Effect of wounding, IBA and ethephon on rooting and growth of Geranium softwood cutting

Layla Shaaban Mohammed, Chanar Salih Mohammed and Jihad Yousif Hassan
E-mail: layla.mohammed@uod.ac , chanarmohammed@uod.ac and jihad.yousif2000@gmail.com
Department of Horticulture, College of Agriculture Engineering Sciences, University of Duhok, Kurdistan region, Iraq,

Abstract:
This experiment was conducted from 15th March 2024 to 20th July 2025, in the lathhouse of the Department of Horticulture at the College of Agriculture, University of Duhok. The study amid the effects of wounding (wounded and non-wounded cuttings), different concentrations of IBA (0, 500, and 1000 mg/L), and varying levels of ethephon spraying (0, 100, and 200 mg/L) on the rooting and growth of geranium plants. Plants arrangement according to the design of this experiment was factorial Randomized Complete Block Design (RCBD) with three factors, key findings indicated that wounded cuttings significantly enhanced rooting performance, achieving the highest rooting percentage of 91.68%, with an average of 20.41 roots per cutting, and increased root dry weight (0.261 g) and root length (21.66 cm), compared to non-wounded cuttings which showed the lowest values. IBA notably improved rooting ability at both tested concentrations (500 and 1000 mg/L), with rooting percentages of 83.15% and 87.04%, respectively, compared to the control. Ethephon application significantly influenced root-related parameters, including root number, root dry weight, and root length, with values reaching 19.94 roots, 0.258 g, and 21.80 cm, respectively.
Overall, wounded cuttings treated with IBA and sprayed with ethephon exhibited the best results in plant growth parameters, including plant height (15.25 cm), number of branches (3.33), stem diameter (0.79 mm), and leaf area (12.94 cm^3), particularly at an ethephon concentration of 100 mg/L. The interaction between the three factors showed that the most favorable results for rooting and growth occurred when wounded cuttings were treated with IBA and sprayed with ethephon.

Key words: Wounding, Concentration IBA and Ethephon Spraying, Geranium plant

Introduction

Geranium is a perennial, evergreen plant belonging to the Geraniaceae family, specifically within the genus Geranium L., which encompasses approximately 325 species **[5,22]**. The extensive diversity among Geranium species has been explored in relation to their habitats and various adaptations to different growing environments **[6, 35, 42]**. These plants are valued not only for their ornamental appeal but also for their bioactive compounds and essential oils, which have diverse applications in pharmaceuticals, medicine, and cosmetics **[38].** Geraniums, particularly *Pelargonium X hortorum*, are a well-known category of decorative potted plants suitable for indoor or outdoor cultivation depending on seasonal and environmental conditions, accounting for a significant market share **[15].** The bioactive compounds found in geraniums possess biological and biotechnological properties, making them a subject of research in pharmaceutical and medicinal fields **[26, 32].** Due to the large number of species and cultivars, as well as their wide distribution, geraniums exhibit high ecological plasticity, allowing them to adapt to various ecoclimatic conditions **[21].** Studies have also examined how factors such as wounding, different plant growth regulators and ethephon influence their development **[3,4, 48].** Parameters such as biomass production, and morphological characteristics during growth are affected by substrate type and growing conditions.

Growth regulators, especially auxins, are considered crucial for promoting the development of adventitious roots; these hormones stimulate root formation on stems and activate lateral buds. Synthetic auxins, such as indole-3-butyric acid (IBA), have been demonstrated to effectively promote root formation on cuttings when applied externally **[23].** However, some cuttings tend to dry out, wilt, or rot, which can decrease the overall propagation success rate. Therefore, selecting the appropriate type of auxin, its concentration, and the correct application method are essential for successful rooting **[47].** In a study involving *Melaleuca viminalis* cuttings, mechanical treatments including (non-wounding and wounding) were used. The results indicated that wounding significantly increased both the rooting percentage and root length, reaching 36.66% and 11.39 cm, respectively. Similarly, research on *Cotoneaster prostrata* cuttings revealed that wounded cuttings had a notably higher rooting success, with an increase of 65.27%, compared to 60.76% for unwounded cuttings **[25]**. A study examining rose-scented geranium (Pelargonium graveolens L.) cuttings investigated the effects of varying IBA concentrations (ranging from 0 to 2000 mg L^{-1}). The results indicated that the application of 2000 mg L^{-1} IBA was the most effective treatment, significantly reducing the number of days required for root initiation and producing the highest number and length of roots per cutting [**28]**
In addition to regulating height, ethephon encourages the growth of axillary shoots without harming the apical meristem or growth point. It is commonly employed to enhance branching in various ornamental crops, including azalea, chrysanthemum, fuchsia, geranium, New Guinea impatiens, lantana, and verbena**.** additionally, ethephon suppresses flower development and causes the early termination of young flowers in numerous species. In seed geraniums treated with 3000 mg/l of ethephon, flowering was postponed by approximately 10 weeks due to the abortion of flower buds **[14]**. **The objectives of this study were** to determine (a) if commercial plant growth regulators could be used to inhibit flowering and promote lateral shoot growth, resulting in more compact and higher quality plants and (b) if subsequent rooting capacity and plant growth and flowering would be affected by the growth regulator treatments.

Material and Methods

Experience site

The study was carried out in the lath house of the Department of Horticulture, College of Agriculture Engineering Sciences, University of Duhok, Kurdistan region, Iraq. For period 15th March 2024 to 20th July 2025, so, the experiment includes (54 experimental units) rooting of shoots cuttings of geranium plant. Harmonized stem cuttings were taken from the tip of stock plants arrangement according to the design of this experiment was factorial Randomized Complete Block Design (RCBD) with three factors (2×3×3=18) treatments. The treatment was repeated three times, and each treatment consisted of 4 pots, each pot contained three cuttings, The analysis of variance indicated the significant differences

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Study factors

The experiment included the study of three factors, namely: First: The first factor wounding and non-wounding Second: The second factor is the three concentrations of IBA (0, 500 and 500 mgl^{-1}). Third: The third factor is the addition of three levels of Ethephon. (0, 100 and 200 mgl^{-1}), and Experience design. **The studied measurements** included rooting percentage (%), number of roots per cutting, dry weight of roots per cutting (g), length of root (cm), height plant (cm) number of branches per cutting, stem diameter, number of leaves per cutting, leaf area cm^3

Field operation

Healthy mother plants of geranium were selected for preparing cuttings. Approximately 10 cm long and 10-12 mm thick stem cuttings were taken from the tips of the parent plants. The cuttings were divided into two groups: one group was wounded, and the other remained non-wounded. For the wounded group, a cut was made at the base of each cutting with a sharp blade, about 1 cm deep, taking care to avoid penetrating the inner bark. The non-wounded group was left intact. Both sets of cuttings were then dipped in various concentrations of IBA for 10 seconds before being planted in a rooting medium. They were subsequently covered with polyethylene to maintain humidity until roots developed. Once the rooting rate reached 95%, the rooted cuttings were transplanted into a medium composed of river soil and peat moss in a 1:3 volume ratio. After 8 to 10 weeks of cultivation in permanent medium, the plants were sprayed with varying concentrations of ethephon at three intervals, each spaced 10 days apart.

Statistical Analysis

The experiment was carried out using a completely randomized design. Each treatment comprised three replicates and four plants for each replication. Collected data were subjected to analysis of variance (ANOVA) and the mean values were assessed by Duncan Test at $P \leq 0.05$ using program (**SAS**).

Results and discussion

Rooting percentage (%): The data in Table 1 clearly indicate that wounding had a significant effect on the rooting percentage of Geranium plants. Wounded cuttings showed a higher rooting percentage (91.68%) compared to non-wounded cuttings (74.07%). IBA concentrations also had a significant effect on rooting percentage; the highest percentages were observed at 1000 $mg \cdot L^{-1}$ IBA (87.04%) and 500 $mg \cdot L^{-1}$ IBA (83.15%), both significantly higher than the control (0), which had the lowest rooting percentage (78.44%).

Table 1. Impact of Wounding and IBA Concentrations on the Rooting Percentage (%) of Geranium Softwood Cuttings

Treatment	0	500	1000	Effect of wounding
Wounding	82.82ab	95.93a	96.30a	91.68a
Non-wounding	74.07ab	70.37b	77.78ab	74.07b
Effect of IBA concentrations	78.44a	83.18a	87.04a	

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The interaction among the studied factors revealed that wounded cuttings treated with 500 mg·L⁻¹ IBA exhibited the highest rooting percentage (95.93%), which significantly differed from other treatments. Conversely, the lowest rooting percentage (70.37%) was observed in non-wounded cuttings treated with 500 mg·L⁻¹ IBA or in untreated (control) cuttings, which recorded 74.07%.

Number of Roots: The analysis of the roots number per cutting reveals in table 2 that non-wounding operation had an inverse effect on rooting success, with wounded cuttings producing the highest average of 20.41 roots, compared to 15.26 roots in non-wounded cuttings. When considering the effect of IBA treatments alone, it was observed that higher concentrations of IBA significantly increased root numbers; specifically, the 500 mg·L⁻¹ and 1000 mg·L⁻¹ IBA treatments resulted in 18.14 and 20.22 roots per cutting, respectively. In contrast, the control treatment, which involved no IBA application (0 mg·L⁻¹), yielded the lowest root number at 15.14 roots. Regarding the impact of spraying ethephon treatments alone, it was found that higher concentrations notably boosted root numbers. Specifically, treatments with 1000 mg·L⁻¹ of ethephon produced 19.94 roots per cutting. Conversely, the control group, which received no ethephon (0 mg·L⁻¹), exhibited the lowest average root count at 15.50 roots. Regarding the triple interaction effects, on the number of root wounded cuttings treated with 1000 mg·L⁻¹ IBA with spraying at 200 ethephon showed the most favorable results, producing 29.67 roots, indicating a significant enhancement in rooting. Conversely, wounded cuttings that did not receive IBA (control) produced the minimum number of roots, only 12.33 roots, highlighting the combined impact of wounding and lack of IBA and foliar application of ethephon on reducing root formation.

Table 2. Impact of Wounding, IBA Concentrations, and Ethephon Spraying on the Number of Roots in Geranium Plant Softwood Cuttings.

Wound situation	IBA concentrations	Ethephon 0	Ethephon 100	Ethephon 200	Wounding x IBA	Effect of wounding
Wounding	0	12.33g	15.67d-g	16.67d-g	14.89c	20.41a
	500	19.17c-f	19.83cde	22.83bc	20.61b	
	1000	20.50cd	27.00ab	29.67a	25.72a	
Non-wounding	0	14.67d-g	15.33d-g	16.17d-g	15.39c	15.26b
	500	13.00fg	16.67d-g	17.33c-g	15.67c	
	1000	13.33fg	13.83efg	17.00c-g	14.72c	
Wounding x ethephon	Wounding	17.33b	20.83a	23.06a	Effect of IBA	
	Non-wounding	13.67c	15.28bc	16.83bc		
IBA x ethephon	0	13.50e	15.50de	16.42b-e		
	500	16.08cde	18.25bcd	20.08abc	0	15.14b
	1000	16.92b-e	20.41ab	23.33a	500	18.14a
Effect of wounding		15.50b	18.06a	19.94a	1000	20.22a

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Dry weight of roots (g): The results of dry root weight, as shown in Table 3, highlight several important findings regarding the response to wounding and plant growth regulators. Wounded cuttings exhibited the highest average dry root weight, measuring 0.261 g, compared to 0.180 g in non-wounded cuttings, indicating a positive response to wounding. When examining the effects of IBA treatments alone, higher concentrations significantly boosted root dry weight, with 500 mg·L⁻¹ IBA producing 0.252 g and, while the control (0 mg·L⁻¹) recorded the lowest at 0.164 g, 200 mg·L⁻¹ of ethephon resulted in an average dry weight of 0.258 g, compared to 0.183 g in the control.

The interaction between treatments revealed that wounded cuttings treated with 1000 mg·L⁻¹ IBA and sprayed with 200 mg·L⁻¹ ethephon achieved the highest dry weight of 0.382 g, demonstrating a synergistic effect on root development. In contrast, wounded cuttings that did not receive IBA (control) had the lowest dry weight at just 0.147 g, underscoring the combined importance of wounding and IBA application and ethephon for maximizing root biomass.

Table 3. Impact of Wounding, IBA Concentrations, and Ethephon Spraying on Root Dry Weight in Geranium Softwood Cuttings.

Wound situation	IBA concentrations	Ethephon			Wounding x IBA	Effect of wounding
		0	100	200		
Wounding	0	0.147d	0.168d	0.232cd	0.182bc	0.261a
	500	0.216cd	0.336ab	0.363a	0.305a	
	1000	0.232cd	0.273bc	0.382a	0.295a	
Non-wounding	0	0.151d	0.143d	0.142d	0.145c	0.180b
	500	0.196cd	0.196cd	0.207cd	0.200b	
	1000	0.158d	0.202cd	0.222cd	0.194b	
Wounding x ethephon	Wounding	0.198c	0.259b	0.325a	Effect of IBA	
	Non-wounding	0.168c	0.180c	0.190c		
IBA x ethephon	0	0.149c	0.155c	0.187cd		
	500	0.206cd	0.266ab	0.285ab	0	0.164b
	1000	0.195cd	0.238bc	0.302a	500	0.252a
Effect of wounding		0.183c	0.220b	0.258a	1000	0.245a

Root length (cm): The results of root length, as shown in Table 4, highlight several important findings regarding the response to wounding and plant growth regulators. Wounded cuttings exhibited the highest average root length, measuring 21.66 cm, compared to 19.26 cm in non-wounded cuttings, indicating a positive response to wounding. When examining the effects of IBA treatments alone, higher concentrations significantly boosted root length, with 1000 mg·L⁻¹ IBA producing 25.164cm, and, while the control (0 mg·L⁻¹) recorded the lowest at 17.25 cm,
200 mg·L⁻¹ of ethephon resulted in an average root length of 21.800 cm, compared to 19.33 cm in 100 mg·L⁻¹ of ethephon. The interaction between treatments revealed that non-wounded cuttings treated with 1000 mg·L⁻¹ IBA and sprayed with 200 mg·L⁻¹ ethephon achieved the highest root length of 30.84 cm, demonstrating a synergistic effect

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on growth. In contrast, non-wounded cuttings had the lowest root length at just 15.39 cm, in non-wounding with 500 mg·L^{-1} IBA and 100 mg·L^{-1} ethephon spraying.

Table 4. Impact of Wounding, IBA Concentrations, and Ethephon Spraying on root length in Geranium Softwood Cuttings.

Wound situation	IBA concentrations	Ethephon			Wounding x IBA	Effect of wounding
		0	100	200		
Wounding	0	16.76de	18.72b-e	18.47b-e	17.98c	21.66a
	500	21.44b-e	17.11cde	22.12b-e	20.22bc	
	1000	25.05ab	24.42a-d	30.84a	26.77a	
Non-wounding	0	15.57e	17.19cde	16.77de	16.51c	19.26b
	500	19.78b-e	15.39e	17.93b-e	17.70c	
	1000	22.86b-e	23.16b-e	24.67ab	23.56ab	
Wounding x ethephon	Wounding	21.08ab	20.08ab	23.81a	Effect of IBA	
	Non-wounding	19.40b	18.58b	19.79ab		
IBA x ethephon	0	16.17c	17.96c	17.62c		
	500	20.61bc	16.25c	20.02bc	0	17.25b
	1000	23.95ab	23.79ab	27.76a	500	18.96b
Effect of wounding		20.24a	19.33a	21.80a	1000	25.16a

Plant height (cm): The results of plant height, as shown in Table 5, highlight several important findings regarding the response to wounding and plant growth regulators. Wounded cuttings exhibited the highest significantly an average plant height, measuring 16.15 cm, compared to 14.26 cm in non-wounded cuttings, indicating a positive response to wounding. When examining the effects of IBA treatments alone, higher concentrations significantly boosted plant height, with the control producing 15.91cm, and, while the 1000 mg·L^{-1} IBA recorded the lowest at 14.01 cm, resulted in control reached an average plant height of 15.89 cm, compared to 14.75cm in the 100 mg·L^{-1} of ethephon.

The interaction between the treatments showed that wounded cuttings sprayed with 200 mg·L^{-1} ethephon and without IBA achieved the highest plant height of 18.80 cm, indicating a synergistic effect on growth. Conversely, non-wounded cuttings treated with 1000 mg·L^{-1} IBA and sprayed with 200 mg·L^{-1} ethephon recorded the lowest plant height of only 11.50 cm

Branches number per cutting: The data presented in Table 6 show that wounding bases of cuttings was a positive process, which increased number of branches per cutting significantly (4.44) branches, in comparison with non-wounded cuttings which showed (3.04) branches. Also, the two concentrations of IBA showed significant difference over control, which provided 4.15 branches per cutting for (500 mgl^{-1} in comparison with control which gave 3.15 branches. 100 mg·L^{-1} of ethephon resulted in an average plant height of 15.25 cm, compared to 14.40 cm in the control. From triple interaction among three factors wounding, IBA and ethephon spraying it can be shown that when cuttings of wounded treated with 1000 mg·L^{-1} of IBA + 200 mg·L^{-1} ethephon provided significantly best

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branch number 7.78 in comparison with 2.11 branches for non-wounded treated with 500 mg·L⁻¹ of IBA + 100 mg·L⁻¹ ethephon treatments.

Table 5. Impact of Wounding, IBA Concentrations, and Ethephon Spraying on the Plant Height of Geranium Softwood Cuttings

Wound situation	IBA concentrations	Ethephon			Wounding x IBA	Effect of wounding
		0	100	200		
Wounding	0	17.33abc	15.10b-e	18.80a	17.08a	16.15a
	500	17.73ab	15.13b-e	15.27a-d	16.04ab	
	1000	16.43abc	17.00abc	12.53de	15.32ab	
Non-wounding	0	15.00b-e	15.27a-d	13.93cde	14.73b	14.26b
	500	14.83b-e	14.50b-e	16.77abc	15.37ab	
	1000	14.03cde	11.50e	12.53de	12.69c	
Wounding x ethephon	Wounding	17.17a	15.74ab	15.53abc	Effect of IBA	
	Non-wounding	14.62bc	13.756c	14.41bc		
IBA x ethephon	0	16.17a	15.18a	16.37a		
	500	16.283	14.82ab	16.02a	0	15.91a
	1000	15.23a	14.25ab	12.53b	500	15.71a
Effect of wounding		15.89a	14.75a	14.97a	1000	14.01b

Table 6. Impact of Wounding, IBA Concentrations, and Ethephon Spraying number of branches of Geranium Softwood Cuttings

Wound situation	IBA concentrations	Ethephon			Woundin g x IBA	Effect of wounding
		0	100	200		
Wounding	0	3.00de	3.11de	3.33de	3.15bc	4.44a
	500	3.00de	3.00de	5.78b	3.93b	
	1000	4.89bc	6.11b	7.78a	6.26a	
Non-wounding	0	2.78de	3.00de	3.67cd	3.15bc	3.04b
	500	2.78de	2.11e	3.22de	2.70c	
	1000	3.56cde	2.5de6	3.67cd	3.26bc	
Wounding x ethephon	Wounding	3.63bc	4.07b	5.63a	Effect of IBA	
	Non-wounding	3.04cd	2.56d	3.52bc		
IBA x ethephon	0	2.89d	3.06d	3.50cd		
	500	2.89d	2.56d	4.50b	0	3.15b
	1000	4.22bc	4.33bc	5.72a	500	3.32b
Effect of wounding		3.33b	3.32b	4.57a	1000	4.15a

Stem diameter per cutting: The data presented in Table 7 indicate that wounding the bases of cuttings was a positive process, significantly increasing the stem diameter per cutting (1.017mm) compared to non-wounded cuttings, which showed a stem diameter of (0.827 mm). Additionally, the concentrations of IBA showed a significant difference over the control, which resulted in a stem diameter of

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1.102 mm at 1000 mg·L⁻¹, compared to 0.759 mm in the control. The application of 200 mg·L⁻¹ of ethephon led to an average stem diameter of 1.007 mm, compared to 0.824 mm in the control.

From the triple interaction among the three factors wounding, IBA, and ethephon spraying it can be observed that cuttings of wounded and treated with 1000 mg·L⁻¹ of IBA + 200 mg·L⁻¹ ethephon exhibited the largest stem diameter of 1.517 mm, in contrast to 0.683 mm for non-wounded cuttings treated with 100 mg·L⁻¹ ethephon.

Table 7. Impact of Wounding, IBA Concentrations, and Ethephon Spraying on stem diameter of Geranium Softwood Cuttings

Wound situation	IBA concentrations	Ethephon			Wounding x IBA	Effect of wounding
		0	100	200		
Wounding	0	0.700e	0.717de	0.775de	0.731c	1.017a
	500	0.817cde	1.183abc	0.950cde	0.983bc	
	1000	1.083b-d	1.410ab	1.517a	1.337a	
Non-wounding	0	0.863cde	0.683e	0.817cde	0.788nc	0.827b
	500	0.767de	0.850cde	0.867cde	0.828bc	
	1000	0.717de	0.767de	1.117bcd	0.867bc	
Wounding x ethephon	Wounding	0.867b	1.103a	1.081a	Effect of IBA	
	Non-wounding	0.782b	0.767b	0.933ab		
IBA x ethephon	0	0.782cd	0.700d	0.796cd		
	500	0.792cd	1.017bc	0.908bcd	0	0.759c
	1000	0.900bcd	1.088ab	1.317a	500	0.906b
Effect of ethephon		0.824b	0.935ab	1.007a	1000	1.102a

Dry weight of shoots (g): The results of dry shoot weight, as shown in Table 8, highlight several important findings regarding the response to wounding and plant growth regulators. Wounded cuttings exhibited the highest average dry shoot weight, measuring 5.43 g, compared to 4.31 g in non-wounded cuttings, indicating a positive response to wounding. When examining the effects of IBA treatments alone, higher concentrations significantly boosted shoot dry weight, with 1000 mg·L⁻¹ IBA producing 5.72g and, while the control (0 mg·L⁻¹) recorded the lowest at 4.43 g, 200 mg·L⁻¹ of ethephon resulted in an average dry weight of 5.34 g, compared to 4.55g in the control.

The interaction between treatments revealed that wounded cuttings treated with 1000 mg·L⁻¹ IBA and sprayed with 200 mg·L⁻¹ ethephon achieved the highest dry weight of 7.79g, demonstrating a synergistic effect on shoot development. In contrast, wounded cuttings that did not receive IBA (control) had the lowest dry weight at just 3.16g, underscoring the combined importance of non-wounding and 200 mg·L⁻¹ ethephon for maximizing shoot biomass.

Number of leaves: The data presented in Table 8 show that wounding bases of cuttings was a positive process, which increased number of leaves significantly (13.284 leaves) in comparison with non-wounded cuttings which showed (11.790) leaves. Also, the concentrations of IBA showed significant difference over control, which provided 14.389 leaves for (1000 mgl^{-1}) in comparison with control which gave 10.037 leaves. 200 mg·L^{-1} of ethephon resulted in an average plant height of 14.074 leaves, compared to 11.370 leaves in the control.

From triple interaction among three factors wounding, IBA, and ethephon spraying it can be shown that when cuttings of wounded and treated with 1000 mg·L^{-1} of IBA + 200 mg·L^{-1} ethephon provided significantly the best number of leaves 20.444 in comparison with 7.000 leaves for wounded treated without IBA and ethephon treatment.

Leaf area (cm²**)**: The data presented in Table 8 clearly show that wounding bases of cuttings was a positive process, which increased leaf area per cutting significantly (12.62) cm², in comparison with non-wounded cuttings which showed (11.17) cm². Also, the two concentrations of IBA showed significant difference over control, which provided 14.69cm² of leaf area per cutting for 500 mg·L^{-1} compared to control, which gave 9.27 cm². 100 mg·L^{-1} of ethephon resulted in an average leaf area of 13.33cm², compared to 10.12 cm² in the control. From the

triple interaction among the three factors wounding, IBA, and ethephon spraying it can be shown that when cuttings of wounded treated with 1000 mg·L^{-1} of IBA + 200 mg·L^{-1} ethephon provided the significantly highest leaf area of 20.57cm² in comparison with 7.97cm² for wounded cuttings did not treated with IBA and ethephon spraying.

Table 8. Impact of Wounding, IBA Concentrations, and Ethephon Spraying on shoot dry weight Softwood Cuttings

Wound situation	IBA concentrations	IBA concentrations			Wounding x IBA	Effect of wounding
		0	100	200		
Wounding	0	4.16cd	4.73bvd	5.48bc	4.79b	5.43a
	500	3.96cd	5.07bcd	5.18bcd	4.74b	
	1000	5.67bc	6.81ab	7.79a	6.76a	
Non-wounding	0	5.11bcd	3.94cd	3.16d	4.07b	4.31b
	500	3.79cd	3.20d	5.48bc	4.16b	
	1000	4.61bcd	4.49cd	4.97bcd	4.69b	
Wounding x ethephon	Wounding	4.60bc	5.54ab	6.15a	**Effect of IBA**	
	Non-wounding	4.50bc	3.88c	4.54ab		
IBA x ethephon	0	4.63bc	4.33bc	4.32bc		
	500	3.88c	4.14bc	5.33abc	0	4.43b
	1000	5.14abc	5.65ab	6.37a	500	4.45b
Effect of ethephon		4.55a	4.71a	5.34a	1000	5.72a

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Table 9. Impact of Wounding, IBA Concentrations, and Ethephon Spraying number of leaves of Geranium Softwood Cuttings

Wound situation	IBA concentrations	Ethephon 0	Ethephon 100	Ethephon 200	Wounding x IBA	Effect of wounding
Wounding	0	7.00f	9.67def	10.89c-f	9.19d	13.28a
	500	12.56b-e	15.22b	13.78bcd	13.85b	
	1000	13.89bcd	16.11b	20.44a	16.82a	
Non-wounding	0	10.11def	8.56ef	14.00bcd	10.89cd	11.79b
	500	14.22bcd	12.33b-e	11.00c-f	12.52bc	
	1000	10.44c-f	11.11c-f	14.33bcd	11.96bc	
Wounding x ethephon	Wounding	11.15bc	13.67ab	15.04a	Effect of IBA	
	Non-wounding	11.59bc	10.67c	13.11abc		
IBA x ethephon	0	8.56c	9.11c	12.44b		
	500	13.39b	13.78b	12.39b	0	10.04b
	1000	12.17b	13.61b	17.39a	500	13.19a
Effect of ethephon		11.37b	12.17b	14.07a	1000	14.39a

Table 10. Impact of Wounding, IBA Concentrations, and Ethephon Spraying leaf area of Geranium Softwood Cuttings

Wound situation	IBA concentrations	Ethephon 0	Ethephon 100	Ethephon 200	Wounding x IBA	Effect of wounding
wounding	0	7.97e	9.75e	8.23e	8.65c	12.62a
	500	9.44e	15.66bc	12.43cde	12.51b	
	1000	10.98de	18.54ab	20.57a	16.70a	
Non-wounding	0	8.55e	10.94de	10.16e	9.88c	11.17b
	500	14.75bcd	8.58e	9.49e	10.94bc	
	1000	9.03e	16.49abc	12.50cde	12.67b	
wounding x ethephon	wounding	9.46c	14.65a	13.74ab	Effect of IBA	
	Non-wounding	10.78c	12.02bc	10.72c		
IBA x ethephon	0	8.26c	10.35bc	9.19bc		
	500	12.10b	12.12b	10.96bc	0	9.27c
	1000	10.00bc	17.52a	16.53a	500	11.73b
Effect of ethephon		10.12b	13.33a	12.23a	1000	14.69a

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Based on the data from the first experiment on wounding presented in Table 1, it is evident that the wounding process significantly affected most of the parameters studied. As shown in Tables 1-8, there was a notable increase in the means of wounded treatments compared to non-wounded ones for traits such as rooting percentage, root number per cutting, plant height, leaf number, and dry weight of roots. Additionally, the number of branches per cutting was higher in wounded cuttings.

The higher rooting percentage observed in wounded cuttings, as shown in Table 1, can be attributed to several physiological and anatomical factors. Some plant species possess sclerenchyma rings with thick walls in the root formation zone, which act as barriers to root primordium penetration. Wounding these rings removes this obstacle, facilitating root development. Additionally, wounding stimulates the production of ethylene, a hormone that indirectly promotes the formation of adventitious roots **[12].** It also enhances respiration rates by increasing oxygen permeability to internal tissues, improves water absorption, and allows for the external application of rooting auxins at the cut surface. Wounding may also lead to the accumulation of natural rooting hormones and carbohydrates at the site, further supporting root formation.

The highest number of roots observed in wounded cuttings, as shown in Table 2, aligns with findings by **[30]** on Myrtus communis. However, low rooting percentages in some cases may result from factors such as non-wounded cuttings not exhibiting high alcohol concentrations, which can cause dehydration, injury, and toxicity at the stem **[3]**. In wounded cuttings, this issue may also occur due to increased surface area for absorption. A significant concern arises when high concentrations of dissolved IBA (indole-3-butyric acid) in alcohol are used; as the alcohol evaporates the IBA concentration can increase beyond the plant's tolerance. Excessively high IBA levels can inhibit growth by promoting ethylene production, which negatively affects rooting. Moreover, very high auxin concentrations can be toxic, damaging cellular components in the cuttings and ultimately hindering root development **[30].** The data on dry weight of roots, as presented in Table 3, showed a significant difference between wounding and non-wounding treatments. Although the mean for wounded cuttings was slightly higher than that for non-wounded cuttings, the difference was statistically significant. These findings are consistent with those of **[3]** on stem cuttings of Photinia plants and **[43]** on Fraser hardwood cuttings. The likely explanation is that wounding increases the cambium area exposed to exogenously applied plant growth regulators, such as auxin (IBA), which can enhance endogenous production and translocation of growth regulators **[7].**

Treating cuttings with varying concentrations of IBA, as detailed in Tables 1–8, resulted in significant differences compared to control treatments (cuttings without IBA). The highest number of roots per cutting was observed at a concentration of 1000 $mg \cdot L^{-1}$, as shown in Table 2. Similarly, maximum dry weight of roots and the highest number of leaves per cutting were also recorded at this concentration, as seen in Tables 3, 7, and 8. Although there were slight variations, parameters such as rooting percentage, dry weight of roots, number of shoots per cutting, and length of the longest shoot per cutting showed no significant

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differences among treatments. Nonetheless, results at 500 mg·L^{-1} were marginally better than those at 1000 mg·L^{-1}, aligning with findings from **[19]** on *Photinia fraseri* hardwood cuttings and **[36]** on *Duranta plumeri* hardwood cuttings.

The increased root number per cutting can be attributed to the influence of auxin on metabolite accumulation at the application site, stimulation of new protein synthesis, callus formation, cell division, and cell enlargement **[51]**. The number and length of roots appeared to be optimal at specific IBA concentrations because auxins promote and regulate root elongation by organizing cell elongation processes and controlling the synthesis of particular enzymes through specific RNA formation, which directs the production of proteins necessary for elongation **[46].**

At a concentration of 1000 mg·L^{-1}, the highest number of leaves per cutting was observed (Table 8). This may be due to the role of growth regulators in mobilizing stored food materials within the cuttings, accelerating sprouting and leaf formation, and promoting carbohydrate utilization at the cutting base through sink induction and photosynthesis efficiency **[34].** Additionally, strong growth and early root initiation influenced by growth regulators could enhance nutrient uptake, resulting in a greater number of leaves **[49]**. The combined effect of growth regulators and increased photosynthetic activity likely contributed to the maximum accumulation of fresh and dry shoot biomass. The effects of ethephon spraying, as presented in Tables 1-8, indicate that the geranium plants experienced significant improvements across all studied characteristics. These increases may be linked to the well-developed root system in the cuttings, which enhances shoot formation by facilitating the efficient movement of water and nutrients from the propagation medium to the growing tips. This, in turn, promotes the development of new shoots, as noted by **[13].** The mechanism of reduction occurred in plant height because of the growth retardant application appears to be due to its effect in slowing down of cell division and reducing cell expansion **[29]. [24]** suggested that reduction in height probably was caused by restriction of cell elongation rather than cell division. In addition, ethephon is not an anti-gibberellin. It releases ethylene to reduce cellular elongation **[50].** These results were compatible with other previous research on poinsettia using plant growth retardants which were reported by many investigators. **[37, 50]** on *Euphorbia pulcherrima.* Ethephon is commonly used to intentionally delay flowering in various crops. For example, stock plant producers may apply it to maintain stock plants and keep cuttings in a vegetative state **[17,20]**. After transplantation, plants can also be treated with ethephon to prevent premature flowering during the vegetative or ‘bulking up’ phase, especially when production cycles are lengthy **[44,11]**.

Controlling flowering with ethephon is particularly beneficial for crops that are already mature and tend to flower readily, such as vegetative propagated plants or those grown in larger containers where flowering may occur before the plants reach an ideal size. Short production cycles mean that delaying flowering can extend the growing period, which is advantageous for seed-propagated annual bedding plants grown in containers. Besides flowering control, ethephon drenches also influence plant size (height and width) and growth (dry weight), as observed in studies on Angelonia plant and

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geranium. These findings align with previous research demonstrating successful growth management of container-grown annuals and perennials using ethephon **[8, 32]**. It was also reported that plant responses to ethephon can vary across different locations **[32]** These findings suggest that ethephon is easily transported through the xylem stream and offer valuable insights into its use as a growth regulator when applied to the root zone **[31]**. The promoting effect of ethephon on the number of branches in *Rosa damascena* has been documented by **[1]**.

Promotion in the number of branches due to the treatments of ethephon more than the untreated plants is mainly attributed to the inhibitory effect of these growth regulators on the cell division in the apical bud, which subsequently might have stopped the growth of the main axis and resulted in more laterals production **[40, 9]**. In addition, plant growth retardants activated lateral buds to grow and fill in with more number of branches **[10]**. The increase in number of branches could be due to inhibition in the auxin activity in the apical bud because of the application of growth inhibitor since they act as anti-auxin. These treatments intern suppressed the apical dominance, thereby diverting the polar transport of auxins towards the basal nodes leading to increase branching rate **[14, 41]**. Additionally, after reducing stevia flowering, applying 200 ppm ethephon for 60 days after transplantation (DAT) to the permanent medium was found to significantly increase root dry weight (Table 3). Flower abscission is driven by the activation of abscission zones, which are strongly stimulated by ethylene **[16,27]**. Compared to the control and other treatments, applying 200 mg/L ethephon at 60 DAT resulted in a larger leaf area (Table 9). Although plant height was lower than in the control, this was due to the increased number of leaves, which compensated for reduced height. These results were compatible with other previous research on poinsettia using plant growth retardants which were reported by many investigators. **[37,50]** on *Euphorbia pulcherrima*

Conclusion

The study concluded that wound treatment significantly enhances the rooting and growth performance of geranium cuttings. The combination of wounding with IBA soaking, particularly at higher concentrations (500 and 1000 mg/L), markedly improved rooting percentages, root number, and root development parameters. Additionally, spraying with ethephon, especially at 100 mg/L, further promoted root formation and overall plant growth, including height, branching, stem diameter, and leaf area. The optimal results for both rooting and growth were achieved when wounded cuttings were treated with IBA and sprayed with ethephon at 100 mg/L, indicating that this integrated approach is most effective for improving geranium propagation and development.

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