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MAGNETIC WATER EFFECTS ON GROWTH AND SOME PHYSIOLOGICAL CHARACTERISTICS OF *PAULOWNIA TOMENTOSA* THUNB UNDER CADMIUM STRESS CONDITIONS

Ara F. Abdullah [a,*], Ikbal M. Albarzinji [a]

[a] Dept. of Biology, Faculty of Science and Health, Koya University, Koya, Kurdistan Region, Iraq (ara.abdullah@koyauniversity.org, ikbal.tahir@koyauniversity.org)

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ABSTRACT:

Paulownia (*Paulownia tomentosa*) is considered as one of the world's fastest-growing species of trees and most widely used for commercial. This research was done as a factorial experiment in Koya city, Erbil, Iraq during 2021-2022 to study the effects of magnetic water (MW) at (0, 500,1000, 1500 and 2000) gauss and cadmium chloride (Cd) at (0, 3.33, 6.66 and 10 mg Kg^{-1}soil) on some growth, physiological and biochemical properties of this plant. Results demonstrate that MW had non-significant differ regarding the survived and the velocity of cutting outgrowth compare to using tap water, whereas Cd application increased the velocity of cutting 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, as well as 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) gauss performed better than high powers (1500 and 2000) gauss in increasing the content of photosynthesis pigments. Utilizing magnetic water greatly enhanced total carotenoids and chlorophyll a, b, regardless to device power. Chlorophyll (a and b) were both significantly reduced by high Cd concentrations; however it was significantly increased at 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, percent of total carbohydrate content, increased ascorbic acid and proline significantly in comparing to the control.

KEYWORDS: Magnetic Water, Cadmium Stress, *Paulownia tomentosa*, Peroxidase, Non-enzymatic Antioxidants.

1. INTRODUCTION

Paulownia (*Paulownia tomentosa* Thunb.) is a genus belongs to the scrophulariaceae family that is important economically. They are deciduous trees, between the fastest growing species and most developed trees in the world commercially for wood production, and other afforestation purposes (Barbu et al., 2022). *P. tomentosa* tree exported to Iraqi Kurdistan region last decay, several paulownia plantations existed in Kurdistan region for wood production. 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). *Paulownia* can be planted from seed, stem and root explants and cuttings. The development of seeds requires more time , has a slower rate of germination, pathogens problems and slow growth than cuttings growing from stem and root explants (Yaycili and Alikamanoglu, 2005). The best type of cuttings can be used successfully for propagation 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. Magnetic water (MW) is that water flows through a magnetic device, thus, some of the water's chemical and physical characteristics are changed, where its viscosity, dielectric stability, the formation of clustering structures, polarization, force of surface tension, conductive electricity, and salt dissolution, all of them distinct from those of normal water (da Silva and Dobránszki, 2014), where MW irrigation may 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). The positive impact of a magnetic field on *P. tomentosa and P. fortunei* node explant`s fresh weight, length, number of leaves, and chlorophyll content was observed by Yaycili and Alikamanoglu (2005). 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 grow in Cd-contaminated soil, their roots absorb the heavy metal, which builds up in different organs and eventually reduces plant growth, meanwhile, 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 various concentrations of Cd, Pb, and Zn, the total dry biomass, leaf area, stomatal conductance, and transpiration rate are all significantly reduced, while the leaf area ratio, net photosynthetic rate, and water usage are all increased (Miladinova et al., 2014). However, even at low concentrations, cadmium inhibited plant development and even led to plant death (Wang et al., 2010). Plants have

* Corresponding author

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). In maize (*Zea mays*) under Cd stress, magnetic water increased SOD and CAT activity, which decreased oxidative stress in this plant (Chen et al., 2011). 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. Thus, this study aims to concentrate on the effects of magnetic water on growth and some physiological responses of *P. tomentosa* plants that grow in Cd polluted soil.

2. MATERIALS AND METHODS

2.1. Plant Materials, Cultivation, and Treatments

Cutting of *Paulownia tomentosa* were collected from one year's stalks exist in a nursery which is specialist 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 7.67 pH, EC= 0.4 dSm^{-1} sandy loam texture. The average environmental conditions throughout the growing season varied from 15.65 - 25.45◦C for temperature, 45.86% relative humidity, and 1.69 mm precipitation.

A factorial experiment with two factors was used to conduct the study. First factor was irrigation with magnetized water (MW) in 5 different powers [0 (tap water), 500, 1000, 1500, and 2000] gauss by using 4 magnetic devices manufactured by Al- Rafidain company for magnetic technologies, Baghdad, Iraq (Figure 1-a), where the irrigation by magnetic water was began with cuttings cultivation until the end of the experiment according to plant needs. Second factor was four concentrations of cadmium chloride $CdCl_2.H_2O$ (0, 3.33, 6.66, and 10) mg Kg^{-1} soil by adding 250 ml of (0, 20, 40, and 60) mg l^{-1} cadmium chloride solutions to each bag at April 26th and repeated at the 1st of June. Each experimental unit consists of 10 bags each with one cutting (Figure 1-b, c, and d).

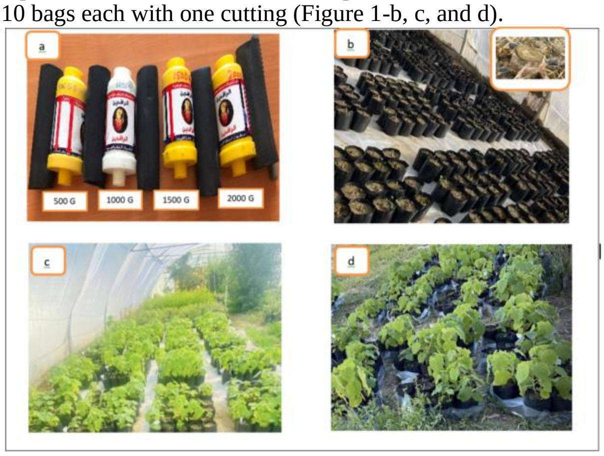

Figure 1. Shows the devices used for magnetizing the water, and different steps of the biological experiment in a greenhouse (a) the magnetic devices (b) planting cuttings of Paulownia tomentosa, with a close view of one of them (c) a view of the experiment inside the greenhouse, and (d) a view of the experiment stalks outside the greenhouse.

2.2. Studied Characteristics

The survival percent and velocity of cutting buds outgrowth was measured as indicated in Al-Barzini, and Khudhur (2015). Three plants were chosen randomly from each experimental unit to determine the following characteristics: plant leaves number, leaf area which computed with the technique of Watson and Watson (1953), number of branches, stem diameter by using caliper micrometer instrument (J0006, size 0-25mm, China), shoot and root length, fresh weight and the percent of dry matter as it is mentioned by Al-Barzini, and Khudhur (2015). Third and fourth full expanded fresh leaves were used to estimate the following characteristics: Chlorophyll a (Chl.a), chlorophyll b (Chl.b), and total carotenoids (TC) estimated as it is mentioned by Lichtenthaler, and Wellburn, (1983), peroxidase enzyme activity (POD) calculated according to the procedure of Nezih, (1985) using guaicaol and H_2O_2 spectrophotometrically at 420 nm, the estimation of ascorbic acid (AA) were done by the method of Elbsheer (2018) spectrophotometrically at 665 nm using the solution of methylene blue. Proline content was determined by using each of sulphosalicylic acid and ninhydrin spectrophotometrically at 520nm which is calibrated with the standard curve of proline according to Bates, et al., (1973), the percent of total carbohydrate (TCHO) estimated spectrophotometrically at 488 nm by using concentrated sulfuric acid (H_2SO_4) and phenol as it is mentioned by Herbert, et al., (1971).

2.3. Statistical Analysis and Experimental Design

A Factorial experiment with complete randomized design with three replications was used to conduct this study. Data were submitted for Duncan's multiple range test and analysis of variance (ANOVA) at a probability level of %5 for comparing the means and their interactions using the SAS program (Al-Mohammadi and Al-Mohammadi, 2002).

3. RESULTS AND DISCUSSIONS

The results in **table (1)** demonstrate that the power of the magnetic device didn't affect significantly on the percent of survived cutting, and the velocity of buds outgrowth compared to tap water. Cd increased the velocity of buds outgrowth significantly for (3.33 and 10) mg Kg^{-1}soil. The percent of survived cutting increased significantly to 100% for G500x Cd6.66 mg Kg^{-1}soil treatment compared to interactions of tap water with high Cd concentrations, and the interaction of high-power magnetic water without Cd, in addition to the treatment G1000 x Cd6.66 mg Kg^{-1}soil, where they gave only 80%. The treatment G1500 x Cd0 mg Kg^{-1}soil decreased the velocity of buds outgrowth to 78 days only, whereas the longest period was detected for G500 x Cd 3.33 mg Kg^{-1}soil which is not differ significantly with the control treatment. Magnetic device power had non-significant effects on plant leaves number except for the 1500 gauss which decreased them significantly to 6.50 compared to other treatments.

Adding Cd especially the low concentration Cd3.33 mg Kg^{-1} soil increased plant leaves number significantly to 9.04 compared to the control treatment (7.67). The treatments G2000 x Cd3.33 and G1000 x Cd6.66 mg Kg^{-1}soil gave the higher leaves number (11.67 and 10.78) compared to the control treatment, while the interactions of G1500 with different Cd concentrations gave the lowest plant leaves number. Plant leaf area increased significantly when (1000 and 2000) gauss were used significantly to (1604.17 and 1552.28) cm^2 compared to 1500 gauss and the control treatments. Applying Cd in different concentrations increased plant leaf area significantly compared to the control treatment which gives lower value (1197.14) cm^2. The control treatment gave the lowest value (900.8 cm^2) significantly compared to all other interaction treatments except the interactions of 1500 gausses with (Cd0 and Cd6.66) mg Kg^{-1}soil treatments. Neither the power of the magnetic water nor the Cd concentrations had significant effects on the plants branch number, whereas each of G500 x Cd10 and G1000 x Cd6.66 mg Kg^{-1}soil treatments gave the highest branch number reached 1.78, whereas G2000 x Cd10 treatment gives the lowest value (1.00) only. The MW 1500 gauss increased stem diameter significantly to 6.57 cm compared to 500 and 2000 gausses treatments. Increasing Cd concentrations increased significantly the stem diameter to 6.39 cm for the Cd10 mg Kg^{-1}soil compared to the control treatment. Most of the interaction treatments did not differ significantly between each other regarding stem diameter.

The results in **table 2** show that plant high increased significantly to 38 cm with 1500 gauss MW compared to all other treatments, whereas the Cd concentrations had no significant effect on this property. The interaction treatments of 1500 gauss regardless Cd concentrations increased plant high significantly compared to most other treatments were the control treatment records the lowest value (23.33 cm). Each of 500 and 1000 gausses increased shoot fresh weight significantly compared to other treatments, where the control treatment gives the lowest value. Adding Cd regardless the concentration, increased shoot fresh weight significantly compares to the control treatment. All interaction treatments increased shoot fresh weight significantly compared to the control treatment (26.10 g).

The percent of shoot dry matter increased significantly by 1000 and 1500 gauss MW compared to other treatments, whereas the Cd had non-significant effect on this property, by same way the percent of shoot dry matter increased significantly by G1000 and G1500 interaction treatments regardless the Cd concentrations compared to G0, G500 and G2000 treatments. Increasing magnetic devices power to 1500 and 2000 gauss and the Cd concentrations to (6.66 and 10) mg Kg^{-1}soil decreased the root length significantly compared to low powers and low Cd concentrations. Using 500 gauss water without Cd increased the root length significantly to 24.67 cm (Table 2). 1000 gauss MW increased root fresh weight significantly compared to other treatments. Adding Cd regardless the concentration increased root fresh weight compared to the control treatment.

The percent of root dry matter increased significantly for 1500 gauss to 19.03%, and the lowest value recorded by the control treatment (9.97%). Cd application with 6.66 mg Kg^{-1}soil increased the percent of root dry matter significantly to 14.27% compared to each of (Cd3.33 and Cd10) mg Kg^{-1}soil treatments only. Interaction treatments of 1500 gauss with all Cd concentrations increased the percent of root dry matter significantly compared to all other treatments, except the G2000 x Cd6.66 mg Kg^{-1}soil treatment. 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 traits, including plant height, leaves' fresh and dry weight, and leaf area, may be attributed to the stimulatory effect of magnetic water. As comparison to nonmagnetic treatments, magnetic treatments enhanced the length, surface area, and number of root points of populus plants as well as their height, diameter, and leaf area (Liu et al., 2017).

According to a theory, 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 reactive oxygen species (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 (Chen et al., 2011). These results are going with those 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 induced or promoted growth and increased leaf area due to increasing water and nutrient availability, which increased photosynthetic pigments, and rapid plant vegetative development, the results also agreed with those reported by Hasan et al. (2019), where the higher leaf area, fresh weight, and dry weight was observed under MW, which might be due to the enhancing the photosynthesis rate. The induction of cell metabolism and mitosis division, an increase in physiological pigment, endogenous promoters, and an increase of protein biosynthesis might be caused by MW's stimulatory effect on growth parameters (Abdullah 2019). 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 roots were obtained. Cd stress may damage the plant's photosynthetic organs and structures, which reduces *E. sativa* growth.

The results in **table 3** showed that using MW regardless the device power increased Chl.a, Chl.b, and TC significantly compared to tap water, whereas, the low powers (500 and 1000) gauss were best than the high powers (1500 and 2000) gauss in increasing these pigments. Regarding Cd application, higher Chl.a, Chl.b and TC were recorded for Cd6.66 and Cd3.33 mg Kg^{-1}soil. The interaction treatments G1000 x Cd0 mg Kg^{-1}soil and G1500 x Cd6.66 mg Kg^{-1}soil gave higher Chl.a and G500 x Cd10 mg Kg^{-1}soil higher Chl.b significantly compared to all other treatments. Most of MW interactions with Cd concentrations increased TC content significantly compared to the tap water.

These results are similar to those reported by 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 These results agreed with the results of 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).

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 disagrees 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. In tolerant plants have frequently been shown to have thicker mesophyll when exposed to heavy metal pollution (Pereira et al. 2016). 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).

POD was likely is the major protective enzyme included in the removal system of reactive oxygen. From the results of table (3) it is shown that G500 MW increased POD enzyme activity to 110.67unit g^{-1} significantly compared to all other treatments. Low Cd concentration (3.33 mg Kg^{-1}soil) significantly increased the enzyme activity, whereas the enzyme activity decreased with increasing the Cd concentration which reached to 88.27 unit g^{-1} for the 10 mg Kg^{-1}soil. 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).

On the other hand interaction treatment G500 x Cd3.33 mg Kg^{-1}soil caused a significant increase in the enzyme activity to 132 unit g^{-1} fresh weight, whereas the lowest value (62.00 unit g^{-1}fresh weight) 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. These results agree with Zhao et el. (2021) where they found that *Sassafras albidum* plant which adapts the activities of SOD and POD in its organs under cadmium stress, eliminating harmful substances such as O^{2-} and H_2O_2 to maintain the normal metabolism of free radicals in plants, and thus increases its tolerance to cadmium in order to adapt 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 increase to above the certain threshold, which limited their ability to remove ROS, severely damaged the plant tissues', cells' functional membranes and enzyme systems.

The effect of MW on AA was clear for (500 and 1000) gauss where it increased significantly to 3.15 and 3.19 mg.100g^{-1} dry weight compared to the tap water (2.31) which is more significantly compared to G1000 and G2000 respectively. Irrigation with 1500 gausses water and adding 10 mg Kg^{-1} soil Cd increased the AA content significantly to 4.25 mg 100 g^{-1} dry weight significantly compared to all other treatments, whereas the lowest value (0.47 mg 100 g^{-1} dry weight) recorded for G2000 x Cd6.66 mg Kg^{-1}soil treatment. The two main metabolites involved in better plant tolerance to environmental stressors are soluble sugars and proline amino acid (Hatamian et al 2019). The plant irrigated with 1000 gauss water increased leaves content of proline significantly to 71.39 Mm g $^{-1}$ fresh weight compared to other treatments, Radhakrishnan (2019) they proved that magnetic field is particularly important for activating proline synthesis, supporting cellular structures.

Increasing Cd concentration to (6.66 and 10) mg Kg^{-1}soil increased proline concentrations significantly compared to the control treatment which reached 62.29 Mm g $^{-1}$ fresh weight which is more significantly than Cd3.33 mg Kg^{-1}soil treatment. The interaction treatments G0 x Cd10 mg l^{-1} and G1000 x Cd6.66 mg Kg^{-1}soil increased the proline concentration significantly to (76.88 and 76.73) Mm g $^{-1}$ fresh weight compared to other interaction treatments especially for the interactions of G2000 with different Cd concentrations. The powers of different magnetic devices differ significantly between each other regarding the percent of Total carbbohydrates (TCHO) where G1500 records the highest value (3.09%), whereas the lowest value (2.43%) recorded for the G500. These results are similar and agreed with results reported by agrees with Radhakrishnan (2019) who proved that carbohydrates were less in plants treated with MF. Tap water records the highest percent of TCHO (2.89%), whereas the lowest value (2.29%) recorded for the Cd6.66 mg Kg^{-1}soil treatment. The interaction treatment G1500 x Cd0 mg Kg^{-1}soil records the highest TCHO percent (3.43%) significantly compared to all other treatments, whereas interaction of tap water with Cd6.66 records the lowest value (1.82%). Our results agree with Talabany and Albarzinji (2023) where Cd application increased peroxidase enzyme activity, ascorbic acid, and proline.

Table 1. Effects of magnetic water, Cd and their interactions on cutting performance and some vegetative growth characteristics of *Paulownia tomentosa*.

Treatments	Survived Cutting (%)	Velocity of Buds Outgrowth (Days)	Plant Leaves Number	Plant Leaf Area (cm^2)	Branch Number	Stem Diameter (cm)
Magnetic Water (MW) (Gauss)						
G0	87.50 ab	92.923 ab	8.72 a	1367.36 b	1.42 a	6.25 ab
G500	93.33 a	96.344 a	8.89 a	1484.43ab	1.45 a	6.06 bc
G1000	91.67 ab	96.962 a	9.17 a	1552.28 a	1.47 a	6.33 ab
G1500	91.67 ab	89.118 b	6.50 b	1187.00 c	1.36 a	6.57 a
G2000	86.67 b	90.755 b	9.61 a	1604.17 a	1.33 a	5.75 c
Cd concentration (mg Kg-1 soil)						
Cd 0	91.33 a	90.019 b	7.67 b	1197.14 b	1.33 a	5.98 b
Cd 3.33	92.00 a	95.570 a	9.04 a	1549.36 a	1.36 a	6.17 ab
Cd 6.66	88.67 a	91.379 ab	8.84 ab	1505.40 a	1.47 a	6.22 ab
Cd 10	88.67 a	95.914 a	8.75 ab	1504.29 a	1.47 a	6.39 a
Interactions effect of MW and Cd						
G0 Cd0	96.67 ab	95.30 a-c	6.89 c-e	900.8 f	1.44 a-c	5.46 ef
G0 Cd3.33	93.33 a-c	91.55 a-c	9.78 a-c	1398.0 c-e	1.56 ab	6.52 a-c
G0 Cd6.66	80.00 d	87.80 b-d	8.78 a-e	1786.5 ab	1.22 b-c	6.66 a
G0 Cd10	80.00 d	97.04 a-c	9.44 a-e	1384.1 c-e	1.44 a-c	6.36 a-d
G500 Cd0	93.33 a-c	93.61 a-c	8.00 b-e	1407.5 c-e	1.44 a-c	5.84 b-f
G500 Cd3.33	93.33 a-c	102.72 a	9.22 a-e	1601.2 b-d	1.22 bc	6.11 a-f
G500 Cd6.66	100.00 a	93.47 a-c	8.78 a-e	1321.8 de	1.33 a-c	5.76 c-f
G500 Cd10	86.67 b-d	95.58 a-c	9.55 a-e	1607.1 b-d	1.78 a	6.53 a-c
G1000 Cd0	96.67 ab	92.60 a-c	8.78 a-e	1321.4 de	1.33 a-c	6.61 ab
G1000 Cd3.33	93.33 a-c	98.74 ab	7.33 c-e	1540.5 b-d	1.22 bc	6.19 a-d
G1000 Cd6.66	80.00 d	98.20 ab	10.78 ab	1619.4 b-d	1.78 a	6.04 a-f
G1000 Cd10	96.67 ab	98.31 ab	9.78 a-c	1727.8 b	1.56 ab	6.46 a-c
G1500 Cd0	90.00 a-d	78.69 d	6.22 e	1162.3 ef	1.22 bc	6.57 ab
G1500 Cd3.33	96.67 ab	87.47 b-d	7.22 c-e	1202.8 e	1.33 a-c	6.37 a-d
G1500 Cd6.66	93.33 a-c	92.20 a-c	6.22 e	1165.5 ef	1.33 a-c	6.65 a
G1500 Cd10	86.67 b-d	98.11 ab	6.33 de	1217.5 e	1.55 ab	6.67 a
G2000 Cd0	80.00 d	89.89 b-d	8.44 a-e	1193.7 e	1.22 bc	5.42 f
G2000 Cd3.33	83.33 cd	97.38 a-c	11.67 a	2004.4 a	1.44 a-c	5.67 d-f
G2000 Cd6.66	90.00 a-d	85.22 cd	9.67 a-d	1633.7 bc	1.67 ab	6.00 a-f
G2000 Cd10	93.33 a-c	90.53 a-d	8.67 a-e	1584.9 b-d	1.00 c	5.91 a-f

* Means followed by the same letters within columns are not significantly different at $p > 0.05$ according to Duncan`s Multiple Range test.

Table 2. Effects of magnetic water, Cd and their interactions on some shoot and root characteristics of *Paulownia tomentosa*.

Treatments	Shoot	Root

	High (cm)	Fresh Weight (g)	Dry Matter (%)	Length (cm)	Fresh Weight (g)	Dry Matter (%)
Magnetic Water (MW) (Gauss)						
G0	29.06 bc	41.97 c	16.07 b	19.42 a	24.63 bc	9.97 c
G500	29.83 b	52.28 a	16.85 b	21.00 a	27.84 ab	11.70 b
G1000	29.58 b	52.71 a	19.08 a	20.25 a	31.32 a	12.58 b
G1500	38.00 a	47.21 b	19.91 a	16.50 b	22.88 cd	19.03 a
G2000	26.22 c	43.32 bc	15.78 b	18.33 ab	20.28 d	12.02 b
Cd concentration (mg Kg^{-1} soil)						
Cd 0	29.96 a	42.34 b	16.77 a	21.13 a	21.94 b	12.96 ab
Cd 3.33	29.98 a	48.84 a	17.76 a	18.93 ab	26.23 a	12.45 b
Cd 6.66	30.31 a	48.37 a	17.93 a	18.67 ab	25.50 a	14.27 a
Cd 10	31.91 a	50.43 a	17.69 a	17.67 b	27.88 a	12.56 b
Interactions effect of MW and Cd						
G0 Cd0	23.33 i	26.10 e	13.36 e	22.00 ab	15.13 ef	9.57 cd
G0 Cd3.33	28.56 e-i	44.23 cd	16.19 c-e	21.33 ab	24.47 cd	9.99 b-d
G0 Cd6.66	33.00 b-e	51.17 a-c	18.55 a-d	17.00 bc	35.17 a	10.95 b-d
G0 Cd10	31.34 c-f	46.37 b-d	16.17 c-e	17.33 bc	23.77 cd	9.38 cd
G500 Cd0	30.56 d-h	50.37 a-c	16.05 c-e	24.67 a	23.03 de	11.83 b-d
G500 Cd3.33	29.11 e-i	52.17 a-c	16.46 b-e	18.33 a-c	25.57 b-d	10.60 b-d
G500 Cd6.66	27.00 e-i	46.87 bc	16.79 b-e	20.00 a-c	26.93 b-d	10.76 b-d
G500 Cd10	32.67 b-e	59.70 a	18.09 a-d	21.00 ab	35.83 a	13.62 b
G1000 Cd0	30.78 c-g	52.03 a-c	19.22 a-c	21.00 ab	35.20 a	13.22 bc
G1000 Cd3.33	31.00 c-g	50.97 a-c	19.17 a-c	20.00 a-c	33.10 ab	11.86 b-d
G1000 Cd6.66	25.78 f-i	51.53 a-c	18.31 a-d	19.67 a-c	25.23 b-d	12.43 b-d
G1000 Cd10	30.78 c-g	56.30 ab	19.63 a-c	20.33 a-c	31.73 a-c	12.79 b-d
G1500 Cd0	36.00 a-d	47.20 bc	21.19 a	17.67 bc	23.02 de	20.12 a
G1500 Cd3.33	37.22 a-c	48.33 bc	20.29 ab	18.00 bc	26.36 b-d	18.61 a
G1500 Cd6.66	38.44 ab	46.23 b-d	18.87 a-d	16.33 bc	20.94 d-f	19.18 a
G1500 Cd10	40.33 a	47.07 bc	19.31 a-c	14.00 c	21.21 d-f	18.22 a
G2000 Cd0	29.11 e-i	36.00 d	14.05 e	20.33 a-c	13.33 f	10.06 b-d
G2000 Cd3.33	24.00 hi	48.50 bc	16.68 b-e	17.00 bc	21.67 de	11.21 b-d
G2000 Cd6.66	27.33e-i	46.03 b-d	17.14 b-e	20.33 a-c	19.23 d-f	18.01 a
G2000 Cd10	24.44 g-i	42.73 cd	15.24 de	15.67 bc	26.87 b-d	8.80

*Means followed by the same letters within columns are not significantly differed at $p > 0.05$ according to the test of Duncan`s Multiple Range.

Table 3. Effects of magnetic water, Cd and their interactions on some photosynthetic pigments and some antioxidants compounds of *Paulownia tomentosa*.

Treatments	Chlorophyll a	Chlorophyll b	Total Carotenoids	Peroxidase (Unit. $Gram^{-1}$ fresh weight)	Ascorbic Acid ($mg.100g^{-1}$ Dry Weight)	Proline (Mm. g^{-1} Fresh Weight)	Total Carbohydrate (%)
	mg g^{-1} Fresh Weight						
Magnetic Water (MW) (Gauss)							
G0	0.856 e	0.817 e	0.345 e	100.33 b	2.31 b	70.48 b	2.54 c
G500	0.901 b	1.132 a	0.360 a	110.67 a	3.15 a	67.04 c	2.43 e
G1000	0.905 a	1.120 b	0.357 b	102.42 b	2.03 c	71.39 a	2.48 d
G1500	0.884 d	1.110 c	0.352 d	91.33 c	3.19 a	62.20 d	3.09 a
G2000	0.889 c	1.052 d	0.355 c	85.83 d	2.06 c	39.41 e	2.82 b
Cd concentration (mg Kg^{-1} soil)							
Cd 0	0.886 b	0.904 d	0.350 b	93.20 c	2.03 c	62.29 b	2.89 a
Cd 3.33	0.884 c	1.174 a	0.358 a	108.33 a	2.64 b	59.83 c	2.63 c
Cd 6.66	0.900 a	1.143 b	0.358 a	102.67 b	2.69 b	63.16 a	2.29 d
Cd 10	0.878 d	0.964 c	0.350 b	88.27 d	2.83 a	63.13 a	2.87 b
Interactions effect of MW and Cd							
G0 Cd0	0.870 f	0.873 m	0.340 c	97.67 e-g	2.00 gh	72.92 d	2.49 l
G0 Cd3.33	0.860 g	0.970 k	0.360 a	116.67 c	1.88 h	73.81 c	2.77 i
G0 Cd6.66	0.890 e	0.880 m	0.350 b	125.00 b	3.03 d	58.31 m	1.82 q
G0 Cd10	0.806 i	0.546 p	0.333 d	62.00 k	2.31 f	76.88 a	3.08 e
G500 Cd0	0.900 d	1.010 i	0.360 a	98.00e f	2.03 g	75.92 b	3.14 d
G500 Cd3.33	0.900 d	1.120 f	0.360 a	132.00 a	3.94 bc	59.58 l	1.99 p
G500 Cd6.66	0.906bc	1.046 h	0.360 a	108.33 d	3.91 c	66.00 h	2.21 o
G500 Cd10	0.900 d	1.353 a	0.360 a	104.33 de	2.72 e	66.65 h	2.39 m
G1000 Cd0	0.920 a	0.893 l	0.350 b	91.00 f-i	1.59 i	71.92 e	2.85 g
G1000 Cd3.33	0.890 e	1.283 b	0.360 a	108.33 d	1.97 gh	67.85 g	2.27 n
G1000 Cd6.66	0.900 d	1.236 d	0.360 a	108.00 d	1.97 gh	76.73 a	1.98 p
G1000 Cd10	0.910 b	1.070 g	0.360 a	102.33 de	2.59 e	69.04 f	2.81 h
G1500 Cd0	0.853 h	0.760 n	0.340 c	92.67 f-h	1.41 j	61.31 k	3.43 a
G1500 Cd3.33	0.860 g	1.210 e	0.350 b	100.67 de	3.03 d	63.50 j	2.73 j
G1500 Cd6.66	0.920 a	1.260 c	0.360 a	89.67 h-j	4.06 b	59.69 l	2.89 f
G1500 Cd10	0.903cd	1.213 e	0.360 a	82.33 j	4.25 a	64.31 i	3.31 c
G2000 Cd0	0.890 e	0.986 j	0.360 a	86.67 h-j	3.13 d	29.38 q	2.54 k

G2000 Cd3.33	0.910 b	1.290 b	0.360 a	84.00 ij	2.38 f	34.42 p	3.39 b
G2000 Cd6.66	0.886 e	1.293 b	0.360 a	82.33 j	0.47 k	55.08 n	2.56 k
G2000 Cd10	0.870 f	0.640 o	0.340 c	90.33 g-i	2.28 f	38.77 o	2.78 i

* Means followed by the same letters within columns are not significantly different at p > 0.05 according to Duncan`s Multiple Range test.

4. CONCLUSIONS AND RECOMMENDATIONS

It was concluded from this study that the application of MW can be used to improve cutting performance and shoot, root, photosynthetic pigments and some enzymatic and non-enzymatic antioxidants like peroxidase, ascorbic acid, proline, and total carbohydrates in *paulownia tomentosa* plants in order to reduce the inhibitory effects of cadmium, so it is concluded that paulownia under cadmium stress may benefit from the application of MW to increase growth and productivity. More studies are recommended such as conducting the study under more Cd concentrations with studying the hormonal and phytochemical response under the study factors.

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