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# Effect of shading levels, salicylic acid and nano-fertilizer on the growth performance of *Dichondra repens* plants

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## Abstract

An experiment was conducted to evaluate the effects of shading levels, salicylic acid, and nano-fertilizer concentrations on the growth performance of the *Dichondra repens* plant under Dohuk Governorate conditions. This experiment was carried out in a field with 0% shading and in a lath-house with a 50% shading level from March 15, 2024, to September 15, 2024, during the spring season. The experiment was laid out using a factorial Randomized Complete Block Design (RCBD) with three factors: shade levels (0% and 50% shade), salicylic acid concentrations (0, 100, and 200 mg $L^{-1}$), and foliar sprays with different concentrations of nano-fertilizer (0, 5, and 10 mg $L^{-1}$). The results indicated that the Dichondra plants grown under 0% shading achieved significantly higher values for plant density, mowing frequency, total phosphorus, total potassium percentage, cumulative dry weight, root dry weight, and total carbohydrates. Plants sprayed with salicylic acid at 200 mg $L^{-1}$ showed a significant increase in most parameters. The use of nano-fertilizers at a concentration of 5 mg $L^{-1}$ resulted in significant improvements in plant density, leaf area, mowing frequency, root dry weight, total phosphorus percentage, total potassium percentage, cumulative dry weight, and total chlorophyll.

**Key words**: *Dichondra repens*, Shading levels, Salicylic acid, Nano-fertilizer, shade tolerance, turf quality, foliar spray

## Introduction

The *Dichondra* genus consists of fourteen species of creeping and spreading herbs characterized by kidney-shaped leaves with smooth edges and subtle flowers. This genus falls under the tribe Dichondreae within the Convolvulaceae family. It is a low-growing perennial plant that originates from Australia and New Zealand. It is increasingly utilized as a low-maintenance ground cover in gardens and parks, particularly in Italy's warmer climates (Hennen *et al.*, 2005). This plant thrives in warm, humid conditions. Additionally, it has adapted to grow in shaded areas as well as in somewhat dry environments. However, it does not tolerate heavy foot traffic or being crushed (Avcıoğlu, 1997).

This species is a perennial herb characterized by its creeping growth, developing roots at its nodes. The leaves vary from kidney-shaped to circular, with lengths ranging from 0.5 to 2.5 cm (0.2–1 in). The leaf base is heart-shaped (cordate), and the tip is either notched or rounded. Both the upper and lower surfaces of the leaves are covered with fine hairs. The small yellowish-green flowers can bloom year-round (Johnson, 1995). Dichondra plants contain essential antioxidant enzymes (Saglam *et al.*, 2011, 2011), which are derived from a variety of plant phenols found in numerous plant sources.

Shade is a commonly utilized method in the cultivation of horticultural plants. It can impact how plants grow and develop by altering their environment, and the most noticeable effect is the change in the shape and structure of the plants. Earlier research has indicated that plants in shaded areas tend to direct their photosynthetic outputs to leaves that support their growth, which can somewhat offset the reduction in growth speed caused by lower light levels. Plants have the ability to detect variations in external light through different photoreceptors, such as phytochromes and phototropins, which activate specific signaling pathways to manage their own growth and development. In conditions with limited light, the overall dry weight of the plant decreases, along with the rates of photosynthesis, transpiration, stomatal opening, and stem thickness (Huang *et al.*, 2024).

Salicylic acid is viewed as a non-enzymatic growth regulator that is crucial for enhancing stress tolerance in plants (Aljalaly *et al.*, 2018). This compound functions as a plant hormone due to its significant roles in plant growth, flowering, and ion absorption, influencing stomatal movement and ethylene production (Al-Obaidy *et al.*, 2020). Furthermore, it helps speed up the development of chlorophyll pigments, enhances photosynthesis, and boosts the activity of key enzymes (Hayat *et al.*, 2007). Recent horticultural research has established that control of environmental factors and the use of growth stimulating chemicals can drastically affect plant physiological performance, vegetative growth and productivity. Salicylic acid application has been reported to increase morpho-physiological traits, flowering behavior and growth response of horticultural plants under different cultivation conditions (Kumari et al., 2025) and nano-based fertilizers have been reported to enhance the nutrient-use efficiency, mineral accumulation and plant productivity under different cultivation conditions (Mahdy et al., 2024; Shahein et al., 2025). The results demonstrate the need to combine the use of growth regulators and advanced nutrient management techniques in order to enhance plant performance and stress adaptation.

A concentration of 10 mg $L^{-1}$ indicated an increase in leaf numbers (Sandoval-Yapiz, 2004) and resulted in a highly significant effect on both fresh and dry weights as well as root length in *Tagetes erecta* when treated with salicylic acid. Atiya *et al.* (2020) pointed out that salicylic acid acts as a growth regulator impacting biological activities in plants, including the action of antioxidant enzymes.

Each of the NPK components plays an important role in plant growth by improving the effective absorption of nutrients. With a notable increase in the root-soil interface due to their nanoscale dimensions compared to classic fertilizers, nano-fertilizers have shown superior performance in improving crop nutritional quality and alleviating plant stressors (Poudel *et al.*, 2023), which in turn increases meristematic activity, enzyme function, and hormone biosynthesis. The use of nano-fertilizers has been demonstrated to improve these processes. According to Jimmy (2021), potassium stimulates energy transfer and root development, phosphorus facilitates protein synthesis and vegetative growth, and nitrogen promotes vegetative growth and protein synthesis.

This study aimed to investigate the effects of shading levels, foliar sprays with different concentrations of salicylic acid, and nano-fertilizers on the growth performance of the *Dichondra repens* plant under the conditions of Dohuk Governorate, Kurdistan Region, Iraq, to cultivate the plant over a wide area in different seasons for its aesthetic value.

## Materials and methods

The study was conducted in the field and lath-house of the Horticulture Department, College of Agricultural Engineering Sciences, University of Duhok, Iraq, from March 15, 2024, to September 15, 2024, for the spring and summer seasons. The seeds were sown by hand in the plots with a seeding rate of 30 g m$^{-2}$. The experiment was performed using a factorial Randomized Complete Block Design (RCBD) with three factors (2 × 3 × 3) and 3 replications, totaling 54 boxes for the spring and summer seasons. The box dimensions were 50 × 50 cm. The design included three factors: shade levels (0% for the field and 50% shade provided by lath-houses constructed with slats spaced 5 centimeters apart, a standardized dimension in Iraq), three concentrations of salicylic acid (0, 100, and 200 mg L$^{-1}$), and three concentrations of nano-fertilizer (0, 5, and 10 mg L$^{-1}$) (N20P20K20).

The studied measurements included the following parameters: plant density (number of plants per 100 cm$^{-2}$), leaf area (cm$^2$), mowing frequency (number of cuts), cumulative dry weight of clipping yield (g), total chlorophyll content in vegetative growth (mg g$^{-1}$ fresh weight, measured using a spectrophotometer), total carbohydrates in vegetative growth (%, measured using a spectrophotometer), total nitrogen in clipping dry matter (%, measured by Micro Kjeldahl's system), total phosphorus in clipping dry matter (%, measured by spectrophotometer), total potassium in clipping dry matter (%, measured by flame photometer), and root dry weight (g).

Some physical and chemical properties of the studied soil in the field are as follows: Sand 66.6%, Silt 15.8%, Clay 17.6%, Soil texture: Sandy loam. Available phosphorus: 17.18 mg/kg, Available potassium: 67.5 mg/kg, Available nitrogen: 126 mg/kg. Organic matter (OM): 2.68%, Soil pH: 7.36, EC: 0.422 dS.m-1, $CaCO_3$: 7.909%.

The data were statistically analyzed using the SAS program (SAS, 2017) and compared with the means using Duncan's multiple range test at the 0.05 level.

## Results

**Plant density (plants 100 cm$^{-2}$)**: The results indicated a significant effect of the 0% shade level on plant density, recording 12.85 plants per 100 cm$^{-2}$ compared to the 50% shading level, where the plant density reached 11 plants per 100 cm$^{-2}$. The plant density varied with the 5 mg L$^{-1}$ concentration of nano-fertilizer, achieving the highest level at 12.61 plants per 100 cm$^{-2}$. The salicylic acid had no significant effect on plant density. A triple interaction appeared in the treatment combining the 5 mg L$^{-1}$ concentration of nano-fertilizer with the 0% shading level and no salicylic acid, reaching a plant density of 17 plants per 100 cm$^{-2}$.

Table 1. Effect of shading levels, salicylic acid and nano fertilizer on the plant density (plants 100 cm$^2$) of *Dichondra* plant

| Shade levels | SA (mg L$^{-1}$) | Nano fertilizer (mg L$^{-1}$) 0 | 5 | 10 | Shade levels mean | SA means |
|---|---|---|---|---|---|---|
| 50% | 0 | 10.33 $^{bc}$ | 11.00 $^{bc}$ | 15.00 $^{a}$ | 11.00 $^{b}$ | |
| | 100 | 11.00 $^{bc}$ | 11.67 $^{bc}$ | 9.67 $^{cd}$ | | |
| | 200 | 7.67 $^{d}$ | 11.00 $^{bc}$ | 11.67 $^{bc}$ | | |
| 0% | 0 | 11.67 $^{bc}$ | 17.00 $^{a}$ | 15.00 $^{a}$ | 12.85 $^{a}$ | 13.33 $^{a}$ |
| | 100 | 12.33 $^{b}$ | 15.00 $^{a}$ | 11.33 $^{bc}$ | | 11.83 $^{b}$ |
| | 200 | 11.67 $^{bc}$ | 10.00 $^{bc}$ | 11.67 $^{bc}$ | | 10.61 $^{c}$ |
| Nano fertilizer | | 10.78 $^{b}$ | 12.61 $^{a}$ | 12.39 $^{a}$ | | |

**Leaf area (cm$^2$)**: The analysis results indicated a significant effect of the 50% shading level, showing a high leaf area of 3.33 cm$^2$ compared to the 0% shading level, which had a leaf area of 2.74 cm$^2$. Salicylic acid had a great effect on leaf area, giving a superior level of 3.14 cm$^2$ with the application of the 200 mg L$^{-1}$ concentration. The results showed that spraying plants with a 5 mg L$^{-1}$ concentration of nano-fertilizer resulted in a leaf area of 3.40 cm$^2$. The triple interaction was observed under the 50% shading level with the application of 5 mg L$^{-1}$ of nano-fertilizer, resulting in a leaf area of 4.08 cm$^2$.

Table 2. Effect of shading levels, salicylic acid and nano fertilizer on leaf area (cm$^2$) of *Dichondra* plant

| Shade levels | SA (mg L$^{-1}$) | Nano fertilizer (mg L$^{-1}$) 0 | 5 | 10 | Shade levels mean | SA means |
|---|---|---|---|---|---|---|
| 50% | 0 | 2.86 $^{c-f}$ | 4.08 $^{a}$ | 3.29 $^{b-d}$ | 3.33 $^{a}$ | |
| | 100 | 2.63 $^{d-g}$ | 3.86 $^{ab}$ | 3.38 $^{a-c}$ | | |
| | 200 | 2.03 $^{g}$ | 3.91 $^{ab}$ | 3.93 $^{ab}$ | | |
| 0% | 0 | 2.34 $^{fg}$ | 2.91 $^{c-f}$ | 2.76 $^{c-g}$ | 2.74 $^{b}$ | 3.04 $^{a}$ |
| | 100 | 2.06 $^{g}$ | 2.53 $^{e-g}$ | 3.09 $^{c-e}$ | | 2.93 $^{a}$ |
| | 200 | 2.45 $^{e-g}$ | 3.13 $^{c-e}$ | 3.36 $^{b-d}$ | | 3.14 $^{a}$ |
| Nano fertilizer | | 2.40 $^{b}$ | 3.40 $^{a}$ | 3.30 $^{a}$ | | |

**Mowing frequency**: The data illustrated that the 0% shading level achieved the highest mowing frequency at 2.85, compared to the 50% shading level where the mowing frequency was 2.59. The mowing frequency reached a greater value with the spraying of 5 and 10 mg L$^{-1}$ concentrations of nano-fertilizer, both giving 2.89. On the other hand, the application of salicylic acid had no significant effect on mowing frequency. A triple combination among the three factors was clearly found in the treatment applying 10 mg L$^{-1}$ of nano-fertilizer and 200 mg L$^{-1}$ of salicylic acid under the 50% shading level, where the mowing frequency reached 3.00.

**Cumulative dry weight of clipping yield (g)**: The 50% shading level did not produce a significant effect on cumulative dry weight, which was 130.16 g, compared to the 0% shading level, which yielded a superior cumulative dry weight of 143.53 g. Spraying salicylic acid at a concentration of 100 mg L$^{-1}$ had a

Table 3. Effect of shading levels, salicylic acid and nano fertilizer on the number of cuts *Dichondra* plant

| Shade levels | SA (mg L$^{-1}$) | Nano fertilizer (mg L$^{-1}$) 0 | 5 | 10 | Shade levels means | SA means |
|---|---|---|---|---|---|---|
| 50% | 0 | 2.00$^{b}$ | 2.67$^{ab}$ | 3.00$^{a}$ | 2.59$^{b}$ | |
| | 100 | 2.00$^{b}$ | 3.00$^{a}$ | 2.67$^{ab}$ | | |
| | 200 | 2.33$^{ab}$ | 2.67$^{ab}$ | 3.00$^{a}$ | | |
| 0% | 0 | 3.00$^{a}$ | 3.00$^{a}$ | 3.00$^{a}$ | 2.85$^{a}$ | 2.78$^{a}$ |
| | 100 | 2.33$^{ab}$ | 3.00$^{a}$ | 3.00$^{a}$ | | 2.67$^{a}$ |
| | 200 | 2.67$^{ab}$ | 3.00$^{a}$ | 2.67$^{ab}$ | | 2.72$^{a}$ |
| Nano fertilizer | | 2.39$^{b}$ | 2.89$^{a}$ | 2.89$^{a}$ | | |

Table 4. Effect of shading levels, salicylic acid and nano fertilizer on the cumulative dry weight (g) of *Dichondra* plant

| Shade levels | SA (mg L$^{-1}$) | Nano fertilizer (mg L$^{-1}$) 0 | 5 | 10 | Shade levels means | SA means |
|---|---|---|---|---|---|---|
| 50% | 0 | 122.49$^{hi}$ | 137.94$^{d-f}$ | 137.72$^{d-f}$ | 130.16$^{b}$ | |
| | 100 | 129.91$^{f-h}$ | 146.80$^{cd}$ | 138.44$^{d-f}$ | | |
| | 200 | 107.98$^{jk}$ | 117.07$^{ij}$ | 133.09$^{e-g}$ | | |
| 0% | 0 | 124.02$^{g-i}$ | 158.77$^{b}$ | 161.69$^{ab}$ | 143.53$^{a}$ | 140.44$^{a}$ |
| | 100 | 104.18$^{k}$ | 170.58$^{a}$ | 152.48$^{bc}$ | | 140.40$^{a}$ |
| | 200 | 138.14$^{d-f}$ | 141.09$^{de}$ | 140.86$^{de}$ | | 129.71$^{b}$ |
| Nano fertilizer | | 121.12$^{b}$ | 145.37$^{a}$ | 144.05$^{a}$ | | |

significant effect on cumulative dry weight, reaching 140.40 g. The addition of nano-fertilizer at 5 mg L$^{-1}$ showed a significantly higher effect on cumulative dry weight, reaching 145.37 g. The triple interaction between the application of 5 mg L$^{-1}$ of nano-fertilizer and 100 mg L$^{-1}$ of salicylic acid under the 0% shading level resulted in a cumulative dry weight of 170.58 g, compared to the lowest value of 104.18 g.

**Root dry weight (g)**: The results documented a clear significant effect under the 0% shading level, where root dry weight reached 16.45 g, while under the 50% shading level, the root dry weight was 14.32 g. Foliar spraying with nano-fertilizer at a concentration of 5 mg L$^{-1}$ increased the root dry weight to 16.16 g. Salicylic acid also significantly affected root dry weight, reaching 15.79 g. The interaction among the three factors was demonstrated in the treatment sprayed with 10 mg L$^{-1}$ of nano-fertilizer and 200 mg L$^{-1}$ of salicylic acid under the 50% shading level, reaching 18.48 g, compared to the lowest value of 12.59 g.

Table 5. Effect of shading levels, salicylic acid and nano fertilizer on the root dry weight (g) of *Dichondra* plant

| Shade levels | SA (mg L$^{-1}$) | Nano fertilizer (mg L$^{-1}$) 0 | 5 | 10 | Shade Levels means | SA means |
|---|---|---|---|---|---|---|
| 50% | 0 | 12.59$^{g}$ | 15.11$^{c-f}$ | 14.11$^{d-g}$ | 14.32$^{b}$ | |
| | 100 | 12.68$^{g}$ | 13.69$^{e-g}$ | 14.42$^{d-g}$ | | |
| | 200 | 13.19$^{fg}$ | 14.61$^{d-g}$ | 18.48$^{a}$ | | |
| 0% | 0 | 15.46$^{b-f}$ | 17.51$^{ab}$ | 17.22$^{a-c}$ | 16.45$^{a}$ | 15.33$^{a}$ |
| | 100 | 15.14$^{c-f}$ | 18.00$^{a}$ | 16.26$^{a-d}$ | | 15.03$^{a}$ |
| | 200 | 14.77$^{d-g}$ | 18.04$^{a}$ | 15.64$^{b-e}$ | | 15.79$^{a}$ |
| Nano fertilizer | | 13.97$^{b}$ | 16.16$^{a}$ | 16.02$^{a}$ | | |

**Total chlorophyll content index (CCI)**: The data registered that chlorophyll contents reached significantly higher levels under the 50% shading level, giving 37.99 mg/g f.w., compared to the 0% shading level, which reached 29.66 mg/g f.w. Fertilization with nano-fertilizer highly increased the chlorophyll content to 37.44 mg/g f.w. The utilization of salicylic acid had a great

Table 6. Effect of shading levels, salicylic acid and nano fertilizer on chlorophyll content in leaves (mg/g f. w.) of *Dichondra* plant

| Shade levels | SA (mg L$^{-1}$) | Nano fertilizer (mg L$^{-1}$) 0 | 5 | 10 | Shade levels means | SA means |
|---|---|---|---|---|---|---|
| 50% | 0 | 28.57$^{f}$ | 39.39$^{b-d}$ | 38.09$^{b-d}$ | 37.99$^{a}$ | |
| | 100 | 33.72$^{e}$ | 42.04$^{ab}$ | 41.30$^{ab}$ | | |
| | 200 | 34.01$^{e}$ | 44.97$^{a}$ | 39.84$^{bc}$ | | |
| 0% | 0 | 25.83$^{fg}$ | 35.66$^{de}$ | 25.54$^{fg}$ | 29.66$^{b}$ | 32.18$^{b}$ |
| | 100 | 23.53$^{g}$ | 29.19$^{f}$ | 29.15$^{f}$ | | 33.15$^{b}$ |
| | 200 | 27.91$^{f}$ | 33.38$^{e}$ | 36.79$^{c-e}$ | | 36.15$^{a}$ |
| Nano fertilizer | | 28.93$^{c}$ | 37.44$^{a}$ | 35.12$^{b}$ | | |

influence, increasing the chlorophyll content to 36.15 mg/g f.w. The interaction among nano-fertilizer, salicylic acid, and shading levels appeared in the treatment with 5 mg L$^{-1}$ of nano-fertilizer and 200 mg L$^{-1}$ of salicylic acid under the 50% shading level, yielding 44.97 mg/g f.w., compared to the lowest value of 23.53 mg/g f.w.

**Total nitrogen in clipping dry matter (%)**: Total nitrogen was significantly affected by the 50% shading level, reaching 3.23%, while the 0% shading level reached a total nitrogen of 3.07%. Foliar nano-fertilizer at concentrations of 5 and 10 mg L$^{-1}$ significantly affected total nitrogen, reaching 3.33% and 3.34%, respectively. The application of salicylic acid at a concentration of 200 mg L$^{-1}$ increased total nitrogen to 3.17%. The triple interaction among salicylic acid, nano-fertilizer, and shading level was obviously recorded in the treatment where total nitrogen reached 3.83% with 0% shading and 10 mg L$^{-1}$ of nano-fertilizer with no salicylic acid, compared to the least value of 2.33%.

Table 8. Effect of shading levels, salicylic acid and nano fertilizer on the total nitrogen in vegetative growth (%) of *Dichondra* plant

| Shade levels | SA (mg L$^{-1}$) | Nano fertilizer (mg L$^{-1}$) 0 | 5 | 10 | Shade levels means | SA means |
|---|---|---|---|---|---|---|
| 50% | 0 | 2.33$^{h}$ | 3.38$^{b-d}$ | 3.22$^{b-e}$ | 3.23$^{a}$ | |
| | 100 | 2.77$^{fg}$ | 3.61$^{ab}$ | 3.48$^{a-d}$ | | |
| | 200 | 3.19$^{b-f}$ | 3.52$^{a-c}$ | 3.54$^{ab}$ | | |
| 0% | 0 | 2.80$^{e-g}$ | 3.34$^{b-d}$ | 3.83$^{a}$ | 3.07$^{b}$ | 3.15$^{a}$ |
| | 100 | 2.45$^{gh}$ | 3.05$^{d-f}$ | 3.40$^{b-d}$ | | 3.12$^{a}$ |
| | 200 | 3.05$^{d-f}$ | 3.10$^{c-f}$ | 2.60$^{gh}$ | | 3.17$^{a}$ |
| Nano fertilizer | | 2.77$^{b}$ | 3.33$^{a}$ | 3.34$^{a}$ | | |

**Total phosphorus in clipping dry matter (%)**: A significant effect was indicated in total phosphorus, reaching 0.22% under the 0% shading level, while total phosphorus under 50% shading reached 0.20%. Foliar application of salicylic acid at a concentration of 100 mg L$^{-1}$ caused a significant effect on total phosphorus (0.22%). Nano-fertilizer at a concentration of 5 mg L$^{-1}$ increased total phosphorus significantly to 0.24%. The combination among shading, nano-fertilizer, and salicylic acid was demonstrated in the 0% shading level; 5 mg L$^{-1}$ of nano-fertilizer and 100 mg L$^{-1}$ of salicylic acid significantly affected total phosphorus, reaching 0.29% compared to the lower value of 0.15%.

**Total potassium in clipping dry matter (%)**: The effect of different shading levels showed that total potassium reached its highest level (1.63%) under the 0% shading level, while utilizing 50% shading resulted in 1.44%. Salicylic acid had no significant

Table 9. Effect of shading levels, salicylic acid and nano fertilizer on the total phosphorus in vegetative growth (%) of *Dichondra* plant

| Shade levels | SA (mg $L^{-1}$) | Nano fertilizer (mg $L^{-1}$) | | | Shade levels means | SA means |
|---|---|---|---|---|---|---|
| | | 0 | 5 | 10 | | |
| 50% | 0 | 0.18 $^{fg}$ | 0.23 $^{bc}$ | 0.19 $^{ef}$ | 0.20 $^{b}$ | |
| | 100 | 0.18 $^{fg}$ | 0.23 $^{bc}$ | 0.20 $^{d-f}$ | | |
| | 200 | 0.15 $^{g}$ | 0.21 $^{b-e}$ | 0.22 $^{b-e}$ | | |
| 0% | 0 | 0.15 $^{g}$ | 0.24 $^{b}$ | 0.24 $^{b}$ | 0.22 $^{a}$ | 0.21 $^{b}$ |
| | 100 | 0.20 $^{d-f}$ | 0.29 $^{a}$ | 0.22 $^{b-e}$ | | 0.22 $^{a}$ |
| | 200 | 0.21 $^{b-e}$ | 0.22 $^{b-e}$ | 0.23 $^{bc}$ | | 0.21 $^{b}$ |
| Nano fertilizer | | 0.18 $^{c}$ | 0.24 $^{a}$ | 0.22 $^{b}$ | | |

effect on total potassium. The 5 mg $L^{-1}$ concentration of nano-fertilizer increased total potassium to a high level of 1.74% compared to the control. The triple interaction among the three factors was found in the treatment reaching 1.89% under 50% shading with the application of 5 mg $L^{-1}$ of nano-fertilizer and 200 mg $L^{-1}$ of salicylic acid.

Table 10. Effect of shading levels, salicylic acid and nano fertilizer on the total potassium in vegetative growth (%) of *Dichondra* plant

| Shade levels | SA (mg $L^{-1}$) | Nano fertilizer (mg $L^{-1}$) | | | Shade levels means | SA means |
|---|---|---|---|---|---|---|
| | | 0 | 5 | 10 | | |
| 50% | 0 | 1.04 $^{ef}$ | 1.54 $^{b-d}$ | 1.71 $^{ab}$ | 1.44 $^{b}$ | |
| | 100 | 0.94 $^{f}$ | 1.70 $^{a-c}$ | 1.66 $^{a-c}$ | | |
| | 200 | 1.00 $^{ef}$ | 1.89 $^{a}$ | 1.53 $^{b-d}$ | | |
| 0% | 0 | 1.45 $^{b-d}$ | 1.89 $^{a}$ | 1.71 $^{ab}$ | 1.63 $^{a}$ | 1.56 $^{a}$ |
| | 100 | 1.37 $^{cd}$ | 1.65 $^{a-c}$ | 1.69 $^{a-c}$ | | 1.50 $^{a}$ |
| | 200 | 1.30 $^{de}$ | 1.78 $^{ab}$ | 1.79 $^{ab}$ | | 1.55 $^{a}$ |
| Nano fertilizer | | 1.18 $^{b}$ | 1.74 $^{a}$ | 1.68 $^{a}$ | | |

## Discussion

Light significantly influenced various parameters evaluated in this study, resulting in enhanced plant density, mowing frequency, cumulative dry weight, root dry weight, total carbohydrates, total phosphorus, and total potassium. On the other hand, levels of total nitrogen and leaf area were found to increase under 50% shading. These findings align with those of Atta *et al.* (2023), who noted that light serves as the primary energy source for photosynthesis and profoundly influences energy generation and material synthesis in plants. As a crucial environmental component for plant development, the strategic use of light conditions can enhance plant quality and manage sugar metabolism.

Furthermore, many studies have indicated that the application of salicylic acid can improve the photosynthetic rate in many plants under abiotic stress (Faried *et al.*, 2017). In accordance with these reports, our results indicated that exogenously applied salicylic acid increased the photosynthetic rate under full sunlight. The reason for this may be that salicylic acid plays an important role in regulating stomatal status, thereby improving photosynthetic capacity as a regulator of photosynthesis under environmental stresses. Therefore, a high level of photosynthetic efficiency means more carbon is fixed from CO2 into sugars and carbohydrates, as photosynthesis is the biochemical pathway that produces carbohydrates in leaves.

Light treatments yield specific photosynthetic and physiological responses in plants. Throughout the growth and maturation of plants, light influences stem elongation, leaf size, flowering times, seed germination, and the distribution and accumulation of biomass. Moreover, the growth of roots underground is also influenced by light from the foliage, utilizing long-distance signaling pathways to adjust root structure in reaction to light exposure, as demonstrated by Hamon-Josse *et al.* (2022). In a study conducted by Rezai *et al.* (2015), two dwarf species of Lisianthus exhibited the best development in conditions with 20% shade. Plants adapt to shaded environments through changes in their morphology and physiological responses. For instance, under appropriate shading conditions, Anthurium andreanum exhibited enhancements in its morphological growth, including increased height, internode length, leaf count, and leaf area, as found by Abduh *et al.* (2017). Meanwhile, a firm root system is developed to increase the capacity for nutrient absorption.

The balance between biomass production and light-harvesting capability in the Dichondra plant was significantly affected by light availability. Due to increased stolon multiplication and structural growth brought on by increased carbon absorption, plants cultivated in full daylight (0% shade) showed higher dry weight and density. Plants exposed to 50% moderate shade, on the other hand, showed higher leaf area and chlorophyll content, suggesting a change in morphological and biochemical characteristics that improve light capture under low irradiance. In high-light conditions, *Dichondra repens* encourages lateral growth and biomass accumulation, but in shaded conditions, it moves resources toward increasing photosynthetic efficiency per unit of tissue at the expense of total dry matter and canopy density. This response demonstrates a classical trade-off in resource allocation.

The use of salicylic acid resulted in enhancements to leaf surface area, root dry mass, overall chlorophyll content, total nitrogen levels, cumulative dry mass, and phosphorus content. These findings align with the research conducted by Echevarría-Machado *et al.* (2007), which focused on Catharanthus roseus transformed roots developed in varying concentrations of salicylic acid ranging 0.1 femtomolar (fM) to 100 picomolar (Pm). Noticeable alterations in the morphology of the lateral roots were observed after two days in the SA-treated samples. The application of salicylic acid causes an enlargement of the root cap and encourages the emergence of lateral roots in close proximity to the root's apex. This evidences the impact of salicylic acid on root development.

Ben-Tal and Cleland (1982) demonstrated that nearly 90% of the labeled salicylic acid absorbed by Lemna gibba remained in its free state 30 minutes after a 10 mM application. Likewise, cells of Mallotus japonicus were noted to take in approximately 57% of the salicylic acid introduced to their culture medium within an hour, with this substance remaining unbound. Salicylic acid enhances the photosynthetic efficiency of plants under stress conditions, and chlorophyll a fluorescence may provide insights into how plants manage environmental stresses. Salicylic acid signaling has the potential to mediate a durable, broad resistance against pathogen attacks, referred to as systemic acquired resistance (Noctor and Foyer, 1998). Furthermore, as a signaling molecule, salicylic acid influences various physiological processes such as respiration, metabolism, seed germination, flower production, aging, and resilience to stress. Additionally, it plays a role in controlling stomatal movements, the content of photosynthetic pigments, the efficacy of photosynthetic mechanisms, and the activity of enzymes that contribute to carbon absorption within plant leaves.

Experimental findings show that salicylic acid can encourage plants' ability to resist abiotic stressors like high temperatures, salt, and heavy metals.

Utilizing salicylic acid at a concentration of 200 mg $L^{-1}$ produced significantly elevated measurements for the number of leaves, leaf dry mass, leaf area, root length, root dry mass, and leaf chlorophyll levels of Gazania rigens species (El-Shanhorey and Hassan, 2021). Likewise, increased nutrient absorption and availability improve various cellular functions when there are high levels of salicylic acid (Souri and Bakhtiarizade, 2019). Salicylic acid serves crucial functions in managing numerous physiological and developmental aspects in plants. Such beneficial impacts might stem from its influence in boosting the levels of internal plant hormones like gibberellins, auxins, and cytokinins, which promote cell division and elongation, ultimately fostering plant growth and progression (Hayat *et al.*, 2007).

The results align with those indicating that nanoparticles exhibit high reactivity due to a larger surface area, a higher concentration of reactive zones, or enhanced reactivity of these zones on the particle surfaces. These characteristics at the nano-scale facilitate their uptake in plants. Shabiya *et al.* (2025) found that directly exposing plants to certain types of nanoparticles leads to an increase in all growth measures at ideal concentrations of the nano-solution. Nano-fertilizers provide a sustainable solution to enhance agricultural productivity. Many studies have indicated that using nano-fertilizers significantly enhanced leaf characteristics such as fresh and dry weight, chlorophyll pigment content, and total number of bracts (Abdulrazzaq and Abdulmajeed, 2025). In addition, values of total carbohydrates and macro- and micro-elements were raised. Moreover, the rate of photosynthesis, water use efficiency, and stomatal conductance were also improved (Mahmoud and Swaefy, 2020).

The results also confirmed that nano-fertilizer increased vegetative parameters, and these elements contributed to increases in amino acids and proteins. In turn, plant cells and tissues grew and developed. Another reason could be due to the application of phosphorus, which has an essential role in photosynthesis processes vital to the plant. It is also involved in respiration and energy storage and translation. These results are compatible with Alhasan *et al.* (2021), who indicated that nano-fertilizers increased growth characteristics and the development of roots and shoots, and can stimulate or control root and seedling growth due to the influence of different nanoparticles. A study by Akhter *et al.* (2025) demonstrated that the foliar application of nano NPK fertilizer significantly enhanced the growth, biochemical, physiological, and yield-related parameters of Coleus aromaticus, showing improvements in shoot and root lengths, fresh and dry weights, and chlorophyll content.

It is necessary to create nano-fertilizers with standardized, stable formulations for a number of crops to avoid toxicity and ensure safety. For greater public or societal acceptance, awareness and research, including in-depth studies on diverse horticultural crops, must be conducted to examine linked risks and impacts on human health (Mandal and Lalrinchhani, 2021). For this reason, in this experiment, we preferred to use very low concentrations of nano-fertilizer (5 and 10 mg $L^{-1}$) to avoid toxicity in the plants.

Energy capture, chlorophyll synthesis, and photosynthesis are all significantly impacted by light intensity. Low light reduces photosynthesis, but high light increases biomass and carbon fixation. Under stressful environmental conditions (such as heat or shade), salicylic acid has been reported to improve light utilization and modify photosynthetic efficiency. The availability of nutrients required for the formation of photosynthetic components (chlorophyll, electron transport) can be induced by nano-fertilizers (Kumar *et al.*, 2025). It has been proven that salicylic acid adjusts physiological and biochemical processes in plants, increasing antioxidant activity and reducing a variety of stresses in crops, including ornamentals.

Applying foliar salicylic acid can induce growth and nutrient uptake, especially in difficult conditions like salinity or drought. Because of their nanoscale characteristics, nano-fertilizers provide better nutrient uptake efficiency, strongly encouraging the synthesis of chlorophyll and the accumulation of biomass. In addition, nano-fertilizers provide nutrients that promote light-induced metabolic activities, while salicylic acid improves photosynthetic capacity and stress resistance (Chen *et al.*, 2023).

It was concluded that the results obtained from this experiment exposed that *Dichondra repens* plants positively responded to full sun with enhanced biomass, while moderate shading improved chlorophyll content. The outcomes related to vegetative growth and chemical constituents revealed that the most effective salicylic acid application was at a concentration of 200 mg $L^{-1}$, which contributed to the production of high-quality results. Additionally, fertilizing with nano-fertilizers, particularly at a low concentration of 5 mg $L^{-1}$, demonstrated a substantial positive impact on most growth parameters.

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