Thespesia populnea* treated with different Cd concentrations than the reduction in stalk and seedling length. The reduction in root length was caused by the accumulation of metals within the root, which decreased the mitotic rate in the meristematic zone and blocked the metaphase in meristematic cells. As a result, the length of the roots was reduced (Kabir *et al.*, 2008). Heavy metals primarily affect plant growth by generating free radicals and reactive oxygen species (ROS), which pose constant oxidative damage by degrading vital cellular components (Pandey *et al*., 2005). Cd's toxicity reduces the assimilation and translocation of nutrients and water in crop plants, increases oxidative damage, disrupts plant metabolism, and impairs plant morphology and physiology, as shown in (Figure 2.5), (Haider *et al*., 2021).

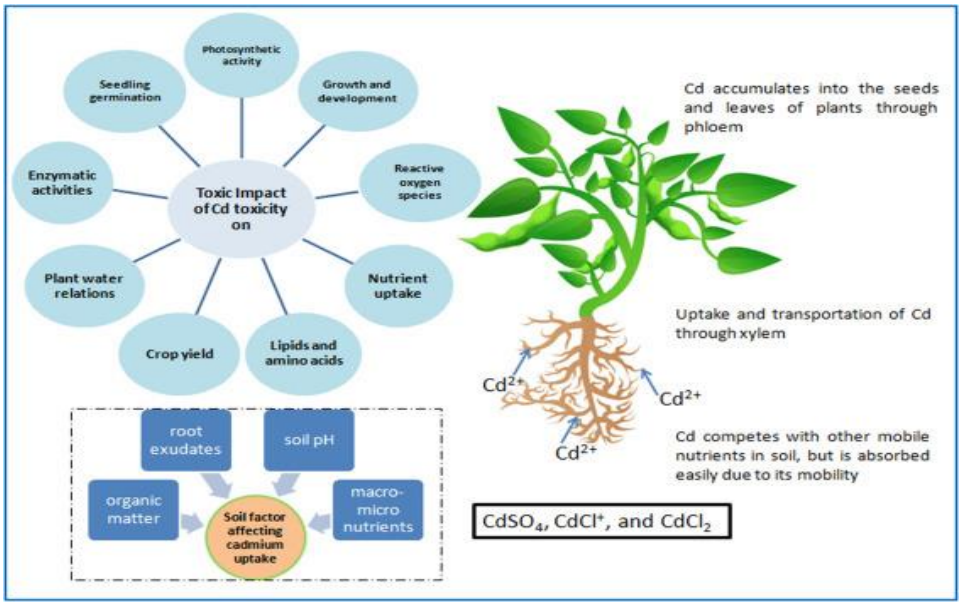

Figure 2.5. *Toxic Effects of Cd Toxicity on Plants* (Haider *et al*., 2021).

2.7.4. Effects of Cadmium on Photosynthesis Pigments

Increased Cd levels inhibit photosynthesis, and photosynthesis is the primary physiological process directly or indirectly affected by Cd in all its phases (the "light" and "dark" reactions) (Dobrikova *et al*., 2021) and (Mobin and Khan, 2007). The accumulation of Cd disrupts the Calvin cycle enzymes, photosynthesis, and carbohydrate metabolism, as well as the antioxidant metabolism, the stomatal opening by influencing the water balance, and crop yield. Chlorophyll biosynthesis, photosynthesis, stomatal behavior, enzymes of the Calvin cycle, and electron transport are exceedingly sensitive to oxidative stress induced by Cd, thiobarbituric acid reactive substances (TBARS), and electrolyte discharge (Mobin and Khan, 2007).

The chloroplasts of cadmium-exposed plants were altered, with thylakoids degenerating and the concentration of photosynthetic pigments, such as chlorophyll a and phycobiliproteins, decreasing (Eder C *et al*., 2012). Cadmium also induces distortion and ultrastructural alterations of chloroplast, leaving in an irregular clustering of grana and a lower chloroplast count (Chen *et al*., 2011a). A reduction in energy transfer and the synthesis of ATP and NADPH are the results of heavy metals' effects on the photosystem. However, PSII is the most sensitive target to metals due to the toxic ones' replacement of necessary cofactors for the water photolysis enzymes (Bahri *et al*., 2014). Heavy metals' physiological effects on plants included the following: 1) Modifications in water relations and gas exchange rates cause stomatal processes to be disturbed; 2) Photosynthetic pigments and activity are reduced; 3) Cellular membrane integrity is impaired (Miladinova *et al*., 2014).

2.7.5. Effects of Cadmium on Some Enzymatic and Non-Enzymatic Anti-oxidants

Cd toxicity results in lipid peroxidation and also modifies antioxidant activities (Munawar *et al*., 2022). Under Cd exposure, the antioxidant enzyme system was activated, as almost all the activities of superoxide dismutase (SOD), peroxidase, catalase, glutathione peroxidase, and ascorbate peroxidase were increased in leaves and roots (Yu *et al*., 2013). In contrast, a plant's antioxidative system, which includes superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), glutathione peroxidase (GPX), and ascorbate peroxidase (APX), as well as non-enzyme antioxidants such as ascorbic acid and glutathione, may adapt to repair this type of injury (Zornoza *et al*., 2010). Due to Cd stress, the enzyme activity of catalase (CAT), ascorbate peroxidase (APX), and superoxide dismutase (SOD) in the roots of tolerant alfalfa (*Medicago sativa* L.) decreased significantly, whereas the content of H_2O_2 increased as an indicator of oxidative stress (Kabir *et*

al., 2016).

Plant resistance or sensitivity to Cd stress has been shown to be dependent on the ability of plants under stress to enhance their antioxidant defense, including highly efficient antioxidant enzymes, such as superoxide dismutase (SOD, EC 1.15.1.1), ascorbate peroxidase (APX), and glutathione reductase (GR,), as well as non-enzymatic antioxidants, such as ascorbate (AsA) and glutathione (GSH) (Paradiso *et al*., 2008).

2.7.6. Effects of Cadmium on Elements Contain

Cd toxicity also diminishes the uptake of nutrients and water by certain crops. Cd concentrations of 3 and 5 mg/kg soil reduced the presence of K, Mg, Ca, and Fe significantly (Jócsák *et al*., 2022). However, a lack of Cd-based Fe and/or P deficiency or inhibition of Mn transport may be the cause of leaf chlorosis (Benavides *et al*., 2005).

The uptake of Cd reduced the absorption of nitrate, and the inhibition of nitrate reductase activity in the stems limited the transport of nitrate from the roots to the stems (Singh *et al.*, 2019). Cadmium inhibits the assimilation of elements including K, Ca, Mg, and Fe because it employs the same transmembrane carriers (Shah *et al*., 2010). Cadmium replaces calcium (Ca) in minerals due to its identical charge, ionic radius, and chemical behavior (Kubier *et al*., 2019). Cadmium additionally limits Fe and Zn absorption by plants, resulting in leaf chlorosis. Cd generally inhibits the transport and absorption of Ca, P, Mg, K, and Mn (Haider *et al*., 2021). Cadmium toxicity substantially reduces N, Ca, Mg, and P levels in alfalfa (*Medicago sativa* L.) roots and shoots (Zhang *et al.*, 2019). Plants can tolerate higher concentrations of Cd without being harmed, but excessive Cd exposure has a negative impact on plant health. By altering the plant's nitrogen and carbohydrate metabolisms, it causes numerous physiological changes (HocaoĞLu-ÖZyİĞİT and GenÇ, 2020).

Nada *et al.* (2007) analyzed the interactions between Cd and nutrients and their consequent effects on sunflower (*Helianthus annuus* L.) plants. As a result of a Cd-induced imbalance in the absorption and translocation of essential elements in plant tissues, Fe and Mn are depleted in the leaves. In addition, it is documented that Cd interferes with NO_3 assimilation in plants by reducing nitrate reductase, a key enzyme in NO_3 assimilation that catalyzes the NAD(P)H reduction of NO_3 to NO_2 (Zulfiqar *et al.*, 2021). Ca, Cu, and Zn concentrations in seedlings were diminished by Cd exposure, whereas their concentrations in roots were elevated. All plant organs exhibited a significant decrease in K and Mg content due to a high Cd concentration. In addition, the

concentration of Fe decreased in the roots, stems, and foliage, but rose in the flowers, seeds, and red ripe fruits. Similarly, when Welsh onion (*Allium fstulosum*) was exposed to varying Cd concentrations, a positive correlation between Cd and mineral elements was observed (Li *et al*., 2016).

Sikka and Nayyar (2012) found the administration of Cd decreased the content of micronutrients (Mn, Fe, Cu, Zn) in Indian mustard Brassica juncea L., but only treatments with Cd concentrations above 50 mg/kg exhibited a significant reduction in Fe. Meanwhile, Liu *et al*. (2011) found in Lonicera japonica Thunb., Cd and Fe interact synergistically in accumulation and translocation, and there is a significant inverse correlation between Cd and Cu or Zn concentrations. Moreover, the influence of heavy metals on nutrient elements varies by cultivar.

2.7.7. The Relationship Between Magnetic Water and Cadmium

Due to heavy metal toxicity in plants, plant disorders may ultimately limit plant growth. Magnetic water is one of the methods that can be used to remediate the soil (Khoshravesh *et al*., 2021). Widespread use of magnetic fields (MF) as a pre-sowing seed treatment to increase seed vigor, seedling growth, and yield, as well as to mitigate the effects of heavy metals. MF has positive effects on the germination, growth, and development of cultivated strawberries; increases mesquite seedling tolerance to As stress; and similarly increases green bean seedling tolerance to Cd stress (Chen *et al.*, 2017). A method for removing heavy metals from water is provided, the method comprises of the stages of adding magnetite to a quantity of heavy metal-containing water. At least a portion, and preferably the preponderance, of the heavy metal in the water is bound to the magnetite by mixing magnetite with the water. Once this occurs, a magnetic field is used to remove the magnetite and assimilated metal from the water (Prenger *et al*., 2003).

Chapter Three

3. Materials and Methods

3.1. Plant Materials

Cutting of *Paulownia tomentosa* were collected from one year's stalks exist in a nursery which specialised for *P. tomentosa* production in Erbil, Iraq. The cuttings were planted in a private nursery in Koya district, Erbil on December 15th 2021 in black polyethylene bags (25cm length and 15cm diameter) filled with 3 Kg of a silty loam soils (Table 3.2, and Figure 3.1). The average environmental conditions throughout the growing season are cleared in table 3.1. After 5 months of cultivation, the cutting, on 11th of May the stalks were transferred outside of the house green.

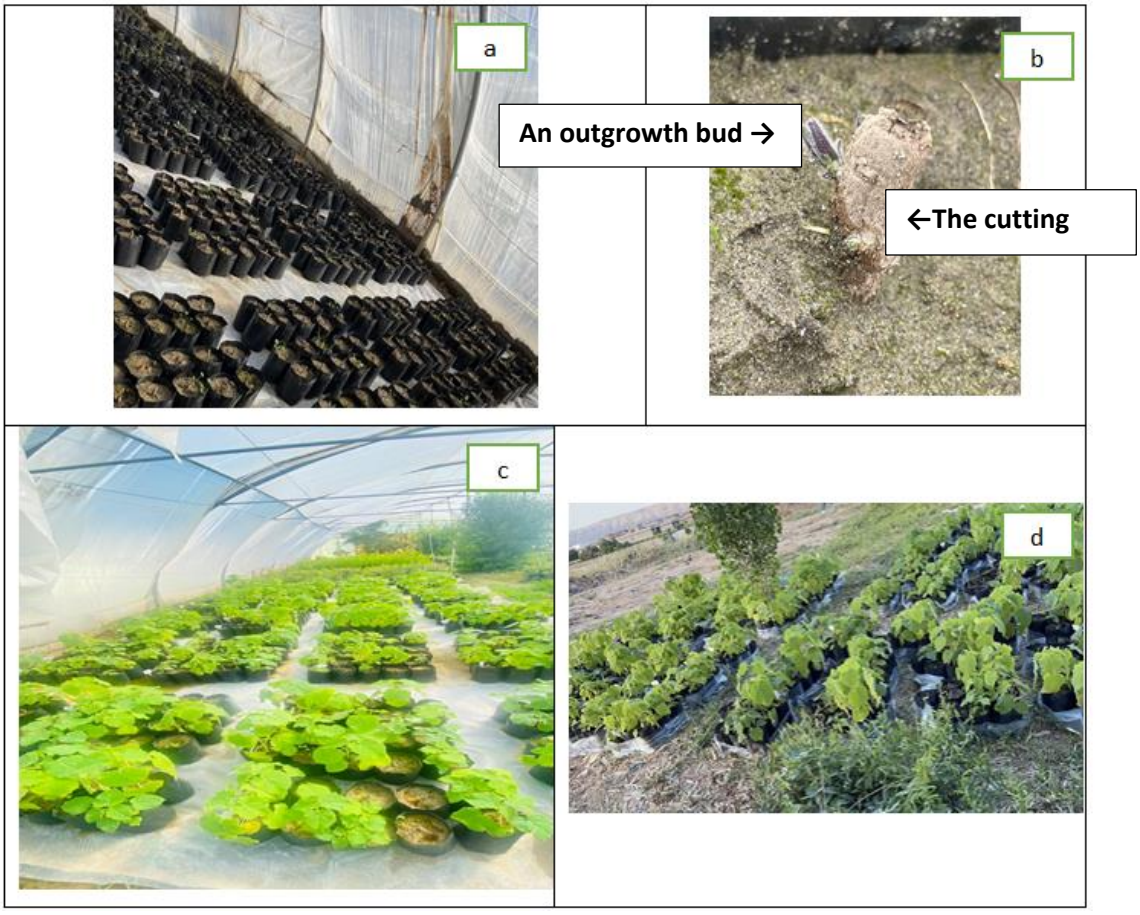

Figure 3.1. *Different Stages of the Study (a) Cutting Cultivation (b) an Emerged Cutting (c) an Overview of the Experiment inside the Greenhouse, and (d) the Stalks Outside the Greenhouse.*

3.2. Preparation of Treatments

3.2.1. Magnetic Water Powers

Irrigation with magnetized water (MW) in 5 different powers (0 (tap water) (not treated with magnetic field), 500, 1000, 1500, and 2000 gausses) was conducted by using 4 magnetic devices manufactured by Al- Rafidain Company for Magnetic Technologies, Baghdad, Iraq, as shown in (Figure 3.2). The irrigation by magnetic water began with cuttings cultivation until the end of the experiment.

Figure 3.2. *The Magnetic Devices Used to Magnetize the Study Waters*

3.2.2. Cadmium Solutions

Cd as $CdCl_2$ monohydrate ($CdCl_2.H_2O$) (Figure 3.3) with molecular weight = 201.33 g. $mole^{-1}$ was used to prepare the following concentrations (0, 3.33, 6.66, and 10 mg Cd. Kg^{-1} soil) as follows:

- For prepare 3.33 mg Cd. Kg^{-1}soil, add 250ml of 20 mg.l^{-1} of $CdCl_2.H_2O$ was dissolved in 1Liter of water.
- For prepare 6.66 mg Cd. Kg^{-1}soil, add 250ml of 40 mg.l^{-1} of $CdCl_2.H_2O$ was dissolved in 1Liter of water.
- For prepare 10 mg Cd. Kg^{-1}soil, add 250ml of 60 mg.l^{-1} of $CdCl_2.H_2O$ was dissolved in 1Liter of water.

Adding cadmium chloride solutions to each bag at April 26th and repeated at the1st of June.

3.3. The Treatments and the Experimental Design

Factorial complete randomized design (CRD) with two factors was implemented; the first factor was irrigation with magnetized water (MW) in five (5) different powers (0 (tap water) (not treated

with magnetic field), 500, 1000, 1500, and 2000 gausses). The second factor was four (4) concentrations of cadmium chloride $CdCl_2.H_2O$ (0, 3.33, 6.66, and 10 mg Cd. Kg^{-1}soil) so the study consists of 20 treatments, as it shown in table 3.1.

Table 3.1. *The Diagram of Experimental Units used in the Study (Magnetic Water Levels, Cd Concentrations, and their Interactions).*

MW	Cd	Experimental unit
G0	Cd0	G0 Cd0
G500		G500 Cd0
G1000		G1000 Cd0
G1500		G1500 Cd0
G2000		G2000 Cd0
G0	Cd3.33	G0 Cd3.33
G500		G500 Cd3.33
G1000		G1000 Cd3.33
G1500		G1500 Cd3.33
G2000		G2000 Cd3.33
G0	Cd6.66	G0 Cd6.66
G500		G500 Cd6.66
G1000		G1000 Cd6.66
G1500		G1500 Cd6.66
G2000		G2000 Cd6.66
G0	Cd10	G0 Cd10
G500		G500 Cd10
G1000		G1000 Cd10
G1500		G1500 Cd10
G2000		G2000 Cd10

3.4. Meteorological Data and Soli Properties

The minimum, maximum, average temperatures, average humidity, and average precipitation were recorded by the Agrometeorological Station at the climate center in Koya city, Erbil during the growing season from December 2021 to July 2022 as shown in table 3.1.

The chemical and physical analyses of the study soil were taken in Agricultural Research Directorate in Soil Department and Laboratory and for agriculture consultancy, Erbil, whereas some of the soil chemical analysis were done by the XRF device in the physics department, Koya university, as shown in table 3.2.

Table 3.2. *Temperatures, Humidity, and Precipitation Data During the Growing Season 2021-2022.*

Month		Temperature (◦C)			Average Relative Humidity (%)	Precipitation (mm)
		Max.	Min.	Average		
2021	15-31 December	15.88	6.82	11.35	64.82	5.41
2022	January	11.74	4.23	7.98	71.23	4.28
	February	17.43	8.68	13.05	55.68	1.52
	March	16.74	12	12.27	55.65	1.13
	April	28.67	16.5	22.58	39.77	0.34
	May	30.23	19.61	24.98	38.35	0.82
	Jun	40.07	27.27	33.62	24.17	0
	July	42.87	30.06	36.31	17.19	0
	Average	25.45	15.65	20.27	45.86	1.69

Table 3.3. *Chemical and Physical properties of the Study Soil.*

Physicochemical Soil Properties	pH	Ec ($ds.m^{-1}$)	O. M $g.\ kg^{-1}$	Sand $g.\ kg^{-1}$	Silt $g.\ kg^{-1}$	Clay $g.\ kg^{-1}$	Texture
	7.78	0.4	1.04	248	500	252	Silty Loam

Essential macro elements	N (%)	P (ppm)	K (ppm)	SO_4 (%)	Ca^{+2}(%)	
	0.11	38	220	0.015	23	
Essential micro Elements	Mn (%)	Zn (%)	Fe (%)	Cu (%)	Ni (%)	
	0.0017	0.0141	7.97	0.0077	0.0462	
Other elements	Cd^{+2}	Pb (%)	Cr (%)	Rb (%)		
	0	0.0026	0.111	0.011		
	Ti (%)	Sr (%)	Ga (%)	As (%)	Y (%)	
	0.844	0.04	0.0014	0.0015	0.0036	

Shaded Elements Cells Were Estimated Chemically, whereas other Elements Were Estimated by the XRF Method.

3.5. The Studied Characteristics

Samples of three whole plants were used to measure leaf number, leaf area, length of shoot, branch number, stem diameter, root length and fresh weight (FW) of shoots and roots (Zha *et al*., 2019). For shoot and root dry weight, ascorbic acid, all the vegetative, parts of the plants and the roots were taken and dried at $65C^0$ for 24 hours in the oven until weight fixing (Salih and Aziz, 2019). For POD activity, proline, chlorophyll a, chlorophyll b, and total carotenoids contents in leaves, third to fourth leaf samples freshly collected were placed in polyethylene bags and quickly placed in a cooler box and transported to the laboratory.

3.5.1. Vegetative and Root Growth

3.5.1.1. The Percentage of the Survived Cutting (%)

The Extraction was done by dividing the number of buds outgrowth cutting on the total number of cultivated cutting multiply by 100 (Swara and Al-barzinji, 2021).

3.5.1.2. Velocity of Buds Outgrowth (days)

The formula of buds outgrowth was determined as it shown by Ranal and Santana (2006) as following :

$$V \text{ (days)} = \sum_{i=1}^{n} NiGi \,/\, \sum_{i=1}^{n} Gi$$

V= Velocity of cuttings outgrowth (days).

G= Number of cutting outgrowth on the day of observation

N= Number of days counted since the day of cultivating until the day of observation.

3.5.1.3. Number of Plant Leaves (plants^{-1})

Three plants were chosen randomly from each experimental unit to determine the plant leaves number (Watson and Watson, 1953)

3.5.1.4. Plant Leaf Area (cm^2)

For measuring the leaf area, three plants were chosen randomly from each experimental unit, and drow the leaf on the paper after that balanced it and computed with the technique of (Watson and Watson, 1953).

3.5.1.5. Plants Branch Number (plants^{-1})

Three plants were chosen randomly from each experimental unit to determine the average of branch number (Al-Barzinji *et al*., 2015).

3.5.1.6. Stem Diameter (cm)

For measuring the stem diameter, three plants were chosen randomly from each experimental unit and caliper micrometer instrument was used (J0006, size 0-25mm, China) (Al-Barzinji *et al.*, 2015).

3.5.1.7. Length of Plant Shoot (cm)

For selected plants, length was measured from the root zone with a stem over the ground to the end top of the head top of shoot by using standard metric tapeline, as it mentioned by (Al-Barzinji *et al*., 2015).

3.5.1.8. Length of Root (cm)

Roots for the three selected plants in each experimental unit where extracted from the bags and washed with slow running tap water , then, measured from the root zone down to the developing apex of the root by standard metric tapeline measurement, as it mentioned by (Al-Barzinji *et al.*, 2015).

3.5.1.9. Dry and Fresh Weight of Shoot and Root (g)

The root and shoot are separated after washing with tap water, dried with cotton fabrics, weighted for the fresh weight then put in oven at 65°C till a constant weight for 24 hours until weight fixation. Then, weighed by a sensitive balance for the dry weight, as it mentioned (Al-Barzinji *et al*., 2015) in the following equations:

$$\text{Shoot dry matter (\%)} = \frac{\text{shoot dry weight}}{\text{shoot fresh weight}} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$\text{Root dry matter (\%)} = \frac{\text{root dry weight}}{\text{root fresh weight}} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

3.5.2. Chlorophyll a and b and total Carotenoids Content in Fresh Leaves (mg.g^{-1} fresh weight)

The amount of chlorophyll a, b and total carotenoids were estimated according to the method 80% acetone by Lichtenthaler and Wellburn (1983). Mixture ratio was 50 ml: 1 g sample, where 0.4g of fresh leaves were mixed with 20 ml 80% acetone then grinded by mortar and pestle and filtered by filter paper. The extraction was placed in a 25 ml glass vial (closed dark bottle), to prevent evaporation and avoid photo-oxidation of pigments, and then read the results by spectrophotometer at 663, 646 and 470 nm wave lengths. Chlorophyll a, chlorophyll b and total carotenoids were calculated as follows:

Chl a = (12.21*A663) - (2.81*A646)

Chl b = (20.13*A646) - (5.03*A663)

TC = (1000*A470 - 3.27*Chl a – 104*Chl b)/229

where, A is Absorbance, Chl a = chlorophyll a (mg.L^{-1}), Chl b = chlorophyll b (mg.L^{-1}) and TC = total carotenoids (mg.L^{-1}).

For converting the concentration from mg.L^{-1} to mg.g^{-1} fresh weight, each value is multiplied by (extraction volume / sample weight *1000).

3.5.3. Enzymatic and Non-Enzymatic Antioxidants

To determine the activity of the antioxidant enzymes: POD sample of the leaves were crushed 1 gm of fresh weight after cutting them with a clean knife into small pieces. They were frozen ground to a powder with mortar and pestle with 10 ml of (0.1M) potassium phosphate organized at cold pH 7.8 after filtering using a centrifuge at 1000 RPM for 10 minute. The process was carried out under cold condition (40°C). The fresh leaves were kept in ice during the course of homogenization. The extracts were prepared for the analysis (Pitotti *et al*., 1994).

3.5.3.1. Peroxidase Enzyme Activity in Leaves (POD) Enzyme Activity ($\mu g.g^{-1}$)

The activity of POD enzyme was determinated according to the method described by Müftügil (1985), as clarified below

Material and used solutions:

A- Guaicaol solution: Prepare by mixing 1.36 ml of guaicaol in a volumetric flask and then complete volume to 250 ml using distilled water.

B- Hydrogen Oxide - H_2O_2 solution at a concentration of 0.1%: Prepare by taking a volume of 0.4 ml of 30 % H_2O_2 and completing to 120 ml by using distilled water

Procedure

A. Mix 1 ml of H_2O_2 solution with 1 ml of guaicaol solution (reaction mixture).

B. The enzyme activity was estimated by adding 2 ml of the reaction mixture in the cuvette, then 0.1 ml of the sample was added and the change is followed up absorption of light every 30 seconds for a period of 3 minutes at a wavelength of 420 nm by spectrophotometer (model 721-2000, China). Blank was prepared in the same way without a sample.

Calculation

The activity of the POD enzyme was calculated by:

$$\text{POD Activity (unit.ml}^{-1}) = \frac{\frac{\Delta \text{ Optical Density Reading}}{\Delta \, Time}}{0.1 \text{ X } 0.01}$$

Where: 0.1: volume of the sample, 0.01: one unit of enzyme (the amount of enzyme that increases in light absorption (they are 0.01 units per minute at a wavelength at 420 nm).

3.5.3.2. Determination of Ascorbic Acid in Leaves ($g.L^{-1}$)

A. Preparation of Solutions

- Stock solution of ascorbic acid:

Ascorbic acid solution (0.1 molL-1) was prepared by dissolving an appropriate volume (0.4 g) of ascorbic acid in distilled water and storing it at 4C in the dark in a glass stopper bottle. Before use, variable concentration solutions were prepared by diluting the stock standard solution with water.

- Methylene blue solution (MB):

(0.0004 mol dm^{-3}) was prepared by dissolving 0.0126 g of methylene blue in 100 ml distilled water.

B. Preparation of Samples

2 ml of glacial acetic acid was added to 2.5 g of coarsely pulverized leaves sample. The mixture was stirred for approximately twenty minutes before being abruptly filtered through a Buchner funnel, transferred to a 100 ml volumetric flask, and diluted to the mark with distilled water. The samples were, then, evaluated using a spectrophotometer.

C. Procedure

To ascertain the amounts of ascorbic acid in the samples, a UV/VIS spectrophotometer (model 721-2000, manufactured in China) was used for the spectrophotometric analysis. Fifty microliters of a sample solution were combined with 125 microliters of an MB (0.0004 mol dm-3) solution and 10 milliliters of distilled water. The absorption was measured at 665 nm. The results were reported in milligrams of ascorbic acid per 100 grams of sample dry weight (Elbsheer, 2018).

3.5.3.3. The Proline Amino Acid in Leaves ($\mu g.ml^{-1}$)

Estimation of the concentration of proline in fresh leaves (figure 3.5) according to the method of (Bates *et al*., 1973). A weight of 0.5 g was taken from the fresh leaves and placed in a porcelain mortar and pestle, and crushed well after adding 10 ml of sulfosalicylic acid (3 %, w/v) dissolving (3 g of sulfosalicylic acid in 100 ml distilled water). Then, separated by centrifuge at 2000 RPM for 10 minutes, taking 2 ml of the plant extract and 2 ml of glacial acetic acid was added and 2 ml of ninhydrin reagent which was prepared by mixing (1.25 g of niniadrine with 30 mL of glacial acetic acid and 20 mL of (6 M) H_3PO_4 phosphoric acid) and the plant leave mixture on a quiet fire with stirring until melting and the appearance of yellow color. After that, the test tubes were placed in a water bath at a temperature of 100 °C for an hour (1 h), the appearance of the red color, and leave the mixture on the room temperature for 2 minutes, and adding 4 ml of toluene. Later, it was

shaked until separated the red layers, then 3 ml of the upper layer was colored with red (containing proline), It was measured by optical spectrophotometer wavelength at 520 nm and has three replicates for each parameter. The blank contained only the toluene. These readings were compared with standard curve of pure proline.

The Standard Curve of Proline:

The standard curve of proline prepared according to the method of Bates *et al*. (1973) using a concentration, extracted from pure proline 10, 30, 50, 70, 90, 110 and 130 $\mu g.ml^{-1}$. After that, 2 ml of each dilution i.e pure proline; was taken and 2 ml of each of the glacial acetic acid and 2 ml ninhydrin were added to it, then put it in water bath 100 °C for 60 minutes. Cool the solution and add 4 ml of toluene and mixing using the test tube stirrer for one minute. Then reading was done with the spectrophotometer at a wavelength of 520 nm, the standard curve of proline comparing with the reading of samples.

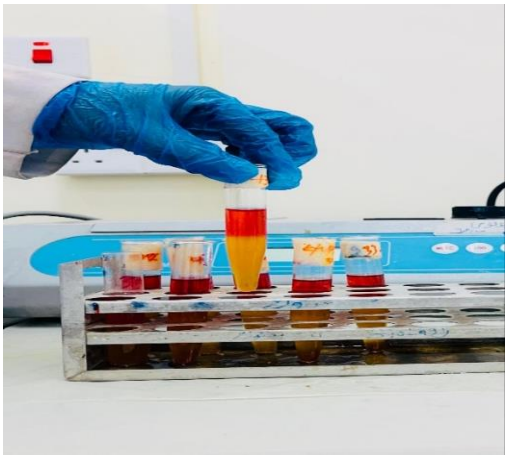

Figure 3.5. *A View of Proline Determination*

3.5.3.4. Total Carbohydrates (TCHO) %

0.1 g of dry leaves were mixed with 50 ml of distilled water, and then it was put in a water bath at 80°C for 30 minutes. Then centrifuged at 2000 RPM for 10 min., after filtaration, the volume of the extract is reduced and placed in a bottle. Then 1 ml of the extract was mixed with 1 ml phenol (5 %), Mix well, then 5 ml of concentrated sulfuric acid (H_2SO_4) and 10 ml of distilled water were added. Then the samples were measured by spectrophotometer at 488 nm (Thiele and Palsson, 2010).

For finding the carbohydrate concentration, the standard curve was obtained by taking 50 mg glucose and 50 mg fructose in 1 liter of distilled water, then 0.0, 0.2, 0.4, 0.6, 0.8, 1.0 mg/L stock solution was prepared. Like the samples, 1 ml of these dilutions was mixed with 1 ml of phenol (5 %) well and then 5 ml of concentrated sulfuric acid (H_2SO_4) were added; Spectra were observed at 488 nm to extract the relationship between concentrations and optical spectrophotometer intensity readings (Al-Hayani, 2015). The percentage of total carbohydrates was determined by the following formula:

$$\text{Total carbohydrate (\%)} = \frac{\text{Concentration from standers curve} * \text{Dilution}}{1000 * 1\text{ ml} * \text{sample weight}} * 100$$

3.6. The Chemical Elements

This analysis was done at the laboratories of the Department of Physics, Faculty of Science and Health, Koya University by using X-ray fluorescence (XRF) spectroscopy (NEX CG, Rigaku, USA) which is a well-established analytical technique for qualitative and quantitative elemental evaluation. It is a multielemental, simultaneous technique and additionally a non-destructive tool, thus it is suitable for plant analysis where about (5 g) of dry plant and soil materials were powdered and compressed by (Die press machine) to obtain a disc which is used for the XRF machine (Rodrigues et al., 2018 and Haschke, 2014)., whereas each of nitrogen, phosphorous and potassium were estimated chemically where leaves were oven dried at 65 °C for 24 hours till weight fixed, then ground by electrical grinder for each experimental unit. A 0.5 g of leaves were dry digested by adding 10 ml of concentrated sulfuric acid (H_2SO_4) and 10 ml of hydrogen peroxide (H_2O_2) with heating gradually for digestion as described by Ryan, et al. (2001) as follows:

3.6.1. Total Nitrogen (%)

The percentage of nitrogen contant was determined from digested samples by kjeldahl method (Allen, et al., 1974)

3.6.2. Total phosphorus (%)

The percentage of phosphorus contant was estimated from digested samples by spectrophotometer at 410 nm as described by Ryan, et al. (2001)

3.6.3. Total potassium (%)

Flame photometer was used for the determination of potassium (Kalra, 1998).

3.7. The Statistical Analysis

A Factorial Complete Randomized Design (CRD) with using three replications to conduct this study. Data were submitted for analysis of variance; Means were compared by Duncans multiple range test at $p \leq 0.05$ level using SAS software (Al-Mohammadi, 2002).

Chapter Four

4. Results

4.1. Effects of Magnetic water, Cadmium, and Their Interactions on Some Vegetative Growth Proprieties of *P. tomentosa*

4.1.1. Percent of Survived Cutting (%)

The results from Table 4.1 show, in comparison to tap water, the power of the magnetic device had non-significant on the percentage of survived cuttings. As like as the percent of survived cutting is unaffected significantly by cadmium concentration. Whereas the treatment 500 gausses increased significantly to 93.33%, compared only to the 2000 gausses treatment (86.67%). In addition to the treatments (G1000 x Cd6.66, G0 x Cd6.66, G0 x Cd10 and G2000 x Cd0) mg Cd. Kg^{-1} soil, where they give only 80%, the percent of survived cutting increased significantly in most interactions especially the treatment G500 x Cd6.66 mg Cd. Kg^{-1} soil (100%).

Table 4.1. *Effects of (MW), cadmium Element and their Interactions on the Percent (%) of P. tomentosa Survived Cutting.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average
MW (Gausses)	0	3.33	6.66	10	MW
0	96.67 ab	93.33 a-c	80.00 d	80.00 d	87.50 ab
500	93.33 a-c	93.33 a-c	100.00 a	86.67 b-d	93.33 a
1000	96.67 ab	93.33 a-c	80.00 d	96.67 ab	91.67 ab
1500	90.00 a-d	96.67 ab	93.33 a-c	86.67 b-d	91.67 ab
2000	80.00 d	83.33 cd	90.00 a-d	93.33 a-c	86.67 b
Average Cd	91.33 a	92.00 a	88.67 a	88.67 a	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.1.2. Velocity of Bud's Outgrowth (days)

Each of (15000 and 2000) gauss decreased plant velocity of buds outgrowth significantly compared to the low power magnifications (500 and 1000) gauss, and non-significantly compared to the tap water treatment, as shown in (Table 4.2). Cd concentration causes a significant increase in the plant's velocity of bud outgrowth compared to control. The interaction treatment G1500 x Cd0 mg Cd. Kg^{-1} soil reduced the velocity of buds outgrowth to only 78.96 days, whereas the interaction treatment G500 x Cd3.33 mg Cd. Kg^{-1} soil, had the longest period.

Table 4.2. *Effects of MW, Cadmium Element and their Interactions on the velocity (days) of P. tomentosa Buds Outgrowth.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average Gausses
Mw (Gausses)	0	3.33	6.66	10	
0	95.30 a-c	91.55 a-c	87.80 b-d	97.04 a-c	92.92 ab
500	93.61 a-c	102.72 a	93.47 a-c	95.58 a-c	96.34 a
1000	92.60 a-c	98.74 ab	98.20 ab	98.31 ab	96.96 a
1500	78.69 d	87.47 b-d	92.20 a-c	98.11 ab	89.11 b
2000	89.89 b-d	97.38 a-c	85.22 cd	90.53 a-d	90.75 b
Average Cd	90.01 b	95.57 a	91.37 ab	95.91 a	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.1.3. Plant Leaves Number. $plant^{-1}$

Except for the 1500 gauss, which significantly reduced plant leaves number to 6.50 compared to other treatments, the tap water did not differ significantly compared to most magnetic devices in respect to plant leaves number, as shown (Table 4.3). In comparison to the control treatment (7.67), adding Cd, especially the low concentration 3.33 mg Cd. kg^{-1}soil significantly increased the number of plant leaves to 9.04. The interaction treatments G2000 x Cd3.33 mg Cd. Kg^{-1} soil produced greater plant leaves number (11.67) significantly compared to all 1500 gauss interactions, (G500 x Cd0 and G1000 x Cd3.33) mg Cd. Kg^{-1} soil in addition to the control treatment.

Table 4.3. *Effects of Magnetic Water, Cd Element and their Interactions on the Leaves Number (plant^{-1}) of P. tomentosa.*

Treatments	Cd (mg Cd.Kg^{-1} soil)				Average Gausses
MW (Gausses)	0	3.33	6.66	10	
0	6.89 c-e	9.78 a-c	8.78 a-e	9.44 a-e	8.72 a
500	8.00 b-e	9.22 a-e	8.78 a-e	9.55 a-e	8.89 a
1000	8.78 a-e	7.33 c-e	10.78 ab	9.78 a-c	9.17 a
1500	6.22 e	7.22 c-e	6.22 e	6.33 de	6.50 b
2000	8.44 a-e	11.67 a	9.67 a-d	8.67 a-e	9.61 a
Average Cd	7.67 b	9.04 a	8.84 ab	8.75 ab	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.1.4. Plant Leaf Area (cm^2)

In comparison to 1500 gauss and the control treatments where they give the lowest values, plant leaf area increased significantly when (2000 and 1000) gauss were utilized, reaching 1604.17 and 1552.28 cm^2, respectively, as shown in (Table 4.4). Comparing the control treatment which gives the lowest leaf area (1197.14 cm^2), Cd application to all concentrations increased significantly plant leaves area to 1549.36, 1505.40, and 1504.29 cm^2 for 3.33, 6.66 and 10 mg Cd. Kg^{-1} soil respectively. Except for the interactions of 1500 gausses with Cd0 and Cd6.66 mg Cd. Kg^{-1} soil treatments, the control treatment produced the lowest plant leaf area (900.8 cm^2) compared to all other treatments, whereas the interactions of G2000 x Cd3.33 mg Cd. Kg^{-1} soil gave the highest plant leaf area reached (2004.4 cm^2).

Table 4.4. *Effects of Magnetic Water, Cd Element and their Interactions on the Leaf Area (cm^2) of P. tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average Gausses
MW(Gausses)	0	3.33	6.66	10	
0	900.8 f	1398.0 c-e	1786.5 ab	1384.1 c-e	1367.36 b
500	1407.5c-e	1601.2 b-d	1321.8 de	1607.1 b-d	1484.43 ab
1000	1321.4 de	1540.5 b-d	1619.4 b-d	1727.8 b	1552.28 a
1500	1162.3 ef	1202.8 e	1165.5 ef	1217.5 e	1187.00 c
2000	1193.7 e	2004.4 a	1633.7 bc	1584.9 b-d	1604.17 a
Average Cd	1197.14 b	1549.36 a	1505.40 a	1504.29 a	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.1.5. Plant Branch Number. $Plant^{-1}$

Table 4.5 shows the number of branches on the plants was not significantly affected by the power of the magnetic water or Cd concentration.

Table 4.5. *Effects of Magnetic Water, Cd Element and their Interactions on the Branch Number ($Plant^{-1}$) of P. tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average Gausses
MW(Gausses)	0	3.33	6.66	10	
0	1.44 a-c	1.56 ab	1.22 bc	1.44 a-c	1.42 a
500	1.44 a-c	1.22 bc	1.33 a-c	1.78 a	1.45 a
1000	1.33 a-c	1.22 bc	1.78 a	1.56 ab	1.47 a
1500	1.22 bc	1.33 a-c	1.33 a-c	1.55ab	1.36 a
2000	1.22 bc	1.44 a-c	1.67 ab	1.00 c	1.33 a
Average Cd	1.33 a	1.36 a	1.47 a	1.47 a	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

While the maximum branch number was achieved by the (G500 x Cd10 and G1000 x Cd6.66) mg Cd. kg^{-1}soil interaction treatments significantly compared to (G0 x Cd6.66, G500 x Cd3.33, G1000 x Cd3.33, G1500 x Cd0, G2000 x Cd0, and the G2000 x Cd10) mg Cd. kg^{-1}soil treatment with produced the lowest value (1.00 branch. $plant^{-1}$).

4.1.6. Stem Diameter (cm)

Using the MW 1500 gauss significantly increased stem diameter to 6.57 cm, compared to (500 and 2000) gauss treatments. The stem diameter significantly increased with increasing Cd concentrations, reaching 6.39 cm for the Cd10 treatment whereas the Cd0 gave the lowest value 5.98 cm, as shown in (Table 4.6). The majority of the interaction treatments did not significantly vary from each other in terms of stem diameter, where higher values were recorded for high concentrations of Cd with 1500 gausses with G0 x Cd6.66 mg Cd. kg^{-1}soil, whereas the lowest values were recorded for the most Cd0 interactions.

Table 4.6. *Effects of Magnetic Water, Cd Element and their Interactions on the Stem Diameter (cm) of P. tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average
MW(Gausses)	0	3.33	6.66	10	Gausses
0	5.46 ef	6.52 a-c	6.66 a	6.36 a-d	6.25 ab
500	5.84 b-f	6.11 a-f	5.76 c-f	6.53 a-c	6.06bc
1000	6.61 ab	6.19 a-d	6.04 a-f	6.46 a-c	6.33ab
1500	6.57 ab	6.37 a-d	6.65 a	6.67 a	6.57 a
2000	5.42 f	5.67 d-f	6.00a-f	5.91 a-f	5.75 c
Average Cd	5.98 b	6.17 ab	6.22 ab	6.39 a	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.1.7. Shoot Length (cm)

The results from the (Table 4.7) show, compared to all other treatments, plant high increased significantly to 38 cm at 1500 gauss MW, whereas the lowest values recorded for the G2000

treatment. Cd concentrations had no significant effect on this property, as presented in (figure 4.1). The interaction treatments of G1500 regardless Cd concentrations promoted plant high significantly in comparison to all other treatments while the control treatment recorded the lowest value (23.33 cm).

Table 4.7. *Effects of Magnetic Water, Cd Element and their Interactions on the Shoot Length (cm) of P. tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average Gausses
MW(Gausses)	0	3.33	6.66	10	
0	23.33 i	28.56 e-i	33.00 b-e	31.34 c-f	29.06 bc
500	30.56 d-h	29.11 e-i	27.00 e-i	32.67 b-e	29.83 b
1000	30.78 c-g	31.00 c-g	25.78 f-i	30.78 c-g	29.58 b
1500	36.00 a-d	37.22 a-c	38.44 ab	40.33 a	38.00 a
2000	29.11 e-i	24.00 hi	27.33 e-i	24.44 g-i	26.22 c
Average Cd	29.96 a	29.98 a	30.31 a	31.91 a	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

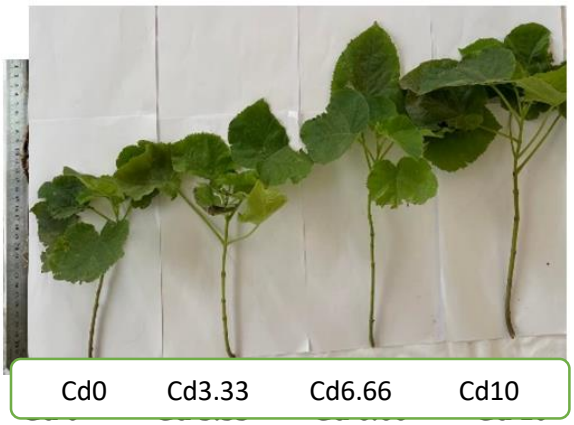

Figure 4.1. Effects of Cadmium on Shoots Length

4.1.8. Plant Shoot Fresh Weight (g)

The results from (Table 4.8) show, in comparison to other treatments, the control treatment gives the lowest value of shoot fresh weight (41.97g), while each of the (G500 and G1000) gauss

significantly increased shoot fresh weight significantly to 52.11 and 52.63g. All Cd concentrations increased shoot fresh weight significantly, compared to the control treatment. All interaction treatments significantly increased shoot fresh weight compared the control treatment (26.10 g), whereas the highest values the were recorded for Cd interactions of G500 treatment.

Table 4.8. *Effects of Magnetic Water, Cd Element and their Interactions on the Shoot Fresh Weight (g) of P. tomentosa*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average
MW(Gausses)	0	3.33	6.66	10	Gausses
0	26.10 e	44.23 cd	51.17 a-c	46.37 b-d	41.97 c
500	50.37 a-c	52.17 a-c	46.87 bc	59.70 a	52.11 a
1000	52.03 a-c	50.97 a-c	51.53 a-c	56.30 ab	52.63 a
1500	47.20 bc	48.33 bc	46.23 b-d	47.07 bc	47.21 b
2000	36.00 d	48.50 bc	46.03 b-d	42.73 cd	43.32 bc
Average Cd	42.34 b	48.84 a	48.23 a	50.37 a	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.1.9. Percent of Shoot Dry Matter (%)

Compared to other treatments, (1000 and 1500) gauss from MW significantly increased the percentage of shoot dry matter, whereas the Cd had non-significant effect on this property, as shown in (Table 4.9). Similarly, as compared to (G0, G500, and G2000) gauss interaction treatments, the percent of shoot dry matter increased significantly by (G1000 and G1500) gauss interaction treatments independent of the Cd concentrations, except the interactions (G0 xCd6.66 and G500 x Cd10) mg Cd. kg^{-1}soil.

Table 4.9. *Effects of Magnetic Water, Cd Element and their Interactions on the Percent of Shoot Dry Matter (%) of P. tomentosa*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average Gausses
MW(Gausses)	0	3.33	6.66	10	
0	13.36 e	16.19 c-e	18.55 a-d	16.17 c-e	16.07 b
500	16.05 c-e	16.46 b-e	16.79 b-e	18.09 a-d	16.85 b
1000	19.22 a-c	19.17 a-c	18.31 a-d	19.63 a-c	19.08 a
1500	21.19 a	20.29 ab	18.87 a-d	19.31 a-c	19.91 a
2000	14.05 e	16.68 b-e	17.14 b-e	15.24 de	15.78 b
Average Cd	16.77 a	17.76 a	17.93 a	17.69 a	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.1.10. Root Length(cm)

The results from (Table 4.10) show, increasing magnetic devices power to 1500 and 2000 gauss and the Cd concentrations to (6.66 and 10) mg Cd. Kg^{-1} soil decreased the root length significantly compared to low powers and low Cd concentrations, as shown in (figure4.2). The root length was significantly increased to 24.67 cm when 500 gauss water without Cd where used (Table 4.10), whereas the lowest value was recorded for G1500 x Cd10 mg Cd. kg^{-1}soil interaction treatment (14.00 cm).

Table 4.10. *Effects of Magnetic Water, Cd Element and their Interactions on the Root Length (cm) of P. tomentosa*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average Gausses
MW(Gausses)	0	3.33	6.66	10	
0	22.00 ab	21.33 ab	17.00 bc	17.33 bc	19.42 a
500	24.67 a	18.33 a-c	20.00 a-c	21.00 ab	21.00 a
1000	21.00 ab	20.00 a-c	19.67 a-c	20.33 a-c	20.25 a
1500	17.67 bc	18.00 bc	16.33 bc	14.00 c	16.50 b
2000	20.33 a-c	17.00 bc	20.33 a-c	15.67 bc	18.33 ab
Average Cd	21.13 a	18.93 ab	18.67 ab	17.67 b	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

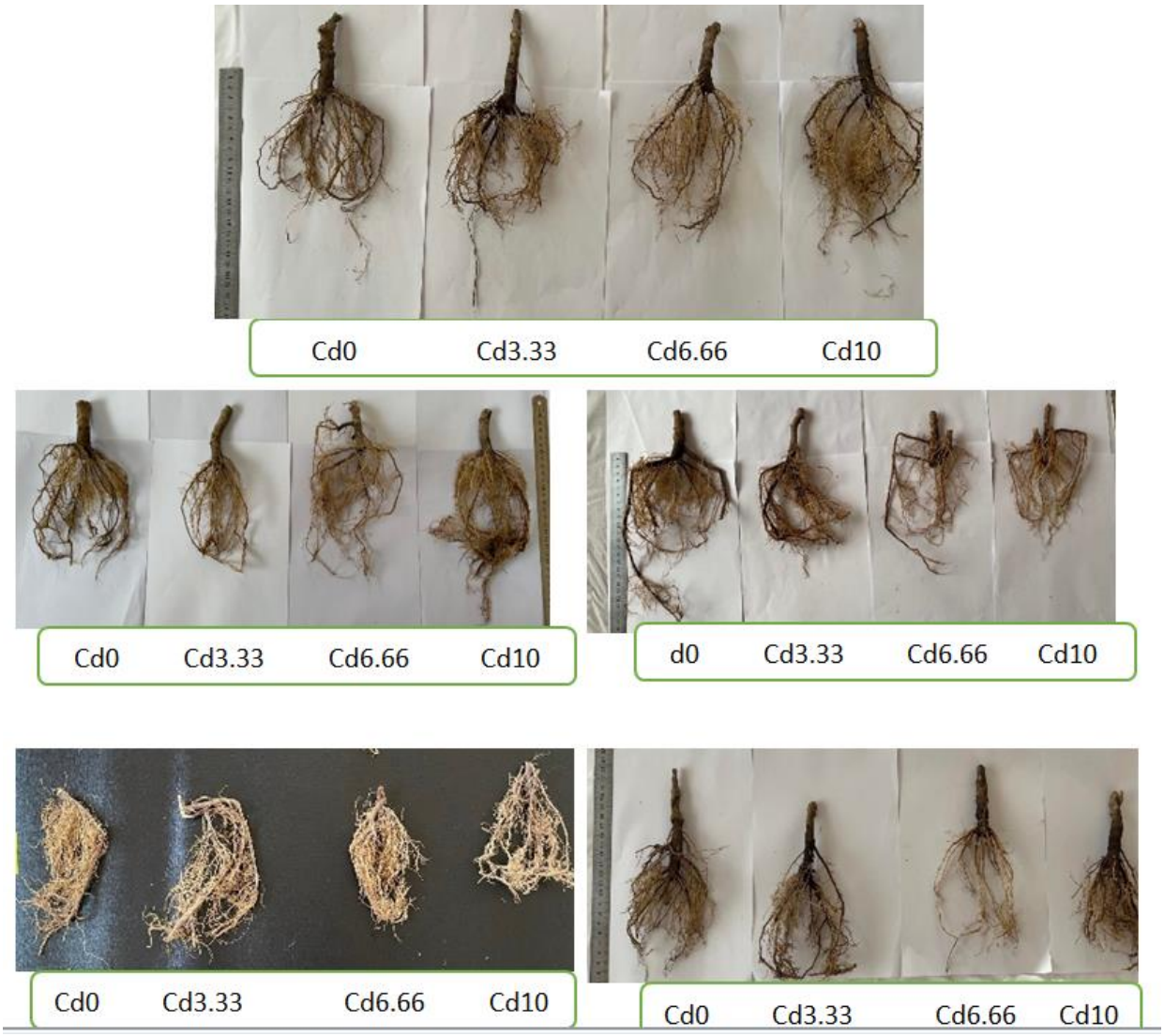

Figure 4.2. *Effects of Cadmium on Roots Length under (a) Gauss 0, (b) Gauss 500, (c) Gauss 1000, (d)Gauss1500 (e) Gauss 2000 Magnetic Water.*

4.1.11. Root Fresh Weight (g)

The power 1000 gauss MW increased root fresh weight significantly to (31.32g) compared to other treatments, whereas increasing the power to1500 and 2000 decreased it significantly to 22.88 and 20.28 g respectively, as shown in (Table 4.11). Regardless the concentration, adding Cd increased

root fresh weight compared to the control treatment. The interaction treatments (G0 x Cd6.66, G500 x Cd10 and G1000 x Cd0) mg Cd. kg^{-1}soil gave the highest root fresh weight significantly compared to most other treatments, whereas G2000 x Cd0 mg.kg^{-1}soil treatment gives the lowest value (13.33g).

Table 4.11. *Effects of magnetic water, Cd element and their interactions on the Root Fresh Weight* (g) *of P. tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average
MW(Gausses)	0	3.33	6.66	10	Gausses
0	15.13 ef	24.47 cd	35.17 a	23.77 cd	24.63 bc
500	23.03 de	25.57 b-d	26.93 b-d	35.83 a	27.84 ab
1000	35.20 a	33.10 ab	25.23 b-d	31.73 a-c	31.32 a
1500	23.02 de	26.36 b-d	20.94 d-f	21.21 d-f	22.88 cd
2000	13.33 f	21.67 de	19.23 d-f	26.87 b-d	20.28 d
Average Cd	21.94 b	26.23 a	25.50 a	27.88 a	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.1.12: Percentage of Root Dry Weight (%)

For 1500 gauss, the percentage of root dry matter increased significantly to 19.03% followed by each of (1000, 2000 and 500) gauss (12.58, 12.02 and 11.70%). The lowest value was recorded by the control treatment (9.97%). In comparison to the (Cd3.33 and Cd10) mg Cd. Kg^{-1} treatments alone, the Cd application with 6.66 mg Kg^{-1} soil significantly increased the percent of root dry matter to 14.27%, as presented in (Table 4.12). Interaction treatments of 1500 gauss with all Cd concentrations increased the percent of root dry weight significantly compared to all other treatments, except the G2000 x Cd6.66 mg Cd. kg^{-1}soil treatments.

Table 4.12. *Effects of magnetic water, Cd element and their interactions on the Root Dry Matter Percentage* (%) *P. tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average Gausses
MW(Gausses)	0	3.33	6.66	10	
0	9.57 cd	9.99 b-d	10.95 b-d	9.38 cd	9.97 c
500	11.83 b-d	10.60 b-d	10.76 b-d	13.62 b	11.70 b
1000	13.22 bc	11.86 b-d	12.43 b-d	12.79 b-d	12.58 b
1500	20.12 a	18.61 a	19.18 a	18.22 a	19.03 a
2000	10.06 b-d	11.21 b-d	18.01 a	8.80 d	12.02 b
Average Cd	12.96 ab	12.45 b	14.27 a	12.56 b	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.2. Leaves Content of Chlorophylls and Total Carotenoids

4.2.1. Chlorophyll a (mg.g^{-1} fresh weight)

The results of table 4.13 showed that the low powers (500 and 1000) gauss were better to the high powers (1500 and 2000) gauss for increasing these pigments. Regardless of device power, using MW increased Chl.a, significantly compared to tap wate, where the powers (500 and 1000) gauss increased the chl. The content, compare to all other treatments, significantly increased to 0.90 mg. g^{-1}, whereas the lowest value (0.85 mg. $g^{-1)}$ soil was recorded for the tap water. Regarding Cd application, higher Chl.a 0.90 mg. g^{-1} was recorded for Cd6.66 mg Kg^{-1}whereas, the lowest value (0.87 mg. g^{-1}) was recorded for the highest Cd concentration 10 mg. kg^{-1}soil. The interaction treatments G1000 x Cd0 mg Cd. kg^{-1}soil and G1500 x Cd6.66 mg Cd. kg^{-1}soil gave higher Chl.a significantly compared to all other treatments, whereas G0 x Cd10 mg Cd. kg^{-1}soil treatment gives the lowest value (0.80 mg.g^{-1}).

Table 4.13. *Effects of magnetic water, Cd element and their interactions on the Chlorophyll a (mg. g^{-1} Fresh Weight Leaves) of P. tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average
MW(Gausses)	0	3.33	6.66	10	Gauuse
0	0.870 f	0.860 g	0.890 e	0.806 i	0.856 e
500	0.900 d	0.900 d	0.906 bc	0.900 d	0.901 b
1000	0.920 a	0.890 e	0.900 d	0.910 b	0.905 a
1500	0.853 h	0.860 g	0.920 a	0.903 cd	0.884 d
2000	0.890 e	0.910 b	0.886 e	0.870 f	0.889 c
Average Cd	0.886 b	0.884 c	0.900 a	0.878 d	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.2.2. Chlorophyll b (mg.g^{-1} fresh weight)

Table 4.14's results showed that utilizing MW, regardless the device power, increased Chl.b significantly compared to tap water, where the highest value was recorded for the 500 gauss treatment (1.13 mg.g^{-1}), whereas the lowest value (0.81 mg.g^{-1}) was recorded where the tap water was used. Cd application increased significantly leaves content of chl.b significantly especial for concentration 3.33 mg.kg^{-1}soil (1.17 mg.g^{-1} fresh), while the lowest value (0.90 mg.g^{-1}) was recorded when tap water was used. The interaction treatments G500 x Cd10 mg Cd. kg^{-1}soil gave higher Chl.b and significantly, compared to all other treatments. The lowest value (0.54 mg.g^{-1}) is produced by the G0 x Cd10 mg Cd. kg^{-1} soil treatment.

Table 4.14. *Effects of magnetic water, Cd element and their interactions on the Chlorophyll b (mg. g^{-1} Fresh Weight Leaves) of P. tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average
MW(Gausses)	0	3.33	6.66	10	Gausses
0	0.873 m	0.970 k	0.880 m	0.546 p	0.817 e
500	1.010 i	1.120 f	1.046 h	1.353 a	1.132 a
1000	0.893 l	1.283 b	1.236 d	1.070 g	1.120 b
1500	0.760 n	1.210 e	1.260 c	1.213 e	1.110 c
2000	0.986 j	1.290 b	1.293 b	0.640 o	1.052 d
Average Cd	0.904 d	1.174 a	1.143 b	0.964 c	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.2.3. Total Carotenoid (mg.g^{-1} fresh weight*)*

The results of table 4.15 showed that using MW, regardless the device power, increased TC significantly, compared to tap water, whereas, Regarding Cd application, the effect was significant and higher TC was recorded for (Cd6.66 and Cd3.33) concentrations.

Table 4.15. *Effects of magnetic water, Cd element and their interactions on the Carotenoid (mg. g^{-1} Fresh Weight Leaves) of P. tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average
MW(Gausses)	0	3.33	6.66	10	Gausses
0	0.340 c	0.360 a	0.350 b	0.333 d	0.345 e
500	0.360 a	0.360 a	0.360 a	0.360 a	0.360 a
1000	0.350 b	0.360 a	0.360 a	0.360 a	0.357 b
1500	0.340 c	0.350 b	0.360 a	0.360 a	0.352 d
2000	0.360 a	0.360 a	0.360 a	0.340 c	0.355 c
Average Cd	0.350 b	0.358 a	0.358 a	0.350 b	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

It is seen that application of Cd for all concentrations and most interactions between the MW and Cd increased the total car significantly compared to the control treatment.

4.3. Effect of Magnetic Water, Cadmium and Their Interactions on Some Enzymatic and Non-Enzymatic Components of *P. tomentosa.*

4.3.1. Peroxidase Enzyme Activity (μg.g^{-1})

From the results of table 4.16, it is shown that G500 MW significantly increased POD enzyme activity, reaching 110.67 μg.g^{-1}. The enzyme activity decreased with increasing the power of the magnetic device where the lowest enzyme activity (85.83 μg.g^{-1}) was recorded for the 2000 gauss. The enzyme activity significantly increased at low Cd concentrations (3.33 mg Kg-1 soil), whereas significantly decreased at high Cd concentration to 88.27 μg.g^{-1}for 10 mg Cd. Kg^{-1} soil. The interaction treatment G500 x Cd3.33 mg Cd. Kg^{-1} soil caused a significant increase in the enzyme activity to 132 μg.g^{-1}, whereas the lowest value (62.00 μg.g^{-1} was recorded for the plants irrigated with tap water and received the highest Cd concentrations, it is also shown that most interactions of (1500 and 2000) gauss with most Cd concentrations recorded low activities of the enzyme.

Table 4.16. *Effects of magnetic water, Cd element and their interactions on the POD (μg.g^{-1}Fresh Weight Leaves) of P.Tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average Gausses
MW(Gausses)	0	3.33	6.66	10	
0	97.67 e-g	116.67 c	125.00 b	62.00 k	100.33 b
500	98.00 e-f	132.00 a	108.33 d	104.33 de	110.67 a
1000	91.00 f-i	108.33 d	108.00 d	102.33 d-e	102.42 b
1500	92.67 f-h	100.67 d-e	89.67 h-j	82.33 j	91.33 c
2000	86.67 h-j	84.00 ij	82.33 j	90.33 g-i	85.83 d
Average Cd	93.20 c	108.33 a	102.67 b	88.27 d	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.3.2. Ascorbic Acid Content ($g.L^{-1}$)

For (500 and 1500) gauss, leaves content of A.A content increased significantly to (3.15 and 3.19) $g.L^{-1}$, compared to tap water (2.31 $g.L^{-1}$). For Cd10 mg Cd. Kg^{-1}, increased AA was observed as a result of Cd application, as shown in (Table 4.17). Irrigation with 1500 gausses water and adding 10 mg Cd. Kg^{-1} soil Cd increased the AA content significantly to 4.25 $g.L^{-1}$dry weight significantly, compared to all the other treatments, whereas the lowest value (0.47 $g.L^{-1}$dry weight) was recorded for G2000 x Cd6.66 mg Cd. Kg^{-1} soil treatment.

Table 4.17. *Effects of magnetic water, Cd element and their interactions on the Ascorbic Acid ($g.L^{-1}$Dry Weight leaves) of P. tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average
MW(Gausses)	0	3.33	6.66	10	Gausses
0	2.00 gh	1.88 h	3.03 d	2.31 f	2.31 b
500	2.03 g	3.94 bc	3.91 c	2.72 e	3.15 a
1000	1.59 i	1.97 gh	1.97 gh	2.59 e	2.03 c
1500	1.41 j	3.03 d	4.06 b	4.25 a	3.19 a
2000	3.13 d	2.38 f	0.47 k	2.28 f	2.06 c
Average Cd	2.03 c	2.64 b	2.69 b	2.83 a	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.3.3. Leaves Proline Content ($\mu g.ml^{-1}$)

The results from (Table 4.18) show, in comparison to other treatments, the plant watered with 1000 gauss treated water significantly increased the proline content of the leaves to 71.39 $\mu g.ml^{-1}$fresh weight and increasing the power to 2000 gauss decreased the proline content significantly to 39.4 $\mu g.ml^{-1}$ fresh weight, compared to the other treatment. Proline concentrations increased significantly with increases in Cd concentration to 6.66 and 10 mg Cd. Kg^{-1} soil, compared to the control treatment, which reached 62.29 $\mu g.ml^{-1}$fresh weight. In comparison to other interaction treatments, the interaction treatments G0 x Cd10 mg Cd. Kg^{-1} soil and G1000 x Cd6.66 mg Cd. Kg^{-1} soil significantly increased the proline concentration to (76.88 and 76.73) $\mu g.ml^{-1}$fresh weight, especially compared to interactions of G2000 with different Cd concentrations.

Table 4.18. *Effects of magnetic water, Cd element and their interactions on the Proline (μg.ml^{-1}Fresh Weight) of P. tomentosa.*

Treatments	Cd (mg Cd. Kg^{-1} soil)				Average Gausses
MW(Gausses)	0	3.33	6.66	10	
0	72.92 d	73.81 c	58.31 m	76.88 a	70.48 b
500	75.92 b	59.58 l	66.00 h	66.65 h	67.04 c
1000	71.92 e	67.85 g	76.73 a	69.04 f	71.39 a
1500	61.31 k	63.50 j	59.69 l	64.31 i	62.20 d
2000	29.38 q	34.42 p	55.08 n	38.77 o	39.41 e
Average Cd	62.29 b	59.83 c	63.16 a	63.13 a	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.3.4. Total Carbohydrate Content (%)

The powers of different magnetic devices vary significantly from one another regarding the percentage of total carbohydrate content (TCHO), from the G1500 recorded the highest value (3.09%) and the G500 recording the lowest value (2.43%). No Cd treated records the highest percent of TCHO (2.89%), whereas the lowest value (2.29%) was recorded for the Cd6.66 mg Cd. Kg^{-1} soil treatment, as presented in (Table 4.19). The interaction treatment G1500 x Cd0 mg Cd. Kg^{-1} soil records the highest TCHO percent (3.43%), compared to all the other treatments, whereas interaction of tap water with Cd6.66 mg Cd. Kg^{-1}Soil records the lowest value (1.82%).

Table 4.19. *Effects of magnetic water, Cd element and their interactions on the Total Carbohydrate (%) of P. tomentosa.*

Treatments	Cd (mg Cd.Kg^{-1} soil)				Average Gausses
MW(Gausses)	0	3.33	6.66	10	
0	2.49 l	2.77 i	1.82 q	3.08 e	2.54 c
500	3.14 d	1.99 p	2.21 o	2.39 m	2.43 e
1000	2.85 g	2.27 n	1.98 p	2.81 h	2.48 d
1500	3.43 a	2.73 j	2.89 f	3.31 c	3.09 a
2000	2.54 k	3.39 b	2.56 k	2.78 hi	2.82 b
Average Cd	2.89 a	2.63 c	2.29 d	2.87 b	

Means followed by the same letter factor and their interactions are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

4.4. Some of Macro, Micro, Beneficial, Heavy Metals and Other Trace Elements in *P. tomentosa*

4.4.1. Essential Macro Elements in *P. tomentosa* Growing Soil

Changes recorded under the influence of MW and Cd on the essential macro elements content in *P. tomentosa* soil. According to the results in table 4.20, the application of MW significantly increased macro elements in soil such as (N, P, K, Ca and S), compared to tap wate. Using of Cd at low concentration significantly increased (P and S), but Cd had non-significant effect on this (K and Ca) content. Also, (N) decreased with increasing Cd. Also essential macro element in soil significantly increased by using power 1500 gauss interaction with Cd, regardless of Cd concentration.

4.4.2. Essential Micro Elements in *P. tomentosa* Growing Soil

Table 4.21 shows the effect of MW and Cd and their interactions on the essential micro elements of *P. tomentosa* soil. Increasing power of MW significantly increased all essential micro elements such as (Fe, Zn, Cu, Cl and Ni). Increasing Cd concentration increased all essential micro elements in soil. The interaction treatments G2000 x Cd6.66 mg Cd. Kg^{-1}soil gaves higher of (Fe and Ni) content, but (Zn, Cu and Cl) increased at high concentration of Cd with interaction of MW.

4.4.3. Beneficial Elements in *P. tomentosa* Growing Soil

Table 4.22 shows the effect of MW and Cd and their interactions on the beneficial elements content of *P. tomentosa* soil. Application of MW significantly increased (Ti and Co). Increasing concentration of Cd increased beneficial elements in soil. Interaction treatments high power of MW and Cd significantly increased beneficial elements in soil.

4.4.4. Non essential Heavy metals Elements in *P. tomentosa* Growing Soil

Based on the results, table 4.23 show the effect of MW, Cd and their interaction on non essential heavy metals elements in *P. tomentosa* soil. elements of non essential heavy metal significantly increased with increasing power of MW. Only Pb decreased. Whereas elements increased with increasing Cd concentration. High power of MW interaction with Cd, regardless of Cd increased some non essential heavy metals elements.

4.4.5. Trace Elements in *P. tomentosa* Growing Soil (part I)

The effect of MW and Cd and their interactions on trace elements in *P. tomentosa* soil is shown in table 4.24.A. the trace elements in soil significantly increased with using of MW, but W content decreased. These elements significantly increased with the application of Cd such as (Ta, Hf, Re and Au). only W content non-significant with adding Cd. Irrigation with high power of MW interaction with high Cd concentration significantly increasesome trace element in soil.

4.4.6. Trace Elements in *P. tomentosa* Growing Soil (part II)

The effects of MW and Cd with their interactions on the trace elements components in *P. tomentosa* are shown in table 4.24.B. All elements in this table significantly increased with utilizing of MW, only Y content had non-significant with application of MW.

Also some elements increased with high concentration of Cd such as (Ga, Ir, Th and Sn), only (Y and Ba) where not effected significantly with used of Cd. Interaction treatments of G2000 x Cd 10 mg Cd. Kg^{-1} soil significantly increased the most elements in table 4.24.B.

Table 4.20. *Effects of magnetic water, Cd element and their interactions on some essential macro elements of P. tomentosa growing soil*

Treatments	N %	P ppm	K %	Ca %	S ppm
Magnetic Water (MW) (Gauss)					
G0	0.20 b	54.37 c	1.77 bc	17.90 b	599.88 c
G500	0.26 a	65.75 a	1.83 b	18.16 b	718.38 b
G1000	0.25 a	56.12 bc	1.66 c	19.32 b	729.38 b
G1500	0.26 a	63.31 a	2.13 a	22.15 a	1031.25 a
G2000	0.20 b	57.50 b	1.87 b	21.77 a	656.00 bc
Cd concentration (mg Kg^{-1} soil)					
Cd 0	0.26 a	54.75 c	1.82 a	19.76 a	639.30 b
Cd 3.33	0.26 a	63.30 a	1.83 a	20.08 a	778.70 a
Cd 6.66	0.20 c	61.10 a	1.88 a	19.61 a	771.30 a
Cd 10	0.23 b	58.50 b	1.89 a	20.00 a	798..60 a
Interactions effect of MW and Cd					
G0 Cd0	0.17 ef	51.00 fg	1.80 b-d	17.10 e	451.50 j
G0 Cd3.33	0.26 c	57.25 c-f	1.70 cd	17.90 de	489.00 ij
G0 Cd6.66	0.18 e	52.25 e-g	1.77 b-d	18.00 de	685.00 f-h
G0 Cd10	0.19 e	57.00 c-g	1.82 b-d	18.60 c-e	774.00 e-g
G500 Cd0	0.28 c	70.00 b	1.79 b-d	17.90 de	556.00 h-j
G500 Cd3.33	0.37 b	81.75 a	1.91 b-d	18.50 c-e	676.50 f-h
G500 Cd6.66	0.19 e	56.75 c-g	1.80 b-d	17.95 de	639.50 f-i
G500 Cd10	0.19 e	54.50 c-g	1.84 b-d	18.30 c-e	1001.50 bc
G1000 Cd0	0.28 c	58.75 cd	1.37 e	17.00 e	753.00 e-g
G1000 Cd3.33	0.28 c	59.25 cd	1.62 de	20.95 b-d	852.00 c-e
G1000 Cd6.66	0.28 c	56.00 c-g	1.86 b-d	19.40 b-e	670.00 f-h
G1000 Cd10	0.18 e	50.50 g	1.80 b-d	19.95 b-e	642.50 f-i
G1500 Cd0	0.16 ef	40.75 h	2.28 a	25.10 a	907.00 b-e
G1500 Cd3.33	0.25 cd	57.50 c-e	2.11 ab	20.75 b-d	1200.00 a
G1500 Cd6.66	0.20 de	82.50 a	2.04 a-c	22.20 ab	1060.00 ab
G1500 Cd10	0.44 a	72.50 b	2.09 ab	20.55 b-e	958.00 b-d
G2000 Cd0	0.40 ab	53.25 d-g	1.86 b-d	21.70 bc	529.00 h-j
G2000 Cd3.33	0.17 ef	60.75 c	1.81 b-d	22.30 ab	676.00 f-h
G2000 Cd6.66	0.13 f	58 c-e	1.93 b-d	20.50 b-e	802.00 d-f
G2000 Cd10	0.13 f	58 c-e	1.90 b-d	22.60 ab	617.00 g-i

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.21. *Effects of magnetic water, Cd element and their interactions on some essential micro elements of P. tomentosa growing soil*

Treatments	Fe %	Zn ppm	Cu Ppm	Cl ppm	Ni ppm
Magnetic Water (MW) (Gauss)					
G0	7.61 a	130.62 c	71.91 c	377.13 a	474.50 bc
G500	7.60 a	133.25 bc	73.62 bc	323.50 b	491.25 ab
G1000	7.13 b	140.92 a	70.32 c	386.50 a	461.00 c
G1500	7.77 a	139.75 ab	77.17 ab	355.63 ab	469.25 bc
G2000	7.80 a	127.87 c	78.78 a	317.38 b	513.13 a
Cd concentration (mg Kg^{-1} soil)					
Cd 0	7.37 b	123.94 c	70.28 c	237.80 d	452.70 b
Cd 3.33	7.55 ab	133.30 b	73.91 b	384.40 b	482.90 a
Cd 6.66	7.65 a	142.20 a	74.34 b	335.70 c	494.30 a
Cd 10	7.75 a	138.50 ab	78.93 a	450.20 a	497.40 a
Interactions effect of MW and Cd					
G0 Cd0	7.57 a-c	124.50 de	71.05 cd	186.50 g	464.50 de
G0 Cd3.33	7.32 c	131 c-e	72.10 cd	262.50 d-g	460.50 de
G0 Cd6.66	7.67 a-c	132 c-e	72.50 cd	342.00 cd	480.00 c-e
G0 Cd10	7.91 a-c	135.00 c-e	72.00 cd	717.50 a	493.00 b-e
G500 Cd0	7.80 a-c	128.00 de	73.90 cd	231.00 e-g	490.50 b-e
G500 Cd3.33	7.72 a-c	137.50 cd	79.30 bc	302.50 c-f	545.00 ab
G500 Cd6.66	7.35 bc	135.50 c-e	69.95 d	289.00 c-g	458.50 e
G500 Cd10	7.53 a-c	132.00 c-e	71.35 cd	471.50 b	471.00 c-e
G1000 Cd0	6.00 d	109.70 f	55.00 e	314.00 c-f	376.00 f
G1000 Cd3.33	7.44 a-c	129.00 c-e	71.25 cd	515.50 b	467.00 de
G1000 Cd6.66	7.48 a-c	170.00 a	78.35 b-d	341.50 cd	481.50 c-e
G1000 Cd10	7.60 a-c	155.00 b	76.70 b-d	375.00 c	519.50 b-d
G1500 Cd0	8.01 ab	136.50 c-e	76.25 b-d	225.50 fg	472.50 c-e
G1500 Cd3.33	7.50 a-c	145.00 bc	73.45 cd	511.00 b	463.00 de
G1500 Cd6.66	7.71 a-c	139.50 cd	76.70 b-d	335.50 c-e	466.00 de
G1500 Cd10	7.86 a-c	138.00 cd	82.30 b	350.50 cd	475.50 c-e
G2000 Cd0	7.48 a-c	121.00 ef	75.20 b-d	232.00 e-g	460.00 e
G2000 Cd3.33	7.80 a-c	124.00 de	73.45 cd	330.50 c-f	479.00 c-e
G2000 Cd6.66	8.06 a	134.00 c-e	74.20 b-d	370.50 cd	585.50 a
G2000 Cd10	7.87 a –c	132.50 c-e	92.30 a	336.50 c-e	528.00 bc

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.22. *Effects of magnetic water, Cd element and their interactions on some beneficial elements of P. tomentosa growing soil*

Treatments	Ti %	Co ppm
Magnetic Water (MW) (Gauss)		
G0	0.65 b	371.13 a
G500	0.66 b	368.38 a
G1000	0.61 c	302.63 b
G1500	0.71 a	312.13 b
G2000	0.68 ab	387.25 a
Cd concentration (mg Kg-1 soil)		
Cd 0	0.62 b	327.40 b
Cd 3.33	0.67 a	322.00 b
Cd 6.66	0.69 a	366.00 a
Cd 10	0.69 a	377.80 a
Interactions effect of MW and Cd		
G0 Cd0	0.64 bc	352.50 b-d
G0 Cd3.33	0.66 a-c	404.00 b
G0 Cd6.66	0.66 a-c	365.00 b
G0 Cd10	0.66 a-c	363.00 b
G500 Cd0	0.67 a-c	403.50 b
G500 Cd3.33	0.67 a-c	375.00 b
G500 Cd6.66	0.66 a-c	350.50 b-d
G500 Cd10	0.67 a-c	344.50 b-d
G1000 Cd0	0.44 d	188.00 e
G1000 Cd3.33	0.60 c	252.50 de
G1000 Cd6.66	0.70 ab	397.50 b
G1000 Cd10	0.70 ab	372.50 b
G1500 Cd0	0.68 a-c	337.00 b-d
G1500 Cd3.33	0.74 a	257.50 c-e
G1500 Cd6.66	0.71 ab	351.50 b-d
G1500 Cd10	0.73 ab	302.50 b-d
G2000 Cd0	0.66 a-c	356.00 bc
G2000 Cd3.33	0.67 a-c	321.00 b-d
G2000 Cd6.66	0.71 ab	365.50 b
G2000 Cd10	0.68 a-c	506.50 a

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.23. *Effects of magnetic water, Cd element and their interactions on some non-essential heavy metals elements of P. tomentosa growing soil*

Treatments	Cr %	Cd ppm	Pb ppm	As ppm	Br ppm	Rb ppm
Magnetic Water (MW) (Gauss)						
G0	0.104 ab	34.40 d	45.33 b	12.12 b	10.27 ab	100.10 a
G500	0.100 b	39.47 cd	57.48 a	10.85 b	10.97 a	101.53 a
G1000	0.11 a	50.85 b	31.70 c	10.97 b	9.07 b	87.35 b
G1500	0.09 b	117.51 a	37.86 c	11.91 b	10.56 ab	99.45 a
G2000	0.11 a	44.67 bc	35.66 c	14.65 a	10.80 a	90.07 b
Cd concentration (mg Kg-1 soil)						
Cd 0	0.10 b	0.00 d	39.00 b	11.32 b	10.30 b	90.71 c
Cd 3.33	0.11 a	40.86 c	36.03 b	11.21 b	9.76 b	97.84 ab
Cd 6.66	0.10 b	71.24 b	51.49 a	11.37 b	9.20 b	94.34 bc
Cd 10	0.09 b	117.43 a	39.92 b	14.50 a	12.08 a	99.92 a
Interactions effect of MW and Cd`						
G0 Cd0	0.12 bc	0 i	52.45 a-d	11.60 bc	11.15 b-e	101.15 a-c
G0 Cd3.33	0.09 de	21.60 h	34.60 e-h	11.90 bc	7.11 f	90.10 d-f
G0 Cd6.66	0.11 b-d	48.20 fg	58.00 a-c	12.60 bc	10.40 b-f	102.15 a-c
G0 Cd10	0.09 de	67.80 e	36.30 d-h	12.40 bc	12.45 bc	107.00 a
G500 Cd0	0.10 b-e	0 i	47.70 b-e	11.00 bc	13.40 ab	95.85 a-f
G500 Cd3.33	0.10 b-e	31.00 gh	58.05 a-c	8.23 c	10.70 b-e	107.00 a
G500 Cd6.66	0.09 de	36.15 gh	59.30 ab	12.30 bc	7.79 ef	99.80 a-c
G500 Cd10	0.10 c-e	90.75 d	64.90 a	11.90 bc	12.00 b-d	103.50 ab
G1000 Cd0	0.09 de	0 i	20.40 h	8.34 c	7.92 ef	72.70 g
G1000 Cd3.33	0.12 b	31.45 gh	23.80 gh	13.15 bc	10.15 b-f	98.90 a-e
G1000 Cd6.66	0.12 bc	61.35 ef	39.85 d-g	12.00 bc	8.84 d-f	87.80 ef
G1000 Cd10	0.11 b-d	110.60 c	42.75 c-f	10.40 bc	9.38 c-f	90.00 d-f
G1500 Cd0	0.11 b-d	0 i	40.00 d-g	14.90 b	9.87 c-f	98.60 a-e
G1500 Cd3.33	0.11 b-d	90.05 d	24.00 gh	11.20 bc	11.50 b-d	101.15 a-c
G1500 Cd6.66	0.08 e	148.50 b	59.60 ab	10.80 bc	10.20 b-f	91.55 c-f
G1500 Cd10	0.09 de	231.50 a	27.85 f-h	10.75 bc	10.67 b-e	106.50 a
G2000 Cd0	0.10 c-e	0 i	34.45 e-h	10.80 bc	9.16 c-f	85.25 f
G2000 Cd3.33	0.14 a	30.20 gh	39.70 d-g	11.60 bc	9.34 c-f	92.05 c-f
G2000 Cd6.66	0.10 c-e	62.00 ef	40.70 d-g	9.17 bc	8.80 d-f	90.40 d-f
G2000 Cd10	0.09 de	86.50 d	27.80 f-h	27.05 a	15.90 a	92.60 b-f

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.24. A. *Effects of magnetic water, Cd element and their interactions on some other trace elements of P. tomentosa growing soil*

Treatments	Ta Ppm	Hf ppm	Re Ppm	Au ppm	W Ppm
Magnetic Water (MW) (Gauss)					
G0	57.72 ab	33.25 b	27.02 c	9.37 b	197.25 a
G500	57.48 ab	32.93 b	29.45 bc	11.12 b	149.38 c
G1000	47.58 c	32.96 b	31.51 b	10.06 b	175.75 ab
G1500	52.22 bc	36.21 b	28.75 bc	10.89 b	138.08 c
G2000	61.75 a	45.13 a	39.93 a	13.91 a	159.00 bc
Cd concentration (mg Kg-1 soil)					
Cd 0	54.84 b	37.39 ab	30.44 b	11.69 ab	157.90 a
Cd 3.33	54.39 b	32.99 c	29.53 b	9.81 b	170.50 a
Cd 6.66	52.41 b	33.79 bc	27.76 b	9.89 b	158.10 a
Cd 10	59.78 a	40.23 a	37.61 a	12.90 a	169.06 a
Interactions effect of MW and Cd					
G0 Cd0	56.70 c-f	35.50 b-g	36.85 b-e	10.80 b-d	196.50 bc
G0 Cd3.33	51.70 d-f	24.35 h	26.70 f-j	8.35 cd	176.50 b-e
G0 Cd6.66	57.60 c-f	34.60 b-h	28.35 e-j	8.33 cd	167.00 b-e
G0 Cd10	64.90 a-c	38.55 b-e	16.20 k	10.00 b-d	249.00 a
G500 Cd0	70.05 ab	42.40 bc	41.25 b	15.10 b	163.00 b-e
G500 Cd3.33	47.20 fg	28.20 e-h	32.10 b-g	9.21 cd	151.50 c-e
G500 Cd6.66	52.25 d-f	30.25 d-h	20.70 jk	11.02 b-d	157.00 b-e
G500 Cd10	60.45 b-e	30.90 d-h	23.75 g-k	9.14 cd	126.00 e
G1000 Cd0	37.60 g	25.70 gh	21.10 jk	9.45 cd	153.50 b-e
G1000 Cd3.33	57.50 c-f	34.25 b-h	33.90 b-f	10.90 b-d	195.00 bc
G1000 Cd6.66	45.65 fg	38.90 b-e	31.65 c-h	7.60 d	203.50 b
G1000 Cd10	49.60 d-f	33.00 c-h	39.40 b-d	12.31 b-d	151.00 c-e
G1500 Cd0	52.35 d-f	44.45 b	22.25 i-k	10.10 b-d	131.00 e
G1500 Cd3.33	54.00 c-f	38.55 b-e	22.65 h-k	10.10 b-d	145.50 c-e
G1500 Cd6.66	54.55 c-f	27.35 f-h	29.90 e-j	12.60 b-d	124.50 e
G1500 Cd10	48.00 e-g	34.50 b-h	40.20 bc	10.78 b-d	151.30 c-e
G2000 Cd0	57.50 c-f	38.90 b-e	30.75 d-i	13.00 bc	145.50 c-e
G2000 Cd3.33	61.55 b-d	39.60 b-d	32.30 b-g	10.50 b-d	184.00 b-d
G2000 Cd6.66	52.00 d-f	37.85 b-f	28.20 e-j	9.89 b-d	138.50 de
G2000 Cd10	75.95 a	64.20 a	68.50 a	22.26 a	168.00 b-e

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.24.B. *Effects of magnetic water, Cd element and their interactions on some other trace elements of P. tomentosa growing soil*

Treatments	Ga	Y	Ir	Th	Ba	Sn
	Ppm					
Magnetic Water (MW) (Gauss)						
G0	13.00 b	36.71 a	14.86 b	15.07 ab	320.00 c	126.75 ab
G500	13.60 ab	37.28 a	15.86 b	16.10 ab	338.37 b	124.12 b
G1000	13.28 b	35.60 a	17.10 b	14.15 b	312.62 c	129.22 ab
G1500	14.23 ab	35.93 a	16.71 b	14.85 ab	362.25 a	133.62 a
G2000	15.27 a	38.33 a	20.17 a	16.33 a	344.12 b	133.12 a
Cd concentration (mg Kg-1 soil)						
Cd 0	13.44 b	35.61 a	17.84 b	15.55 ab	331.20 a	129.08 ab
Cd 3.33	13.43 b	35.99 a	13.85 c	14.28 b	341.70 a	127.00 b
Cd 6.66	13.15 b	37.12 a	15.27 c	14.54 b	330.80 a	125.30 b
Cd 10	15.49 a	38.38 a	20.81 a	16.84 a	338.20 a	136.10 a
Interactions effect of MW and Cd						
G0 Cd0	13.25 b-d	37.65 ab	15.90 de	16.00 b-d	310.50 e-g	1 22.50 b-d
G0 Cd3.33	15.20 bc	34.80 bc	13.00 de	14.35 b-d	310.50 e-g	124.50 b-d
G0 Cd6.66	11.15 cd	37.25 ab	15.15 de	15.36 b-d	317.50 d-g	125.00 b-d
G0 Cd10	12.40 b-d	37.15 ab	15.40 de	14.60 b-d	341.50 a-f	135.00 a-d
G500 Cd0	15.45 b	40.00 ab	21.65 bc	18.00 b	329.50 b-g	123.00 b-d
G500 Cd3.33	13.65 b-d	36.00 a-c	13.15 de	15.00 b-d	361.00 a-c	131.50 a-d
G500 Cd6.66	11.60 b-d	34.95 bc	12.95 de	16.35 bc	328.50 c-g	120.00 cd
G500 Cd10	13.70 b-d	38.20 ab	15.70 de	15.05 b-d	334.50 b-g	122.00 b-d
G1000 Cd0	11.04 cd	29.05 c	17.00 b-e	11.76 d	298.50 g	123.40 b-d
G1000 Cd3.33	13.25 b-d	36.55 ab	12.15 e	15.15 b-d	320.50 d-g	129.50 a-d
G1000 Cd6.66	15.80 b	38.25 ab	17.20 b-e	15.00 b-d	323.00 c-g	118.50 d
G1000 Cd10	13.05 b-d	38.55 ab	22.05 b	14.70 b-d	308.50 fg	145.50 a
G1500 Cd0	14.60 b-d	35.95 a-c	17.95 b-d	16.35 bc	378.00 a	144.50 a
G1500 Cd3.33	14.50 b-d	36.20 a-c	13.95 de	14.40 b-d	367.50 ab	119.50 cd
G1500 Cd6.66	13.35 b-d	36.45 ab	17.00 b-e	12.90 c-d	350.00 a-d	131.00 a-d
G1500 Cd10	14.50 b-d	35.15 bc	17.95 b-d	15.75 b-d	353.50 a-d	139.50 ab
G2000 Cd0	12.90 b-d	35.40 a-c	16.70 c-e	15.65 b-d	339.50 b-f	132.00 a-d
G2000 Cd3.33	10.56 d	36.40 ab	17.00 b-e	12.50 c-d	349.00 a-e	130.00 a-d
G2000 Cd6.66	13.85 b-d	38.70 ab	14.05 de	13.0 cd	335.00 b-g	132.00 a-d
G2000 Cd10	23.80 a	42.85 a	32.95 a	24.10 a	353.00 a-d	138.50 a-c

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

4.4.7. Essential Macro Elements in *P. tomentosa* Roots

Table 4.25 shows the effect of MW, Cd and their interactions on the essential macro elements content in *P. tomentosa* roots. Utilizing MW significantly increased essential macro element in root such as (N, K, Ca and S), only P content significantly decreased with applying MW. Whereas using high concentration of Cd significantly increased of elements such as (N and K), but decreased element of (P and Ca), also Cd had non-significantly effect on S contents. The interaction treatments high power of MW and Cd increased essential macro element, only P content decreased.

4.4.8. Essential Micro Elements in *P. tomentosa* Roots

The results shown in table 4.26 reflect the influence of MW, Cd, and the interactions between them on the essential micro element in *P. tomentosa* in roots. Application of MW and Cd significantly decreased essential micro elements in root such as (Mn, Zn, Cu and Ni), only Cl content increased. The interaction treatments of G500 x Cd 3.33 mg Cd. Kg-1 soil significantly increased most essential micro element in root.

4.4.9. Beneficial Elements in *P. tomentosa* Roots

Table 4.27 shows the effect of exposure to MW and Cd and their interactions on beneficial element in *P. tomentosa* roots. Adding of MW significantly decreased (Ti and Co). Increased concentration of Cd significantly increased most beneficial element. The interaction treaments of Cd with high power of MW increased most elements.

4.4.10. Non essential Heavy Metal Elements in *P. tomentosa* Roots

Table 4.28 indicates the effect and interaction of MW and Cd on non essential heavy metal elements in *P. tomentosa* roots. The effect of MW on (Cd, RB, Br and Sn) significantly decreased. Also effect of Cd concentration significantly decreased (Rb and Br) content, only (Cd and Sn) increased. The interaction treatment low power of MW with adding Cd significantly increased most element in table 4.28.

Table 4.25. *Effects of magnetic water, Cd element and their interactions on some essential macro elements of P. tomentosa roots*

Treatments	N %	P %	K %	Ca %	S %
Magnetic Water (MW) (Gauss)					
G0	1.13 a	0.48 a	5.61 c	3.96 b	0.93 d
G500	1.06 b	0.13 d	6.31 c	4.82 b	1.48 b
G1000	1.00 c	0.25 b	9.64 b	2.61 c	2.26 a
G1500	0.96 d	0.13 d	14.60 a	6.32 a	1.17 c
G2000	1.15 a	0.20 c	5.77 c	4.27 b	1.46 b
Cd concentration (mg Kg-1 soil)					
Cd 0	0.98 c	0.40 a	10.79 a	5.45 a	1.46 a
Cd 3.33	1.23 a	0.18 c	5.41 c	3.79 b	1.42 a
Cd 6.66	1.14 b	0.21 b	6.37 b	3.99 b	1.39 a
Cd 10	0.90 d	0.15 d	10.97 a	4.36 b	1.57 a
Interactions effect of MW and Cd					
G0 Cd0	1.28 bc	1.31 a	6.98 d-f	4.09 c-g	1.12 e-g
G0 Cd3.33	1.34 ab	0.20 c-e	4.48 g	3.69 c-g	0.98 f-h
G0 Cd6.66	0.93 h	0.22 c	4.34 g	2.84 f-h	0.58 hi
G0 Cd10	0.97 gh	0.19 c-f	6.64 ef	5.21 b-d	1.05 e-g
G500 Cd0	0.98 gh	0.14 g-i	7.21 d-f	6.95 b	2.39 a
G500 Cd3.33	1.31 b	0.10 ij	3.82 g	2.81 f-h	0.93 gh
G500 Cd6.66	1.17 de	0.20 c-e	4.80 g	4.09 c-g	1.25 e-g
G500 Cd10	0.80 i	0.09 j	9.43 c	5.44 bc	1.34 d-g
G1000 Cd0	0.70 j	0.30 b	2.15 h	1.52 h	2.75 a
G1000 Cd3.33	1.37 a	0.31 b	4.01 g	2.38 gh	1.99 b
G1000 Cd6.66	1.14 ef	0.21 cd	6.41 f	3.38 d-h	2.54 a
G1000 Cd10	0.78 i	0.18 c-f	26.00 b	3.19 d-h	1.76 bc
G1500 Cd0	0.83 i	0.11 ij	33.55 a	10.40 a	0.44 i
G1500 Cd3.33	1.01 g	0.13 h-j	8.06 c-f	5.48 bc	1.74 b-d
G1500 Cd6.66	1.28 bc	0.16 f-h	8.52 cd	4.62 c-f	1.41 c-f
G1500 Cd10	0.72 j	0.12 ij	8.27 c-e	4.81 c-f	1.11 e-g
G2000 Cd0	1.10 f	0.18 c-f	4.09 g	4.33 c-g	0.61 hi
G2000 Cd3.33	1.12 ef	0.16 e-h	6.71 ef	4.58 c-f	1.48 c-e
G2000 Cd6.66	1.1 de	0.30 b	7.80 d-f	5.03 c-e	1.20 e-g
G2000 Cd10	1.22 cd	0.17 d-g	4.49 g	3.14 e-h	2.57 a

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.26. *Effects of magnetic water, Cd element and their interactions on some essential micro elements of P. tomentosa roots*

Treatments	Mn %	Zn ppm	Cu Ppm	Cl %	Ni ppm
Magnetic Water (MW) (Gauss)					
G0	0.10 b	589.25 b	170.73 b	0.79 b	236.38 b
G500	0.20 a	1166.58 a	321.84 a	0.79 b	1611.68 a
G1000	0.03 d	125.16 c	80.90 d	0.80 b	77.28 c
G1500	0.08 c	673.14 b	132.68 c	0.68 b	103.64 bc
G2000	0.09 bc	211.63 c	185.90 b	1.38 a	234.80 b
Cd concentration (mg Kg-1 soil)					
Cd 0	0.09 b	316.24 b	196.58 b	0.65 c	231.78 b
Cd 3.33	0.19 a	1447.00 a	319.40 a	0.63 c	1378.32 a
Cd 6.66	0.05 c	277.26 bc	98.87 c	0.78 b	101.24 c
Cd 10	0.08 b	172.10 c	98.78 c	1.50 a	99.67 c
Interactions effect of MW and Cd					
G0 Cd0	0.12 e-g	779.0 d	277.50 b	0.75 ef	339.5 b-d
G0 Cd3.33	0.17 bc	1092.0 c	196.50 cd	0.62 e-g	445.5 b
G0 Cd6.66	0.03 ij	300.5 ef	88.20 e-g	0.61 e-g	81.3 cd
G0 Cd10	0.11 e-g	185.5 ef	120.70 ef	1.19 c	79.2 cd
G500 Cd0	0.12 d-f	241.0 ef	265.50 bc	1.07 cd	358.5 b-d
G500 Cd3.33	0.46 a	4137.5 a	850.70 a	0.37 gh	5794.2 a
G500 Cd6.66	0.08 gh	104.8 f	84.15 e-g	0.23 h	154.5 b-d
G500 Cd10	0.13 c-e	183.0 ef	87.00 e-g	1.49 b	139.5 b-d
G1000 Cd0	0.02 j	42.2 f	38.40 g	0.51 fg	44.9 d
G1000 Cd3.33	0.03 ij	91.0 f	65.30 fg	0.67 ef	52.4 d
G1000 Cd6.66	0.04 ij	220.5 ef	93.50 e-g	1.18 c	74.5 cd
G1000 Cd10	0.06 hi	147.0 ef	126.40 ef	0.86 de	137.4 b-d
G1500 Cd0	0.05 h-j	330.5 ef	140.52 de	0.24 h	71.0 cd
G1500 Cd3.33	0.19 b	1660.0 b	209.00 b-d	0.67 ef	213.5 b-d
G1500 Cd6.66	0.03 ij	445.0 e	84.00 e-g	0.73 ef	59.0 d
G1500 Cd10	0.05 h-j	257.0 ef	97.20 e-g	1.10 cd	71.1 cd
G2000 Cd0	0.16 b-d	188.5 ef	261.00 bc	0.67 ef	345.0 b-d
G2000 Cd3.33	0.09 f-h	254.5 ef	275.50 b	0.82 e	386.0 bc
G2000 Cd6.66	0.09 f-h	315.5 ef	144.50 de	1.16 c	137.0 b-d
G2000 Cd10	0.05 h-j	88.0 f	62.60 fg	2.85 a	71.2 cd

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.27. *Effects of magnetic water, Cd element and their interactions on some beneficial elements of P. tomentosa roots*

Treatments	Ti %	Co Ppm
Magnetic Water (MW) (Gauss)		
G0	0.10 ab	62.69 b
G500	0.11 a	285.09 a
G1000	0.07 c	58.15 b
G1500	0.08 bc	39.95 b
G2000	0.07 c	60.23 b
Cd concentration (mg Kg-1 soil)		
Cd 0	0.09 ab	62.62 b
Cd 3.33	0.07 b	218.66 a
Cd 6.66	0.08 ab	52.77 b
Cd 10	0.10 a	70.83 b
Interactions effect of MW and Cd		
G0 Cd0	0.08 c-g	47.85 bc
G0 Cd3.33	0.10 a-f	66.90 bc
G0 Cd6.66	0.09 b-g	52.00 bc
G0 Cd10	0.13 a-c	84.00 bc
G500 Cd0	0.09 a-f	93.40 b
G500 Cd3.33	0.10 a-f	876.40 a
G500 Cd6.66	0.13 ab	99.65 b
G500 Cd10	0.11 a-d	70.90 bc
G1000 Cd0	0.04 g	24.55 c
G1000 Cd3.33	0.05 fg	70.20 bc
G1000 Cd6.66	0.07 d-g	37.50 bc
G1000 Cd10	0.13 a-c	100.35 b
G1500 Cd0	0.14 a	50.00 bc
G1500 Cd3.33	0.07 d-g	40.40 bc
G1500 Cd6.66	0.06 d-g	21.30 c
G1500 Cd10	0.06 d-g	48.10 bc
G2000 Cd0	0.10 a-e	97.30 b
G2000 Cd3.33	0.06 e-g	39.40 bc
G2000 Cd6.66	0.06 d-g	53.40 bc
G2000 Cd10	0.06 d-g	50.80 bc

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.28. *Effects of magnetic water, Cd element and their interactions on some non-essential heavy metals and other elements of P. tomentosa roots*

Treatments	Cd ppm	Rb ppm	Br ppm	Sn ppm
Magnetic Water (MW) (Gauss)				
G0	407.29 b	21.04 b	34.53 c	91.33 a
G500	484.25 a	142.24 a	90.46 a	105.51 a
G1000	189.84 d	16.91 b	27.62 c	41.18 c
G1500	237.15 cd	21.24 b	35.23 c	64.90 b
G2000	310.30 c	28.96 b	69.52 b	60.91 b
Cd concentration (mg Kg-1 soil)				
Cd 0	9.40 c	29.51 b	59.79 a	74.38 a
Cd 3.33	390.47 b	102.08 a	68.58 a	81.92 a
Cd 6.66	416.65 b	28.23 b	38.14 b	76.75 a
Cd 10	486.54 a	24.49 b	39.39 b	58.02 b
Interactions effect of MW and Cd				
G0 Cd0	12.65 g	22.50 b	32.75 c-f	88.95 b-e
G0 Cd3.33	669.50 b	20.00 b	39.80 c-f	129.50 a
G0 Cd6.66	429.50 cd	18.90 b	31.40 c-f	84.45 b-f
G0 Cd10	517.50 b-d	22.75 b	34.20 c-f	62.45 d-i
G500 Cd0	28.50 g	37.80 b	53.20 cd	136.00 a
G500 Cd3.33	146.00 fg	435.70 a	190.20 a	56.00 e-j
G500 Cd6.66	683.00 b	50.40 b	59.60 c	123.05 ab
G500 Cd10	1079.50 a	45.05 b	58.85 c	107.00 a-c
G1000 Cd0	0.00 g	10.20 b	14.44 f	24.78 ij
G1000 Cd3.33	152.35 fg	11.01 b	21.45 ef	41.10 h-j
G1000 Cd6.66	244.00 ef	16.95 b	27.95 d-f	42.55 g-j
G1000 Cd10	363.00 de	29.50 b	46.65 c-e	56.30 e-j
G1500 Cd0	5.85 g	31.90 b	60.10 c	74.01 c-h
G1500 Cd3.33	418.00 cd	22.40 b	33.80 c-f	83.05 c-g
G1500 Cd6.66	158.75 fg	16.15 b	22.25 ef	59.00 e-j
G1500 Cd10	366.00 de	14.50 b	24.80 d-f	43.55 f-j
G2000 Cd0	0.00 g	45.15 b	138.50 b	48.20 e-j
G2000 Cd3.33	566.50 bc	21.30 b	57.65 c	99.95 a-d
G2000 Cd6.66	568.00 bc	38.75 b	49.50 c-e	74.70 c-h
G2000 Cd10	106.70 fg	10.66 b	32.45 c-f	20.80 j

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

4.4.11. Essential Macro Elements in *P. tomentosa* Stem

The data in table 4.29 shows the effect of MW and Cd and their interactions on essential macro elements in *P. tomentosa* Stem. The effect of MW on most macro elements in stem significantly increased such as (N, P, Ca and S). Also adding concentration of Cd significantly increased elements such as (N and S) but (P and Ca) content decreased.

The higher power of MW interaction with high concentration of Cd significantly increased most essential macro elements of *P. tomentosa* in stem.

4.4.12. Essential Micro Elements in *P. tomentosa* Stem

The results shown in table 4.30 are the effect of MW and Cd and their interactions on micro elements in *P. tomentosa* Stem. Utilizing of MW increased essential micro elements in stem (Mn, Fe, Zn, Cu and Cl). Also adding high Cd concentration significantly increased essential micro elements, only Cl content decreased with used Cd. Most essential micro elements increased with (G1000 x Cd10 and G1500 x Cd0) mg Cd. Kg^{-1} soil.

4.4.13. Beneficial Elements in *P. tomentosa* Stem

Table 4.31 shows the effect of MW and Cd and their interactions on the beneficial elements of *P. tomentosa* in stem. The effect of MW on beneficial elements in stem significantly increased (Ti). Whereas adding Cd concentration decreased element (Ti). Also G1500 interaction with high concentration of Cd significantly increased element (Ti).

4.4.14. Non essential Heavy Metal Elements in *P. tomentosa* Stem

The results of table 4.32 show the effect of MW and Cd with their interactions on the non essential heavy metal elements in *of P. tomentosa* Stem. It is observed that the application of MW increased elements such as (Cd, Rb, Br and Sn). Also using high concentration Cd significantly increased elements in this table, only Rb content decreased. The high concentration of Cd interaction with G1000 recorded the highest value such as (Cd, Br and Sn).

Table 4.29. *Effects of Magnetic Water, Cd Element and their Interactions on some Essential Macro Elements of P. tomentosa Stem.*

Treatments	N	P	Ca	S
	%			
Magnetic Water (MW) (Gauss)				
G0	1.49 b	0.20 b	5.89 c	0.69 b
G500	0.98 d	0.11 d	4.53 d	0.73 ab
G1000	1.43 c	0.24 a	13.36 a	0.74 ab
G1500	1.43 c	0.19 b	6.78 b	0.55 c
G2000	1.62 a	0.14 c	13.93 a	0.77 a
Cd concentration (mg Kg-1 soil)				
Cd 0	1.42 b	0.18 ab	17.17 a	0.59 c
Cd 3.33	1.50 a	0.19 a	7.32 b	0.71 b
Cd 6.66	1.38 b	0.17 ab	6.22 c	0.96 a
Cd 10	1.26 c	0.16 b	4.87 d	0.53 c
Interactions effect of MW and Cd				
G0 Cd0	1.74 c	0.15 d-f	7.12 d-f	0.89 bc
G0 Cd3.33	1.94 b	0.40 a	7.66 d	1.02 b
G0 Cd6.66	1.11 ij	0.13 e-g	3.96 ij	0.28 ij
G0 Cd10	1.17 hi	0.14 d-g	4.82 hi	0.57 e-g
G500 Cd0	0.94 k	0.09 g	5.25 h-g	0.20 j
G500 Cd3.33	1.23 f-h	0.14 d-g	4.28 ij	0.48 f-h
G500 Cd6.66	1.06 j	0.10 fg	3.52 j	1.44 a
G500 Cd10	0.69 l	0.12 e-g	5.10 g-i	0.80 cd
G1000 Cd0	1.56 d	0.39 a	35.04 a	0.94 bc
G1000 Cd3.33	1.79 c	0.18 d	6.39 d-g	0.59 ef
G1000 Cd6.66	1.29 ef	0.27 b	5.95 f-h	0.78 cd
G1000 Cd10	1.09 ij	0.12 e-g	6.08 e-h	0.66 de
G1500 Cd0	1.54 d	0.11 e-g	5.13 g-i	0.49 e-h
G1500 Cd3.33	1.20 gh	0.17 de	10.94 c	0.65 de
G1500 Cd6.66	1.72 c	0.24 bc	7.57 d	0.84 c
G1500 Cd10	1.26 e-g	0.24 bc	3.47 j	0.23 j
G2000 Cd0	1.32 e	0.14 d-g	33.34 b	0.42 g-i
G2000 Cd3.33	1.34 e	0.09 g	7.36d e	0.82 c
G2000 Cd6.66	1.74 c	0.13 d-g	10.11 c	1.46 a
G2000 Cd10	2.08 a	0.19 cd	4.91 hi	0.39 hi

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.30. *Effects of magnetic water, Cd Element and their Interactions on some Essential Micro Elements of P. tomentosa Stem.*

Treatments	Mn ppm	Fe %	Zn ppm	Cu ppm	Cl %
Magnetic Water (MW) (Gauss)					
G0	288.6 b	0.06 c	203.0 c	195.8 b	1.17 b
G500	192.4 b	0.07 c	194.7 c	144.0 b	1.07 b
G1000	2250.3 a	0.74 b	4159.6 b	3027.1 a	0.68 c
G1500	2221.1 a	0.94 a	5878.5 a	3132.5 a	0.44 d
G2000	499.2 b	0.11 c	263.3 c	272.3 b	1.72 a
Cd concentration (mg Kg^{-1} soil)					
Cd 0	1308.0 b	0.53 b	3147.1 b	1842.4 b	1.26 a
Cd 3.33	502.4 c	0.15 c	1236.7 c	829.2 c	0.98 b
Cd 6.66	233.0 c	0.08 c	191.2 d	167.0 d	0.95 b
Cd 10	2317.8 a	0.78 a	3984.4 a	2578.7 a	0.87 b
Interactions effect of MW and Cd					
G0 Cd0	317.5 e	0.07 d	252.0 e	198.0 d	1.71 bc
G0 Cd3.33	329.0 e	0.07 d	236.5 e	259.0 d	0.67 ef
G0 Cd6.66	290.5 e	0.07 d	215.0 e	216.5 d	0.43 fg
G0 Cd10	217.5 e	0.06 d	108.5 e	109.5 d	1.86 b
G500 Cd0	271.0 e	0.12 d	317.5 e	218.5 d	0.29 fg
G500 Cd3.33	151.5 e	0.06 d	153.0 e	127.0 d	0.66 ef
G500 Cd6.66	120.6 e	0.03 d	120.5 e	116.2 d	1.99 b
G500 Cd10	226.5 e	0.09 d	188.0 e	114.2 d	1.33 cd
G1000 Cd0	239.5 e	0.08 d	303.5 e	278.0 d	1.04 de
G1000 Cd3.33	1369.0 d	0.40 c	5140.5 d	3196.5 c	0.55 fg
G1000 Cd6.66	231.0 e	0.13 d	174.0 e	154.5 d	0.63 e-g
G1000 Cd10	7161.5 a	2.34 a	11020.5 b	8479.5 a	0.49 fg
G1500 Cd0	5153.0 b	2.26 a	14667.5 a	8346.7 a	0.34 fg
G1500 Cd3.33	321.5 e	0.14 d	392.5 e	283.0 d	0.21 fg
G1500 Cd6.66	253.3 e	0.08 d	271.0 e	136.5 d	1.07 de
G1500 Cd10	3156.5 c	1.30 b	8183.0 c	3764.0 b	0.15 g
G2000 Cd0	559.0 e	0.12 d	195.0 e	170.8 d	2.90 a
G2000 Cd3.33	341.0 e	0.07 d	261.0 e	280.5 d	2.81 a
G2000 Cd6.66	269.9 e	0.10 d	175.4 e	211.6 d	0.65 ef
G2000 Cd10	827.0 de	0.14 d	422.0 e	426.5 d	0.53 fg

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.31. *Effects of Magnetic Water, Cd Element and their Interactions on some Beneficial Elements of P. tomentosa Stem.*

Treatments	Ti ppm
Magnetic Water (MW) (Gauss)	
G0	260.80 b
G500	203.01 c
G1000	241.13 bc
G1500	381.43 a
G2000	370.30 a
Cd concentration (mg Kg-1 soil)	
Cd 0	313.94 b
Cd 3.33	424.60 a
Cd 6.66	225.06 c
Cd 10	201.73 c
Interactions effect of MW and Cd	
G0 Cd0	340.00 c
G0 Cd3.33	339.00 c
G0 Cd6.66	134.55 fg
G0 Cd10	229.65 d-f
G500 Cd0	350.00 c
G500 Cd3.33	191.50 e-g
G500 Cd6.66	119.85 g
G500 Cd10	150.70 e-g
G1000 Cd0	402.50 c
G1000 Cd3.33	193.50 e-g
G1000 Cd6.66	241.50 de
G1000 Cd10	127.00 g
G1500 Cd0	121.20 g
G1500 Cd3.33	767.50 a
G1500 Cd6.66	322.20 cd
G1500 Cd10	314.80 cd
G2000 Cd0	356.00 c
G2000 Cd3.33	631.50 b
G2000 Cd6.66	307.20 cd
G2000 Cd10	186.50 e-g

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.32. *Effects of magnetic water, Cd Element and their Interactions on some Non-Essential Heavy Metals and other Elements of P. tomentosa Stem.*

Treatments	Cd Ppm	Rb ppm	Br ppm	Sn ppm
Magnetic Water (MW) (Gauss)				
G0	4.61 b	10.35 c	12.78 d	72.95 b
G500	8.09 a	7.93 c	8.54 d	74.58 b
G1000	10.26 a	93.87 b	90.06 a	91.98 a
G1500	11.61 a	401.90 a	68.02 b	82.16 ab
G2000	8.51 a	12.31 c	32.55 c	62.42 c
Cd concentration (mg Kg-1 soil)				
Cd 0	3.99 c	201.76 a	53.45 b	83.43 b
Cd 3.33	6.10 bc	76.88 c	11.92 c	74.23 c
Cd 6.66	8.87 b	8.72 d	8.62 c	56.64 d
Cd 10	15.51 a	133.70 b	95.57 a	92.99 a
Interactions effect of MW and Cd				
G0 Cd0	0.00 g	8.41 d	17.05 e	77.00 d-g
G0 Cd3.33	9.55 de	14.73 d	13.25 e	100.10 bc
G0 Cd6.66	0.00 g	9.82 d	9.32 e	73.50 d-g
G0 Cd10	8.91 ef	8.45 d	11.51 e	41.20 ij
G500 Cd0	0.00 g	11.67 d	12.00 e	100.40 bc
G500 Cd3.33	4.79 f-h	5.46 d	7.81 e	63.50 f-h
G500 Cd6.66	9.82 c-e	4.70 d	7.32 e	47.65 h-j
G500 Cd10	17.75 b	9.89 d	7.05 e	86.80 c-f
G1000 Cd0	0.00 g	11.77 d	7.69 e	71.35 d-g
G1000 Cd3.33	0.00 g	342.13 c	18.50 e	76.75 d-g
G1000 Cd6.66	13.67 b-d	14.60 d	14.30 e	63.95 f-h
G1000 Cd10	27.40 a	6.97 d	319.77 a	155.90 a
G1500 Cd0	0.00 g	966.29 a	179.39 b	112.60 b
G1500 Cd3.33	16.20 b	11.14 d	10.30 e	66.65 e-h
G1500 Cd6.66	6.77 e-g	8.52 d	3.61 e	60.20 g-i
G1500 Cd10	23.50 a	621.65 b	78.80 c	89.20 c-e
G2000 Cd0	2.76 gh	10.76 d	51.15 d	55.80 g-j
G2000 Cd3.33	0.00 g	10.96 d	9.73 e	64.15 f-h
G2000 Cd6.66	14.10 bc	5.98 d	8.57 e	37.90 j
G2000 Cd10	0.00 g	21.55 d	60.75 d	91.85 b-d

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

4.4.15. Essential Macro Elements in *P. tomentosa* Leaves

Table 4.33 shows the effect of exposure to MW and Cd and their interactions on essential macro-element in *P. tomentosa* Leaves. The effect of MW on essential macro elements in leaves signif icantly increased. Also high concentration of Cd increased elements such as (N, P, Ca and S), only (K) decreased, but increased Cd. Interaction treatment of (G1000 x Cd3.33 and G2000 x Cd6.66) mg Kg-1 soil increased some elements in essential macro element.

4.4.16. Essential Micro Elements in *P. tomentosa* Leaves

The results shown in table 4.34 reflect the influence of MW, Cd, and the interactions between them on essential micro elements in *P. tomentosa* Leaves. The effect of MW in 1000 gauss significantly increased most essential micro element in leaves.

Whereas, concentration of Cd significantly increased (Mn and Fe) but (Zn, Cu, Cl and Ni) were decreased. Also interacttion treatment of G1000 with high concentration Cd significantly increased elements such as (Mn, Fe, Zn, Cu and Ni).

4.4.17. Beneficial Elements in *P. tomentosa* Leaves

Table 4.35 shows the effect of MW, Cd and their interactions on the beneficial elements in *P. tomentosa* Leaves. Using of MW on beneficial element in leaves significantly increased. Whereas increasing concentration of Cd decreased element (Ti) content. G1500 interaction with tap water without using of Cd increased most beneficial elements.

4.4.18. Non essential Heavy Metals and Trace Elements in *P. tomentosa* Leaves

The effects of MW and Cd with their interactions on non essential heavy metals and trace elements in *P. tomentosa* Leaves are shown in table 4.36. Power of 1000 gauss increased all elements in this table. Also concentration of Cd 3.33 increased elements such as (Rb, Br, Cr, Sc and Sn). Only interaction treatment of G1000 x Cd3.33 mg Kg-1 soil elements of this table increased.

Table 4.33. *Effects of Magnetic Water, Cd Element and their Interactions on some Macro Essential Elements of P. tomentosa Leaves.*

Treatments	N %	P%	K %	Ca%	S %
Magnetic Water (MW) (Gauss)					
G0	3.03 a	0.26 d	11.47 a	3.30 bc	1.66 d
G500	2.18 e	0.32 c	5.25 c	3.69 b	2.64 c
G1000	2.54 d	0.40 a	6.75 b	9.40 a	2.99 b
G1500	2.65 b	0.35 b	5.22 c	3.05 bc	3.48 a
G2000	2.58 c	0.35 b	3.25 d	2.76 c	2.58 c
Cd concentration (mg Kg^{-1} soil)					
Cd 0	2.40 d	0.33 b	4.04 b	3.00 b	2.86 a
Cd 3.33	2.53 c	0.35 a	12.49 a	7.72 a	2.71 ab
Cd 6.66	2.57 b	0.35 a	4.38 b	3.48 b	2.59 ab
Cd 10	2.88 a	0.32 b	4.65 b	3.57 b	2.51 b
Interactions effect of MW and Cd					
G0 Cd0	2.96 cd	0.33 de	6.14 cd	3.89 b-d	1.85 fg
G0 Cd3.33	2.92 de	0.21 h	31.76 a	3.85 b-d	1.52 g
G0 Cd6.66	3.26 b	0.26 g	3.93 d-g	3.09 cd	0.88 h
G0 Cd10	2.98 c	0.23 h	4.07 d-g	2.37 de	2.41 d-f
G500 Cd0	1.97 n	0.30 f	3.49 d-g	2.41 de	2.33 d-f
G500 Cd3.33	2.57 h	0.33 de	5.95 cd	3.74 b-d	1.95 e-g
G500 Cd6.66	2.29 k	0.32 d-f	6.75 c	5.47 b	3.93 ab
G500 Cd10	1.90 o	0.32 d-f	4.82 c-f	3.16 cd	2.34 d-f
G1000 Cd0	2.08 m	0.38 c	3.15 e-g	3.91 b-d	3.32 bc
G1000 Cd3.33	2.33 j	0.43 a	15.19 b	24.50 a	4.56 a
G1000 Cd6.66	2.46 i	0.39 bc	3.61 d-g	3.77 b-d	1.81 fg
G1000 Cd10	3.29 b	0.41 b	5.06 c-f	5.43 b	2.28 d-f
G1500 Cd0	2.45 i	0.34 d	4.87 c-f	2.41 de	3.88 ab
G1500 Cd3.33	2.62 g	0.44 a	5.99 cd	3.58 b-d	3.30bc
G1500 Cd6.66	2.20 l	0.32 d-f	6.11 cd	4.02 b-d	3.89 ab
G1500 Cd10	3.35 a	0.32 d-f	3.92 d-g	2.19 de	2.86 cd
G2000 Cd0	2.55 h	0.31 ef	2.54 fg	2.37 de	2.94 cd
G2000 Cd3.33	2.22 l	0.33 de	3.58 d-g	2.93 c-e	2.25 d-f
G2000 Cd6.66	2.66 f	0.45 a	1.49 g	1.04 e	2.46 d-f
G2000 Cd10	2.89 e	0.33 de	5.39 c-e	4.71 bc	2.68 c-e

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.34. *Effects of Magnetic Water, Cd Element and their Interactions on some Micro Essential Elements of P. tomentosa Leaves.*

Treatments	Mn ppm	Fe %	Zn ppm	Cu ppm	Cl %	Ni ppm
Magnetic Water (MW) (Gauss)						
G0	174.76 b	0.17 b	180.44 b	73.44 b	1.40 a	24.11 b
G500	177.91 b	0.25 b	152.12 cd	61.45 b	0.87 b	25.83 b
G1000	228.13 a	3.37 a	273.27 a	181.40 a	0.64 c	109.10 a
G1500	158.65 b	0.25 b	159.35 c	58.49 b	0.50 c	18.18 b
G2000	128.61 b	0.18 b	138.76 d	48.96 b	1.20 a	23.23 b
Cd concentration (mg Kg^{-1} soil)						
Cd 0	142.50 c	0.18 b	139.45 c	50.89 b	1.43 a	21.80 c
Cd 3.33	200.51 a	0.61 b	241.55 a	167.07 a	0.65 c	61.89 a
Cd 6.66	186.30 a	7.97 a	190.28 b	64.43 b	0.71 bc	51.41 b
Cd 10	165.14b	0.23 b	151.88 c	56.60 b	0.89 b	25.26 c
Interactions effect of MW and Cd						
G0 Cd0	202.00 b-d	0.11 b	204.50 d	77.40 bc	3.22 a	22.85 c
G0 Cd3.33	246.00 ab	0.22 b	310.00 b	124.75 b	0.68 d-g	34.10 c
G0 Cd6.66	138.85 e-h	0.24 b	125.85 f	55.21 bc	0.10 h	21.69 c
G0 Cd10	112.20 h	0.13 b	81.40 gh	36.40 c	1.61 c	17.80 c
G500 Cd0	118.10 h	0.20 b	99.85 fg	39.47 c	0.38 f-h	27.10 c
G500 Cd3.33	171.05 c-f	0.22 b	168.15 e	66.45 bc	0.55 d-h	23.85 c
G500 Cd6.66	257.00 a	0.36 b	209.00 d	91.00 bc	1.53 c	28.80 c
G500 Cd10	165.50 d-g	0.25 b	131.50 f	48.90 c	1.04 d	23.60 c
G1000 Cd0	148.50 e-h	0.20 b	126.40 f	53.45 c	0.61 d-h	23.50 c
G1000 Cd3.33	282.00 a	2.14 b	410.00 a	526.00 a	1.04 d	215.45 a
G1000 Cd6.66	274.00 a	3.45a	378.70 a	78.20 bc	0.27 f-h	166.00 b
G1000 Cd10	208.00 b-d	0.32 b	178.00 de	67.95 bc	0.66 d-g	31.45 c
G1500 Cd0	132.10 f-h	0.23 b	136.15 f	53.25 c	0.63 d-g	15.55 c
G1500 Cd3.33	182.00 c-e	0.27 b	200.75 de	64.35 bc	0.45 e-h	15.10 c
G1500 Cd6.66	194.00 cd	0.34 b	176.00 de	70.10 bc	0.75 d-f	27.30 c
G1500 Cd10	126.50 f-h	0.17 b	124.50 f	46.25 c	0.17 gh	14.80 c
G2000 Cd0	111.80 h	0.16 b	130.35 f	30.90 c	2.33 b	20.00 c
G2000 Cd3.33	121.50 gh	0.20 b	118.85 f	53.80 c	0.54 d-h	20.99 c
G2000 Cd6.66	67.65 i	0.08 b	61.85 h	27.65 c	0.93 de	13.30 c
G2000 Cd10	213.50 bc	0.29 b	244.00 c	83.50 bc	0.99 d	38.65 c

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.35. *Effects of Magnetic Water, Cd Element and their Interactions on some Beneficial Elements of P. tomentosa Leaves.*

Treatments	Ti ppm
Magnetic Water (MW) (Gauss)	
G0	158.84 b
G500	299.10 b
G1000	663.98 a
G1500	253.20 b
G2000	201.06 b
Cd concentration (mg Kg-1 soil)	
Cd 0	202.67 b
Cd 3.33	580.50 a
Cd 6.66	239.57 b
Cd 10	238.20 b
Interactions effect of MW and Cd	
G0 Cd0	118.5 b
G0 Cd3.33	133.5 b
G0 Cd6.66	237.9 b
G0 Cd10	145.5 b
G500 Cd0	278.9 b
G500 Cd3.33	257.0 b
G500 Cd6.66	431.0 b
G500 Cd10	229.5 b
G1000 Cd0	200.5 b
G1000 Cd3.33	643.0 a
G1000 Cd6.66	105.4 b
G1000 Cd10	307.0 d
G1500 Cd0	236.8 b
G1500 Cd3.33	257.0 b
G1500 Cd6.66	344.0 b
G1500 Cd10	175.0 b
G2000 Cd0	178.7 b
G2000 Cd3.33	212.0 b
G2000 Cd6.66	79.6 b
G2000 Cd10	334.0 b

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Table 4.36. *Effects of Magnetic Water, Cd Element and their Interactions on some Non-Essential Heavy Metals and some other Trace Elemnts of P. tomentosa Leaves.*

Treatments	Rb ppm	Br ppm	Cr ppm	Sc ppm	Sn ppm
Magnetic Water (MW) (Gauss)					
G0	5.97 b	11.49 b	9.18 b	482.55 b	28.90 c
G500	6.79 b	10.76 b	15.65 b	315.69 c	34.52 b
G1000	19.32 a	81.37 a	42.06 a	1246.50 a	184.27 a
G1500	6.08 b	6.98 b	12.50 b	246.88 c	37.77 b
G2000	5.16 b	11.14 b	11.39 b	219.84 c	21.34 d
Cd concentration (mg Kg^{-1} soil)					
Cd 0	5.71 b	10.41 b	10.85 c	270.48 b	25.72 d
Cd 3.33	16.74 a	62.82 a	27.03 a	1162.99a	137.71 a
Cd 6.66	5.92 b	12.55 b	20.75 ab	270.19 b	47.04 b
Cd 10	6.29 b	11.61 b	13.99 bc	305.50 b	34.98 c
Interactions effect of MW and Cd					
G0 Cd0	5.41 bc	13.47 b	6.70 c	361.0 c-f	21.60 h-j
G0 Cd3.33	9.22 b	18.00 b	7.22 c	1127.5 b	46.65 c
G0 Cd6.66	5.63 bc	7.93 b	12.90 c	232.7 d-f	19.28 ij
G0 Cd10	3.64 bc	6.60 b	9.90 c	209.0 d-f	28.10 e-i
G500 Cd0	6.37 bc	8.28 b	12.58 c	225.3 d-f	27.11 f-i
G500 Cd3.33	5.05 bc	11.78 b	14.80 c	207.5 d-f	34.95 c-g
G500 Cd6.66	9.23 b	14.50 b	21.45 c	527.0 c	39.40 c-e
G500 Cd10	6.49 bc	8.51 b	13.80 c	303.0 c-f	36.65 c-f
G1000 Cd0	6.38 bc	12.10 b	13.54 c	377.0 c-f	26.35 f-i
G1000 Cd3.33	57.87 a	266.65 a	88.88 a	4003.0 a	554.80 a
G1000 Cd6.66	4.05 bc	28.35 b	47.05 b	123.5 ef	116.15 b
G1000 Cd10	8.98 bc	18.40 b	18.85 c	482.5 cd	39.80 c-e
G1500 Cd0	6.03 bc	5.61 b	12.47 c	197.5 d-f	33.35 d-h
G1500 Cd3.33	6.18 bc	7.94 b	11.45 c	226.0 d-f	29.10 e-i
G1500 Cd6.66	7.74 bc	8.25 b	15.13 c	388.0 c-e	46.10 c
G1500 Cd10	4.40 bc	6.13 b	10.96 c	176.0 ef	42.55 cd
G2000 Cd0	4.35 bc	12.65 b	8.99 c	191.6 d-f	20.20 ij
G2000 Cd3.33	5.40 bc	9.76 b	12.88 c	251.0 c-f	23.08 g-j
G2000 Cd6.66	2.95 c	3.74 b	7.23 c	79.8 f	14.28 j
G2000 Cd10	7.96 bc	18.45 b	16.45 c	357.0 c-f	27.80 e-i

Means followed by the same letter for each factor and their interactions within column are not significantly different at $p \leq 0.05$ according to the Duncan Multiple test, and vice versa.

Chapter Five

5. Discussion

5.1. Effects of Magnetic Water, Cadmium, and Their Interactions on Cutting Performance and Some Vegetative Growth Proprieties of *Paulownia t.*

As it shown in the tables 4.1 and 4.2 generally, at least some of magnetic water powers increased the percent of survived cutting and enhanced early but`s outgrowth. In contrast adding Cd decreased the percent of survived cutting and increased the period for bud`s outgrowth in all Cd treatments. Numerous researchers have concluded that magnetic treatment of irrigation water improves plant growth and crop yield because magnetic fields induce magnetic changes in water properties (Saletnik *et al*., 2022). Increasing magnetic water powers increased significantly plants leaves number, whereas Cd application decreased it, as shown in tables (Tables 4.3 and 4.4). Regarding the leaf area property, each of the powers of the magnetic water (most of them) and Cd application increased this property, compared to the control treatment, those results disagree with Hatamian *et al*. (2020) who found that higher level of cadmium, reduced plant leaf area, likely as a result of restraints on cell division and expansion. The result was parallel to that of Mohammadi et al. (2019), where the leaf area index of the plants irrigated by the MW was higher, suggesting the application of the MW might be used as a growth promoter to increase leaf area.This is because of increased water and nutrient availability, increased photosynthetic pigments, and rapid plant vegetative development, the results also agree with Hasan *et al*. (2019), under MW, larger leaf area, fresh weight, and dried weight were observed, which may have been caused by an increase in photosynthesis rate.

Table 4.5 shows that the number of plants branches was not significantly impacted by the Cd treatment or the power of the magnetic water. This result disagrees with Maheshwari and Grewal (2009) who showed that using a magnetic field to purify irrigation water mitigates the detrimental effects of salty soil or water on plant growth. It is reported that by increasing the quantity of water, plant height, shoot length, and leaf number were enhanced (Mostafa *et al*., 2016). The induction of cell metabolism and mitosis division, an increase in pigments, endogenous promoters, and an increase in protein biosynthesis are thought to be the causes of MW's stimulatory effect on growth parameters (Abdullah, 2019).

As it shown in the tables 4.6 and 4.7 generally, the power of magnetic water increased the stem diameter and plant high. In contrast, adding Cd increased the stem diameter and decreased the plant

high. Opposite to this result, Alattar *et al*. (2021) stated that in plants watered with magnetized water, vegetative parameters, including stem thickness, were unaffected. This may be attributed to having no change in the amount of photosynthetic pigments concentrations (carotenoids and chlorophylls) as well as protein biosynthesis that provided the required amount of assimilates for plant growth. As a result, the stem diameter of corn (*Zea mays*) plants was unaffected by the magnetic field. It has been demonstrated that the magnetic field modifies the transport properties of cellular membranes, which regulate the assimilation of nutrients required for cell function.

According to a mentions of Chen *et al.* (2011b), a magnetic field could stimulate the biosynthesis of nitric oxide (NO), which would activate physiological processes like cell division and differentiation, growth and development, photosynthesis, and ROS elimination, subsequently, a number of biochemical and physiological reactions would be sped up, including the capacity of ROS elimination and the capacity for photosynthesis. As comparison to non-magnetic treatments, magnetic treatments enhanced the length, surface area, and number of root points of populus plants (*Populus*) as well as their height, diameter, and leaf area (Liu *et al*., 2017).

Regarding the effects of MW and Cd on the vegetative growth, same results were demonstrated by Mostafa *et al*. (2016) who showed that the improvement of growth metrics, including plant height, leaves fresh and dry weight, and leaf area, may be attributed to the stimulatory effect of magnetic water. Increasing magnetic water powers increased significantly shoot fresh weight and percentage of shoot dry matter (Tables 4.7 and 4.8), Cd application (most of them) increased shoot fresh weight compared to the control treatment, but the effects of Cd was non-significant on the percentage of shoot dry matter, similar results were confirmed by Alattar *et al*. (2021) who showed the positive effect of the magnetic field on plant dry weight. It has been hypothesized that the biochemical processes (transport of assimilates, formation of free radicals, activity of proteins and enzymes, water and ion absorption, and growth regulator) would be altered by the magnetic field treatment. Thereby regulating and altering the pattern of plant growth and biomass. Variable concentrations of Cd influence the fresh weight of *Lemna polyrrhiza.* The reduction in growth in L. polyrrhiza may also be due to an irreversible inhibition exerted by Cd on the proton pump responsible for the elongation growth rate of cells (John *et al*., 2008).

As shown in the table 4.10, comparing high powers and high Cd concentrations to low powers and low Cd concentrations, the root length decreased significantly. As comparison to nonmagnetic treatments, magnetic treatments enhanced the length, surface area, and number of root in populus

plants (*Populus*) as well as their height, diameter, and leaf area (Liu *et al*., 2017). 18 days after sowing, chickpea (*Cicer arietinum*) plants irrigated with magnetically treated water were 2.67 centimeters taller than plants irrigated with untreated tap water (Nasher, 2008). Portia tree (*Thespesia populnea)* was more prevalent in distinct Cd concentration treatments compared to both shoot and seedling length. The reduction in root length was caused by the accumulation of metals within the root, which decreased the mitotic rate in the meristematic zone and blocked the metaphase in meristematic cells. As a result, the length of the roots was reduced (Kabir *et al*., 2008).

As shown in the tables 4.11 and 4.12, some of the magnetic water powers increased the shoot fresh and dry weight. In contrast, adding Cd regardless the concentration increased root fresh weight compared to the control treatment, and decreased shoot dry weight. In addition to the chemical properties of the water, surface tension, viscosity, and evaporation rate were altered under the influence of the magnetic field, which contributed to the growth enhancement of plants treated with magnetized water (Alattar *et al*., 2022). Fuzhong *et al.* (2010) found that arugula (*Eruca sativa)* was negatively impacted by Cd stress in terms of growth and metabolism. As Cd stress levels increased, shorter shoots and shorter root were seen. Cd stress may have caused to damage to the plant's photosynthetic organs and structures, which may account for the decrease in *E. sativa* growth.

5.2. Effects of Magnetic Water, Cadmium, and Their Interactions on Some Photosynthetic Pigments in *Paulownia t.*

The results of tables 4.13, 4.14 and 4.15 showed that using MW, regardless the device power, increased chl a., chl b. and TC significantly compared to tap water. Also adding Cd increased chl a., chl b. and TC. Our results agree with Aly *et al.* (2015) who found that compared to the control, MW had an increasing influence on the content of photosynthetic pigments. The increase in essential elements brought about by magnetic water helped treated water plants produce more chlorophyll, which increased the amount of carbohydrates, also it agrees with Mostafa *et al*. (2016) where the MW raised nutrient uptake and assimilation as well as chlorophyll a and b levels. This is explained by the higher nutrient uptake through the roots of magnetized water plants compared to untreated plant. Irrigation with MW may enhance plant metabolism, including the harmony of enzyme activity and photosynthesis as well as secondary metabolites (Alattar *et al*. 2022).

The induction of cell metabolism and mitosis division, an increase in physiologic pigment, endogenous promoters, and an increase in protein biosynthesis are thought to be the causes of MW's stimulatory effect on growth parameters (Abdullah, 2019). Hozayn and Qados (2010) showed that a magnetic field improved the levels of chlorophyll a and b and carotenoids in chickpea seedlings as well as the free water molecules, whereas Ennab (2022) reported that irrigation of navel and Valencia oranges with MW improved the concentrations of chlorophyll a, b, carotenoids, lowered proline, and enhanced total carbohydrate contents. Additionally, it observed that Chl.b was more sensitive to Cd-stress than Chl.a, with greater impacts on Chl.b as Cd-stress levels increased (Waheed *et al*., 2022).

Regarding the effects of Cd on photosynthesis pigments our result was opposite to Zhao *et al.* (2021) who found that net growth in plants with higher levels reduced with increasing cadmium concentration, the reason of this disagree maybe due to low concentrations of Cd used in our study. The enhanced photosynthesis that took place at low Cd concentrations may be attributed to thicker photosynthetic tissues in addition to an increase in CO_2 in the leaf mesophyll. Intolerant plants have frequently been shown to have thicker mesophyll when exposed to heavy metal pollution (Pereira *et al*., 2016). Fuzhong *et al*. (2010) found that *Eruca sativa* was negatively impacted by Cd stress in terms of growth and metabolism. As Cd stress levels increased, shorter shoots and shorter root were seen. Cd stress may have caused damage to the plant's photosynthetic organs and structures, which may account for the decrease in *E. sativa* growth.

5.3. Effect of Magnetic Water, Cadmium, and Their Interactions on Some Enzymatic and Non-Enzymatic Characteristics *Paulownia t.*

As it shown in the table 4.16, the magnetic water increased the POD enzyme activity. Adding at low concentration of Cd significantly increased the enzyme activity, whereas the enzyme activity decreased with increasing the Cd concentration. Hence, *Celosia argentea* species activated more antioxidant enzymes with the aid of the external magnetic field to scavenge the excessive ROS caused by the deposited Cd(Niu *et al*., 2021). These results agree with Zhao et al. (2021) where they observed the *Sassafras albidum* plant, which adapts the activities of SOD and POD in its organs in response to cadmium stress, eliminating harmful substances such as O_2^- and H_2O_2 to maintain the normal metabolism of free radicals in plants, thereby increasing its tolerance to cadmium in response to the increase in reactive oxygen species (ROS). Regarding high Cd, each of SOD, CAT, and POD in stressed plants were inhibited when the cadmium content went above

a certain threshold, which limited their ability to remove ROS and severely damaged the plant tissues' and cells' functional membranes and enzyme systems.

Ascorbic acid (vitamin C) is one of the most essential water-soluble antioxidants in plants, modulating plant development via hormone signaling and functioning as a coenzyme in the metabolism of carbohydrates, lipids, and proteins (Hashem and Hegab, 2018b). As shown in the table 4.17, at least some of magnetic water powers and Cd applications increased AA and proline. In this respect, ascorbic acid (AA) is one of the universal non-enzymatic antioxidants capable of not only scavenging reactive oxygen species (ROS), but also modulating a number of fundamental plant functions under both stress and non-stress conditions. On the contrary, since MW reduced proline accumulation in both leaves and fruits, it was hypothesized that increased proteolysis or decreased protein synthesis may be responsible for proline accumulation (Mohamed and Sherif, 2020).

Magnetized water purification can mitigate the effects of salinity stress by reducing proline levels. Proline contributes to the stabilization of subcellular structures (membranes and proteins) and induces salinity-responsive genes. As a protective response to salinity stress, proline levels increase with increasing salinity stress severity (Sutiyanti and Rachmawati, 2021). Radhakrishnan (2019) proved that magnetic field is important for activating proline synthesis, supporting cellular structures. Our results agree with Talabany and Albarzinji (2023) where Cd application increased peroxidase enzyme activity, ascorbic acid, and proline. Proline accumulation in plants under Cd stress is induced by a Cd-imposed decrease in plant water potential; its functional significance lies in its contribution to water balance maintenance; proline-mediated alleviation of water deficit stress could significantly contribute to Cd tolerance (Zengin and Munzuroglu, 2005).

Accumulated proline during stress episodes is degraded for energy supply, which is utilized to fuel growth and alleviate stress, thereby promoting growth under long-term stress. Exogenously administered proline tends to mitigate the deleterious effects of Cd on growth parameters, antioxidative enzyme capacities, and thus MDA and H_2O_2 concentrations (Hassan *et al*., 2021). Moreover, proline plays an important role as an antioxidant that stimulates stress-responsive genes, regulates cytoplasmic osmotic pressure, protects cells from reactive oxygen species (ROS) that negatively impact plant metabolism via the oxidative damage of lipids, proteins, and nucleic acids, and stabilizes the cellular membrane and proteins. Proline also plays an important role under stressful conditions by harmonizing the cytosol and vacuole osmotic pressure with that of the external environment, thereby enhancing water and nutrient uptakes (Okba *et al*., 2022).

The two main metabolites involved in better plant tolerance to environmental stressors are soluble sugars and proline amino acid (Hatamian *et al.*, 2019). Total soluble carbohydrates are the most important soluble component for osmotic adjustment in plants. Additionally, carbohydrates provide rapidly growing cells with energy and the carbon skeletons necessary for the synthesis of organic compounds (El-Beltagi and Mohamed, 2013). The power of magnetic water increased the TCHO, as shown in table 4.18, whereas Cd application do not effected in TCHO, which may be attributable to their effect on increasing photosynthetic pigment, which reflected on the photosynthesis process and lead to an increase in carbohydrate content (Aly *et al.*, 2015).

5.4. Effect of MW, Cadmium, and Their Interactions on Some Elements Content in Paulownia Parts and the Growing Soil

5.4.1 Soil Content of Elements

As shown in the table 4.20, magnetic water increased the N and K in paulownia soil. In contrast adding Cd decreased the N content and increased the P content. Opposite to this result Maheshwari and Grewal (2009) proved that the magnetic water treatment resulted in higher concentrations of mobile forms of nitrogen, enhanced the dissolution of fertilizers in the soil, accelerated the rate of water absorption, and explained the variation induced by magnetic fields in the ionic currents across the cellular membrane, which causes a change in osmotic pressure. The concentrations of nitrogen, phosphorus, potassium and calcium in soils irrigated with magnetic water differ from those of soils irrigated with conventional water. Magnetic water makes it easier for plants to absorb nutrients from soil solutions, most likely as a result of the accelerated crystallization and precipitation processes of the solute minerals. Also, N, P, and K% as well as Fe, Mn, Zn, and Cu (ppm) increased significantly in irrigation water containing magnetic particles (Shahin *et al.*, 2016b). The amount of K in *Raphanus sativus* L. was significantly higher in the soil extracts of plants irrigated with magnetized water than in the soil extracts of plants irrigated with regular water (Al-Ghamdi, 2020). Soil contamination with cadmium can modify the uptake, transport and utilization of different macro elements such as P, K or Ca in plants (Ciećko *et al.*, 2004) and (Das *et al.*, 1997).

The power of magnetic water increased the P and Ca as in table 4.20, whereas adding Cd increased the P content and Cd application was not effected in Ca. Similar results were confirmed by Anand *et al*. (2012) in a culture of peas (*Pisum sativum* L.) and celery (*Apium graveolens* L.), there was

an increase in the concentrations of Ca and P, as well as effects of MW on the reduction of soil pH, resulting in increased nutrient assimilation. High cadmium concentrations in the soil did not significantly alter the amount of phosphorus in the plant's stalk (Ciećko *et al.*, 2000). There is no correlation between cadmium and the P content of sunflower plants. It can be concluded that the effect of cadmium on phosphorus content varies from plant species to species (Simon, 1998). We found significantly higher soil Ca concentration in plants irrigated with magnetized water. This finding is in line with (Al-Ghamdi, 2020).

Table 4.20 shows that at least some of magnetic water powers increased of the K content, whereas the K content was not significantly impacted by the Cd concentrations. This result was confirmed by Hédiji *et al*. (2015) who showed that with a high Cd concentration, K was drastically reduced, indicating that Cd has a detrimental influence on their uptake and translocation. In addition, we have discovered that Cd reduces Ca, Mn, Zn, and Cu accumulation in the photosynthetic organs while increasing their accumulation in the roots. As it shown in the table 4.21, most of the magnetic water powers increased Fe content in soil. Opposite to this result Al-Ghamdi (2020) who found that Fe absorption decreased when plants were irrigated with magnetic water.

The results of tables 4.21 and 4.22 showed that increasing magnetic water powers increased significantly Cd content, whereas Pb decreased in the soil. However, the reseacher found decreased levels of Cd and Pb when plants irrigated by magnetic water (Al-Ghamdi, 2020). Plants grown in soil irrigated with magnetized water are protected from heavy metals, including lead and nickel, because the water has been shown to inhibit the translocation of these metals from the soil into the plants.

5.4.2 Paulownia Root Content of Elements

As shown in the table 4.25, at least some of magnetic water powers increased the macro element content in root (N, K, Ca and S), adding Cd decreased the N, P, K and Ca. Our results agree with Talabany and Albarzinji (2023) who found that Cd levels were significantly affected by the contents of total elements in lettuce, and when the concentration of Cd increased leads to decrease of all major macro elements N, P, K, and Ca respectively, depending for the results which we obtained indicated that Cd is a strong antagonist of these ions metallurgical elements of Cu and Mn. The level of metals such as Ca and K increased in plants supplied with magnetized water.

The increase in N under magnetic water treatment can be attributed to the magnetic field's strong

influence on the hydrogen bonds of water molecules, which increases solubility.

In addition, the magnetic field altered the membrane permeability and ion movement of faba bean cell membranes (Stange *et al*., 2002). It was discovered that large doses of cadmium increased the nitrogen and phosphorus content of oat straw and roots and maize roots; cadmium contamination of soil may increase the magnesium content of grain, oat straw and roots, and maize roots (Wyszkowski and Wyszkowska, 2009). Increasing the concentration of Cd in the external medium replaces Ca at the binding site on the exterior surface of the plasma membrane with other heavy metal cations, thereby increasing the Ca requirement. Cadmium reduces Ca due to competition between Cd and Ca at Ca channels and intracellular Ca-binding proteins (Nazar *et al*., 2012).

Cd at 1.0 M significantly decreased the concentrations of P, K, Ca, Cu, Mn, Zn, Mo, and B in the roots of barley (*Hordeum vulgare* L.), while the concentrations of these elements in the stalks were unaffected, compared to the control (Haider *et al*., 2021).

Researchers believe that the accumulation of certain minerals, such as K, in Fennel (*Foeniculum vulgare* Mill.), contributes to preserving cell turgor and improving the morphological and physiological characteristics of plants by preventing the degradation of cell walls against reactive oxygen species, boosting the activity of antioxidant enzymes, and enhancing water use efficiency (Faridvand *et al*., 2021).

As shown in the table 4.26, comparing low powers and low Cd concentrations to high powers and high Cd concentrations, the Mn content increased significantly. Mn content was lower in Cd-treated plants than in control plants' roots and branches because Cd is known to reduce the availability of Mn (Sarwar *et al.*, 2010).

5.4.3 Paulownia Stem Content of Elements

Nitrogen is an indispensable macronutrient and a crucial component of numerous structural, genetic, and metabolic compounds in plants, probably related to the maintenance of protein synthesis, electron transfer in photosynthesis, and respiration processes, shoots contained more nitrogen than roots (Gomes *et al.*, 2013). The power of magnetic water increased the N, P and Ca content (Table 4.29), whereas Cd application at low concentration effected in N and P content in the stem part, and Cd application does not effect in Ca.

Increased Ca and P concentrations in celery shoots and Ca concentrations in snow pea pods suggest enhanced availability, uptake, assimilation, and mobilization of these nutrients within the plant system. This may have contributed to the increased productivity of celery and snow pea plants

grown in magnetically treated water (Maheshwari and Grewal, 2009). Additionally, an increase in Cd accumulation in the stalks would result in an increase in N content, as N is required to produce Cd-detoxifying chelator molecules such as glutathione and phytochelatins (Gojon and Gaymard, 2010). Phosphate is an essential component for plant energy transfer and protein metabolism (Marschner, 1995). In addition, the higher P levels observed in shoots when Cd was present in high concentrations appeared to be associated with the proliferation of antioxidant systems (i.e. superoxide dismutase, ascorbate peroxidase, and catalase) that can mitigate oxidative stress and prevent membrane injury (Wang *et al*., 2009b).

It was explained that magnetic water interacts with the structural calcium in cell membranes, making the membranes more permeable. The decreased surface tension of magnetic water results in improved water infiltration and decreased water and chemical consumption. Therefore, it was determined to analyze the nutrient levels of the soil and plant material during the nursery trial (Boogaers, 2019). Plasma membrane surfaces are typically negatively charged, and high concentrations of Ca2+ would tend to neutralize them, thereby reducing the toxicity of Cd. Similarly, high Ca concentrations near ion channels could reduce the influx of Cd (Sarwar *et al*., 2010).

As shown in the table 4.30, increasing magnetic water powers increased the Mn and Cu content in paulownia stem, also adding Cd at high concentration increased these elements. Those results agree with Cd increases Cu uptake but inhibits its transport to seedlings, as demonstrated by the current study (Gomes *et al*., 2013). Regression analysis revealed a substantially negative correlation between Cd and Mn, indicating that Cd has an antagonistic effect on Mn absorption and translocation (Dong *et al*., 2006).

5.4.4 Paulownia Leaves Content of Elements

As shown in the table (4.33), increasing magnetic water powers only decreased the N and K content but increased all other macro-elements. Adding Cd increased the macro element, whereas only the S was decreased. It was observed that irrigation with magnetically treated water increased the concentration of all elements. This occurs because diamagnetic elements are repelled by a magnetic field.

The use of magnetically treated water increased the concentrations of nitrogen and phosphorus in leaves, indicating that it induced greater nitrogen assimilation, resulting in improvements in agronomic characteristics (leaf number, fresh and dried shoot weight, fresh and dry root weight)

(Putti *et al.*, 2023). The macronutrient elements (N, P, and K) are an integral part of our agricultural system for optimizing crop yield and for achieving sustainable agriculture.

Nitrogen supplementation to Cd-stressed plants increases Cd tolerance by increasing photosynthetic capacity, while phosphorus application neutralizes the deleterious effect of Cd through dilution and boosts plant growth and yield (Nazar *et al*., 2012). Similarly, increasing K nutrition in stressed plants has been shown to reduce oxidative cell damage by reducing ROS formation during photosynthesis and inhibiting oxygen radical-generating NADPH oxidase activity (Shen *et al*., 2000).

The results of the table 4.34 showed that using low power magnetic device increased Mn and Fe content significantly compared to tap water. Also increasing concentration of Cd increased content of Mn and Fe. Our results disagree with Sun and Shen (2007) who found that the decrease in S, P, Mn, and Fe concentrations in the leaves of Cd-sensitive cultivars under Cd stress is the primary cause for the inhibition of leaf photosynthesis and the diminution of cabbage growth. It is stated that Mn uptake and accumulation in all maize cultivars decreased significantly with increasing Cd ions in nutrient solution (Liu *et al.*, 2006). Iron contributes to Cd mitigation by limiting Cd absorption and translocation, as well as by promoting plant growth, photosynthetic pigment accumulation, and an intensified light phase of photosynthesis. Iron has been shown to help plants combat the negative effects of Cd by preserving both the quantity and quality of chloroplasts. However, in Cd-treated (25, 50, 100, and 150 M) almond seedlings, a decrease in Fe causes a decrease in the ferredoxins required for the light-induced oxidation-reduction process and a decrease in chlorophyll content (Nada *et al*., 2007).

Chapter Six

6. Conclusions and Recommendations

6.1. Conclusions

From the data analysis and discussions, we have reached these conclusions.

1- The application of MW on *p.tomentosa.* at least, one of MW powers increased significantly each of the cutting performance and some of vegetative growth parameters such as plant leaf-area, stem diameter, shoot and root fresh weight and dry matter content. All Cd concentrations increased the number of leaves, leaf area, and stem diameter with MF applay. Roots has been more impacted by Cd than plants shoots, however, compared to the control treatment, it significantly increased both the fresh weight of shoot and roots.

2- Irrigating *P. tomentosa* cuttings with MW at low powers (500 and 1000 gausses) show increasing in the content of photosynthesis pigments. Regardless of the device's power, using magnetic water significantly increased chlorophyll a, b, and total carotenoids. High concentration of Cd significantly decreased chlorophyll a and b content but increased total carotenoids.

3- Peroxidase enzyme activity and proline content significantly increased at low MW powers, but ascorbic acid and total carbohydrate increased at high powers. Application of Cd significantly increased proline and ascorbic acid compared to the control, whereas it significantly reduced peroxidase enzyme activity and the percent of total carbohydrate content.

4- Macro elements, heavy metals and some other elements in the soil increased at high power of MW, but micro elements were decreased. Macro, micro, heavy metal and some other elements increased with high concentration of Cd.

5- High powers of MW increased only the macro elements in root, but decreased micro elements, heavy metals and some other elements. At least, some concentrations of Cd increased the macro element but micro element and some other elements increased at low concentration of Cd.

6- Application of MW had more positive effect on most of the elements in stem, whereas cadmium caused a significant increase in all element in stem.

7- Using 1500 gauss of MW was more effective for significant increasing most elements in leaves. As well as Cd application at 3.33 $mg.kg^{-1}$soil increased all element content in leaves.

6.2. Recommendations

1- Using other methods of MW applications like soaking cutting in MW for several days.
2- Conducting study under more Cd concentrations with studying the hormonal and phytochemical response under the studied factors.
3- Using paulownia seed with same study factors.
4- Studying more physiological parameters under Cd stress including; stomatal conductivity, membrane stability index, electrolytic leakage (EL), malondialdehyde (MDA), glycine betaine, and H_2O_2.
5- Studying the effects of other heavy metals like Ni, Pb and Hg under the same experiment factors.
6- Studying other varieties to determine the most suitable varaiety for the Iraqi environment or Kurdistan region

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جمهورية العراق الفدرالي

حكومة إقليم كوردستان

وزارة التعليم العالي والبحث العلمي

جامعة كوية

تأثير الماء الممغنط على النمو وبعض الخصائص الفسيولوجية لنباتات *Paulownia tomentosa* تحت إجهاد الكادميوم

رسالة مقدمة الى مجلس كلية العلوم والصحة في جامعة كوية وهي جزء من متطلبات نيل شهادة الماجستير في (اختصاص علوم الحياة)

من قبل

نارا عبدالله فتاح

بكالوريوس في الزراعة (2011)

با شراف

ا. د. إقبال محمد غريب البرزنجي

1445 هجرية

الخلاصة

يعتبر نبات البولونيا (*Paulownia tomentosa*) واحدة من أسرع أنواع الأشجار نموًا في العالم والأكثر استخدامًا للأغراض التجارية. أجريت هذه الدراسة كتجربة عاملية في مدينة كوية- أربيل، العراق خلال الفترة 2021-2022 لدراسة تأثير المياه المغناطيسية (MW)عند (0 ، 500 ، 1000 ، 1500 و 2000) غاوس وكلوريد الكادميوم (Cd) عند (0 ، 3.33 ، 6.66 و 10 ملجم الكادميوم. كجم$^{-1}$ تربة) على بعض الخصائص الفسيولوجية والكيموحيوية لهذا النبات. أظهرت النتائج أن MW ليس له تأثير معنوي فيما يتعلق بنسبة وسرعة العقل النابتة مقارنة باستخدام الماء العادي، بينما أدى استخدام Cd إلى زيادة سرعة نمو العقل. أدت واحدة على الأقل من معاملات MW إلى زيادة ملحوظة في مساحة أوراق النبات وقطر الساق والوزن الطري للجزء الخضري والجذري ومحتوى المادة الجافة، وزادت جميع تركيزات الكادميوم من عدد أوراق النبات ومساحة الأوراق وقطر الساق. كان للكادميوم تأثير على الجذور أكثر من الجزء الخضري، حيث كان له تأثير غير معنوي على المادة الجافة، بينما أدى إلى زيادة الوزن الطري للجزء الخضري والجذور بشكل معنوي مقارنة بمعاملة المقارنة. كان أداء MW منخفض الطاقة (500 و 1000) كاوس أفضل من القوى العالية (1500 و 2000) كاوس في زيادة محتوى صبغات التمثيل الضوئي. أدى استخدام المياه المغناطيسية إلى تحسين الكاروتينات الكلية والكلوروفيل أ و ب وبغض النظر عن قوة الجهاز. أدت التركيزات العالية من الكادميوم إلى انخفاض معنوي في كل من الكلوروفيل أ و ب، ومع ذلك فقد زادت معنوياً بتركيزات منخفضة مقارنة بالمعاملات الأخرى. قلل MW عالي الطاقة بشكل معنوي من نشاط إنزيم البيروكسيديز ومحتوى البرولين بينما قلل من نسبة الكربوهيدرات الكلية مقارنة بالمعاملات الأخرى. أدى استخدام الكادميوم إلى تقليل نشاط إنزيم البيروكسيديز والنسبة المئوية لمحتوى الكربوهيدرات الكلي وزيادة حمض الأسكوربيك والبرولين بشكل معنوي بالمقارنة مع معاملة المقارنة. من ناحية أخرى، زادت المعاملة G1500 بشكل كبير من محتوى التربة من العناصر الكبرى، بينما الماء العادي والمعاملة G2000 زادتا محتوى العناصر الصغرى في التربة، مع زيادة قوة المياه المغناطيسية زادت بشكل معنوي من العناصر الثقيلة في التربة. المعاملة G2000 زاد بشكل معنوي من العناصر الأخرى في التربة مثل (Ta، Hf، Re، Au،Sn). عند التركيز المنخفض من الكادميوم زادت معنوياً العناصر الكبرى في التربة مثل (N، P، S) والتي زادت أيضا عند زيادة تركيز الكادميوم إلى (Cd6.66 و Cd10) ملغم كغم$^{-1}$ ، في حين أدى زيادة تركيز الكادميوم إلى 10 مجم الكادميوم. كغم$^{-1}$ أدى إلى زيادة المعادن الثقيلة والعناصر الأخرى في التربة بينما لم يؤثر الكادميوم معنوياً في عنصرw . أدى استخدام MW بغض النظر عن قوة الجهاز إلى زيادة العناصر الكبرى في الجذر بشكل معنوي، بينما زادت المعاملة G1500 بشكل معنوي كل من العناصر الصغرى والعناصر الثقيلة وبعض العناصر الأخرى في الجذر، بينما لم يؤثر اضافة الكادميوم في العناصر الكبرى في الجذر. كما أدت إضافة الكادميوم في معاملات التربة إلى زيادة العناصر الصغرى والعناصر الأخرى في الجذر مقارنة بالعناصر الأخرى ، لكن استخدام الكادميوم في معاملات التربة (Cd3.33 و Cd10) ملغم الكادميوم. كغم أدى إلى زيادة معنوية في المعادن الثقيلة في التربة. أدى استخدام MW بغض النظر عن قوة الجهاز إلى زيادة العناصر الكبرى في السيقان بشكل معنوي مقارنة بالماء العادي، بينما زادت قوة الماء المغناطيسي الى G1500 من العناصر الصغرى والمعادن الثقيلة في السيقان. مع زيادة تركيز الكادميوم، زادت غالبية العناصر في سيقان البولونيا. بينما أدت قوى الماء المغناطيسية G1000 إلى زيادة معظم العناصر في الورقة ، كما أدت إضافة تركيز منخفض من الكادميوم Cd3.33 ملغم الكادميوم. كغم إلى زيادة العناصر في الورقة بشكل معنوي.

کۆماری فیدراڵی عێراق
حکومەتی هەرێمی کوردستان
وەزارەتی خوێندنی باڵا و توێژینەوەی زانستی
زانکۆی کۆیە

کاریگەری ئاوی موگناتیسی لەسەر گەشەکردن و هەندێک تایبەتمەندی فیزیۆلۆژی ڕووەکی *Paulownia tomentosa* لە ژێر فشاری کادمیۆم دا

ماستەرنامەیەکە پێشکەشکراوە بۆ فاکەڵتی زانست و تەندروستی

لە زانکۆی کۆیە وەك بەشێك لە پێداویستییەکانی بەدەستهێنانی بڕوانامەی ماستەر

لە (بایۆلۆجی)

لەلایەن

ئارا عبداللة فتاح

بەکالۆریۆس لە (کشتوکاڵ) (2011)

بە سەرپەرشتی: **پ.د.إقبال محمدغریب البرزنجی**

2723 کوردی

پوختە

پاولۆنیا (*Paulownia tomentosa*) بە یەکێک لە جۆرە درەختەکانی جیهان دادەنرێت کە خێراتر گەشە دەکات و زۆرترین بەکارهێنانی بۆ بازرگانی بەکاردەهێنرێت. لە شاری کۆیە سەر بە پارێزگای هەولێر ، ئەم توێژینەوەیە وەک تاقیکردنەوەیەکی فاکتۆریال ئەنجامدراوە، لە ماوەی ساڵانی ٢٠٢١-٢٠٢٢ بۆ لێکۆڵینەوە لە کاریگەرییەکانی ئاوی موگناتیسی (MW) لە (٠، ١٠٠٠، ٥٠٠، ١٥٠٠ و ٢٠٠٠) گاوس و کادمیۆم (Cd) لە (0، 3.33، 6.66 و10) mg Cd. Kg^{-1}soil لەسەر هەندێک تایبەتمەندی گەشەکردن، فیزیۆلۆژی و بایۆکیمیایی ئەم ڕووەکە. ئەنجامەکان نیشان دەدەن کە MW جیاوازییەکی نابەرچاوی هەبووە سەبارەت بە بەردەوام بوون و و خێرایی گەشەی بڕین بەراورد بە بەکارهێنانی ئاوی چارەسەر نەکراوی MW، لەو کاتەی بەکارهێنانی Cd خێرایی گەشەی دەرچوونی قەڵەمەکان زیاد کردووە.

بەڵایەنی کەمەوە یەکێک لە مامەڵەکانی موگناتیسی بە شێوەیەکی بەرچاو زیاد دەکات هەریەک لە ڕووبەری گەڵاکانی ڕووەک، تیرەی لق، کێشی تازەی لق و ڕەگ و ڕێژەی مادەی وشک، هەموو چڕییەکانی Cd ژمارەی گەڵاکانی ڕووەکەکان، ڕووبەری گەڵا، تیرەی لق زیاد دەکات. Cd کاریگەری زیاتری لەسەر ڕەگەکان هەبووە لە چاو لقەکانی ڕووەک، کە کاریگەرییەکی نابەرچاوی لەسەر مادەی بەرز یان وشکی لقەکان هەیە، لە کاتێکدا هەریەک لە کێشی تازەی لق و ڕەگی بە شێوەیەکی بەرچاو زیاد دەکات بە بەراورد بە مامەڵەی کۆنترۆڵ. مامەڵەی کەمی موگناتیسی (500 و 1000 گاوس) لە زیادکردنی ناوەڕۆکی ڕەنگە فۆتۆسینتێزەکاندا باشتر لە هێزی بەرز (1500 و 2000 گاوس) ئەنجامیان دا. بەکارهێنانی ئاوی موگناتیسی زۆر کۆی گشتی کارۆتینۆیدەکان و کلۆرۆفیل a، b و بەبێ گوێدانە هێزی ئامێرەکە بەرزکردەوە.

چڕیی بەرزی Cd بووە هۆی کەمبوونەوەی بەرچاوی هەردوو کلۆرۆفیل a و b، بەڵام بە شێوەیەکی بەرچاو زیاد بوو بە چڕیی نزم بە بەراورد لەگەڵ چارەسەرەکانی دیکە. MW هێزی بەرز چالاکیی ئەنزیمەکانی پەرۆکسیدایز و ڕێژەی پرۆلین بە شێوەیەکی بەرچاو کەمکردەوە لە کاتێکدا ڕێژەی سەدی کۆی گشتی کاربۆهیدراتی کەمکردەوە بە بەراورد بە چارەسەرەکانی دیکە. بەکارهێنانی Cd هەریەک لە چالاکیی ئەنزیمەکانی پەرۆکسیدایز و لەسەدا کۆی ڕێژەی کاربۆهیدراتی کەمکردەوە و ترشی ئەسکۆربیک و پرۆلین بە شێوەیەکی بەرچاو زیاد دەکات. بە بەراورد بە کۆنترۆڵ. لە لایەکی دیکەوە، G1500 بە شێوەیەکی بەرچاو خاکی پاولۆنیای لە توخمە ماکرۆییەکان زیاد کردبوو، لە کاتێکدا لە ئاوی چارەسەر نەکراوی MW و G2000 توخمە بچووکەکانی لە خاکدا زیاد کردبوو، لەگەڵ بەکارهێنانی زیادکردنی هێزی ئاوی موگناتیسی کانزا قورسەکانی لە خاکدا بە شێوەیەکی بەرچاو زیاد کردبوو. لە کاتێکدا لەگەڵ بەکارهێنانی هێزی بەرزی ئاوی موگناتیسی لە G2000، بە شێوەیەکی بەرچاو توخمەکانی تری لە خاکدا زیاد کردووە وەک.(Ta, Hf, Re, Au and Sn) لە چڕیی کەمی Cd بە شێوەیەکی بەرچاو توخمە ماکرۆکان لە خاکدا زیاد دەکات وەک (N، P و S)، بەڵام لە توخمە ماکرۆکان لە خاکدا زیاد دەکات لە زیادبوونی چڕیی Cd (Cd6.66 و Cd10) mg Cd. Kg^{-1} چارەسەرەکانی خاک، لە کاتێکدا زیادبوونی چڕیی Cd لە چارەسەرەکانی خاکی mg Cd. Kg^{-1} Cd10، زیادبوونی کانزا قورسەکان و توخمەکانی دیکە لە خاکدا لە کاتێکدا Cd کاریگەرییەکی نابەرچاو لە توخمەکانی wدا هەبوو.

بەکارهێنانی MW بەبێ گوێدانە هێزی ئامێرەکە توخمە ماکرۆکانی لە ڕەگدا بە شێوەیەکی بەرچاو زیاد دەکات، لە کاتێکدا G 1500 بە شێوەیەکی بەرچاو زیادی کردووە (توخمە بچووکەکان، کانزای قورس و توخمەکانی تر) لە ڕەگدا، لە کاتێکدا بەکارهێنانی Cd کاریگەری لەسەر توخمە ماکرۆکان لە ڕەگدا نییە. هەروەها بەکارهێنانی Cd لە چارەسەرەکانی خاکی

Cd3.33 mg Cd. Kg^{-1}، زیادبوونی توخمە بچووکەکان و توخمەکانی تر لە ڕەگدا بە بەراورد بە توخمەکانی دیکە ، بەڵام بەکارهێنانی بۆ چڕیی (Cd3.33 و Cd10) mg Cd. Kg^{-1} چارەسەرەکانی خاک، بووە هۆی زیادبوونی بەرچاو لە کانزای قورس لە خاکدا. بەکارهێنانی MW بەبێ گوێدانە هێزی ئامێرەکە توخمە ماکرۆکانی لە لقدا بە شێوەیەکی بەرچاو زیاد دەکات بە بەراورد بە ئاوی شلەتین، بەڵام هێزی ئاوی موگناتیسی لە G1500 توخمە مایکرۆ و کانزای قورس لە لقە پاولۆنیا زیاد دەکات. لەگەڵ زیادبوونی چڕیی Cd، زۆربەی توخمەکانی ناو لقە پاولۆنیا زیاد بوون. لە کاتێکدا کە هێزەکانی ئاوی موگناتیسی لە G1000 زۆرترین توخمەکانی لە گەڵادا زیاد کرد، هەروەها زیادکردنی لە چڕیی کەمی Cd لە چارەسەرەکانی خاکی Cd3.33 mg Cd. Kg^{-1}، بە شێوەیەکی بەرچاو توخمەکانی لە گەڵادا زیاد کرد.