



# Densities and Fertilizer Dosages based Study on the Development and Yield of *Solanum procumbens* Lour. in the Central Vietnam

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## ABSTRACT

**Background:** *Solanum procumbens* Lour. is a precious medicinal plant in Vietnam, effective in treating toothache, snakebites, bone pain, alcohol poisoning, especially liver detoxification and hepatitis diseases. The study was conducted in Central Vietnam with the aim of determining the appropriate density and fertilizer dosage for *Solanum procumbens* Lour. with the local climatic and soil conditions.

**Methods:** The two-factors experiment was arranged in a split-plot design, with 3 replicates; fertilizer arranged in the large plot with three fertilizer dosages and density arranged in the small plot with three density levels.

**Result:** Results showed that applied fertilizer dosage per hectare was 1.0 tons of NPK 20-15-5 + TE + 5.0 tons of manure + 1.5 tons of biofertilizer + 500 kg of lime powder comprised with the planted density of 50,000 plants per hectare, *Solanum procumbens* Lour. grew optimally and gave the highest yield, reached 6.03 net dried tons per hectare after five months of planting. Therefore, if we cultivate *Solanum procumbens* Lour. with this fertilizer dosage and density, it is considered to be suitable for the climatic and soil conditions in the Central of Vietnam.

**Key words:** Density, Fertilizer, *Solanum procumbens* Lour, Yield.

## INTRODUCTION

*Solanum procumbens* Lour. is a medicinal plant distributed widely in Vietnam and tropical countries (Fig 1) (To *et al.*, 2022). It has good effects in treating toothache, alcohol poisoning, snakebites and bone pain (Loi, 2015; Institute of Medicinal Materials, 2004). In addition, other research have shown strong effectiveness of *Solanum procumbens* Lour. in liver cooling, liver detoxification and anti-hepatitis by affecting its alkaloids (solasodine) (Man *et al.*, 1999; Khai *et al.*, 2001; Thu, 2002). This plant can be harvested after about 5 to 6 months of planting, 2-3 harvests per year for 3-5 years continuously; thus, it has brought a high economic value of about 15,000 \$ per hectare (Sau *et al.*, 2016; Thanh *et al.*, 2018).

Currently, research on *Solanum procumbens* Lour. mainly focuses on the pharmacological effects and extraction of active ingredients of this plant (Man *et al.*, 1999; Khai *et al.*, 2001; Thu, 2002). Some but few studies on the technical processes to improve productivity and quality of medicinal materials have been carried out and had results at limited localities of provinces of Phu Tho, Hanoi, Thanh Hoa and Nghe An (Northern region of Vietnam). These research's results have determined the appropriate planting densities and amount of fertilizers in some localities, for example the densities of 250,000 plants (25×25 cm) in Hanoi region (Ha *et al.*, 2017); density of 11,110 plants per hectare (30×30 cm) and fertilizer amount of 20 tons of manure+200 kg N+150 kg P<sub>2</sub>O<sub>5</sub>+125 kg K<sub>2</sub>O per hectare per year in Nghe An province (Thanh *et al.*, 2018); amount fertilizer of 20 tons of manure+200 kg N+150 kg P<sub>2</sub>O<sub>5</sub>+125 kg K<sub>2</sub>O per hectare per year comprised

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with planting density of 6000plant perhectare (30×50 cm) in Thanh Hoa province and density of 5,000 plants per hectare (40×50 cm) in Yen Dinh, Thanh Hoa (Tien *et al.*, 2020), density of 50,000 plants per hectare (40×50 cm) comprised with fertilizer amount of 20 tons of manure+220 kg N+150 kg P<sub>2</sub>O<sub>5</sub>+125 kg K<sub>2</sub>O per hectare per year in hilly land of Phu Tho province (Thien *et al.*, 2019); *etc.* Thus, planted density in different localities was different, while the amount of fertilizer was quite similar, mainly using

inorganic chemical fertilizers. However, until now, there are very few studies related to density and fertilizer for *Solanum procumbens* Lour. in Central Vietnam. Hence, in order to perfect the cultivation techniques, improve productivity and sustainable development of *Solanum procumbens* Lour. in this region, we conducted the study "Studying influences of densities and fertilizer dosages on development and yield of *Solanum procumbens* Lour. in the Central Vietnam".

## MATERIALS AND METHODS

### Experimental layout

The experiment was conducted in February 2022, arranged in Split-plot style with 3 replicates. In which, large plots were inorganic fertilizer factors with three different formulas (F1, F2 and F3), the small plots were density factors with three different formulas (D1, D2 and D3), area of each plot was 10 m<sup>2</sup>. Large plot factor (fertilizer-F): F1: 10 tons of manure+3.0 tons of biological fertilizer+500 kg of lime powder (control). F2: 5.0 tons of manure+1.5 tons of biological fertilizer+500 kg of lime powder+1.0 tons of inorganic fertilizer NPK 20-15-5+TE. F3: 5 tons of manure+1.5 tons of biological fertilizer+500 kg of lime powder+1.5 tons of inorganic fertilizer NPK 20-15-5+TE. Small plot factor (density-D): D1: 30 cm×40 cm (equivalent to 66,666 plants per ha). D2: 40 cm×40 cm (equivalent to 50,000 plants per ha) (control). D3: 50 cm×40 cm (equivalent to 40,000 plants per ha).

### Agricultural techniques

Plants were cultivated on the bed with 30 cm high, 80 cm wide, bed to bed was 40 cm. Regularly weed, watered to keep moist and managed pests and diseases. Harvesting in July 2022 by using a sickle to cut 15 cm from the surface ground.

### Monitoring criteria

Each experimental plot monitored 10 plants, periodically monitored 15, 25, 35, 45, 55, 65 days after planting and at the harvesting time. Monitoring criterias include: Main stem

height (cm)-measured from the ground to its development tip of main stem; main stump diameter (mm)-measured at a position 5.0 cm above surface ground by using Pame measure; number of first-level branch (first-level branch per plant)-counted the number of first-level branch growing from main stem; length of first-level branch (cm) - choos a first-level branch, measuring from branching point to its development tip. Fresh and dried individual yield (g): Selected and harvested 05 representative plants per plot, weighed and average fresh value of them. Dried these 05 plants until unchanged weight, weighted and averaged their values. From that fresh and dried yield per hectare of all formulas was calculated. Net-fresh and dried yield per ha (tons): Each experimental plot, harvested 5 m<sup>2</sup>, weighted their net-fresh. Dried all untill unchanges weight, then converted to net-fresh and dried yield per hectare.

### Data processing methods

Research data was statistically processed by using Microsoft Excel 2016 and Statistix for Windows 10.0 software (Tallahassee, Floria, USA). To evaluate the influences of different fertilizers and densities on mean agronomic traits and yield plant<sup>-1</sup>, we applied two ways ANOVA and Tukey test at p<0.05.

## RESULTS AND DISCUSSION

### Influences of density and fertilizer dosages on development dynamics of main stem height

Stem height is one of the important indicators of plant development ability. Stem height usually leads to high bio-productivity. However, the height of a plant depends on many factors such as varieties, cultivation techniques, caring, climatic-soil conditions, living space and photosynthetic ability of the plant. The main stem height development dynamics in the experimental formulas are shown in Table 1.

When density decreased from D1 to D3, main stem height tended to decrease. At harvesting time, main stem height in formula D1 was the highest (142.22 cm) and significant higher than that of formulas D2 (138.31 cm) and



Fig 1: *Solanum procumbens* Lour.

D3 (136.41 cm) ( $p < 0.05$ ). Thus, when crops are planted at high density, their height grows quickly and vice versa. This was because when plant was planted at high density, there was strong competition for living conditions such as living space and reduced photosynthetic ability; therefore, plants tended to grow higher to absorb sunlight in high-density areas (Thanh *et al.*, 2018; Thien *et al.*, 2019; Tien *et al.*, 2020, Gonyane and Sebetha, 2021). Formulas applied with inorganic fertilizer F2 and F3 were insignificant differences in main stem height; however, they were significantly higher than that of formula F1 without inorganic fertilizer (10 tons of manure+3.0 tons of biological fertilizer+500 kg of lime powder) ( $p < 0.05$ ). This result showed that the influence of nutritional factors of inorganic fertilizers has increased the development of main stem height of *Solanum procumbens* Lour. Boroomand and Sadat (2012) and Asama *et al.*, (2019) indicated that macro elements such as N, P and K promote the ability to branch, leaf out, expand foliage, form yield and essential oil content of plants.

The interaction of fertilizer and density ( $F \times D$ ) affected the development dynamics of main stem height of *Solanum procumbens* Lour. In general, the main stem height in the period 15-25 days after planting had negligible differences between experimental formulas. The reason was that at this time, the tree was newly planted, small, had few roots and and absorbs little nutrition. Thus, the development speed of the stem's height was slow. It led to negligible differences between experimental formulas. The difference in main stem height was significant starting from 35 days after planting to harvesting. At the five-months after planting (harvesting time), main stem height of experimental formulas reached from 128.80 to 145.57 cm, with a significant difference at

$p < 0.05$ . In which, the formula F1D3 was the lowest height (128.80 cm), the highest was the F2D1 formula (145.57 cm). These results indicated that as the amount of inorganic fertilizer comprised with density increased, plants tended to develop taller. Therefore, this result showed that under the dual influences of increased inorganic fertilizer with increased density, plant height increased even more than without applied fertilization and less density.

#### Effects of density and fertilizer dosages on number of leaves on the main stem

Leaves are important organs of plants that function in photosynthesis to synthesize organic substances to provide for the life activities of plant. Speed of leaf production and number of leaves depends on each stage of development of the plant, living conditions, space and care regimes (Tan *et al.*, 2006). On the other hand, the color, shape and thickness of the leaf reflect the light intensity in the cultivation areas.

Number of leaves on the main stem tended to increase when planted at a lower density (Table 2). At the harvesting time, the highest number of leaves was in formula D3 with 53.82 leaves and the lowest was in formula D1 with 50.51 leaves ( $p < 0.05$ ). The reason was that when the plant density decreased, the length of the nodes will shorten; as a result, the number of primary branches and the number of leaves will increase. In the other hand, number of leaves on main stem also increased significantly ( $p < 0.05$ ) when applied inorganic fertilizer (53.81 leaves in formula F3) compared to formula without applied inorganic fertilizer F1 (49.66 leaves). So when we added more

**Table 1:** Dynamics of main stem height development of *Solanum procumbens* Lour. in experimental formulas (cm).

| Factors                      | Formulars | After cultivating (days) |                     |                      |                      |                      |                     |                       |
|------------------------------|-----------|--------------------------|---------------------|----------------------|----------------------|----------------------|---------------------|-----------------------|
|                              |           | 15                       | 25                  | 35                   | 45                   | 55                   | 65                  | Harvesting            |
| Density (D)                  | D1        | 15.53 <sup>a</sup>       | 26.32 <sup>a</sup>  | 45.47 <sup>a</sup>   | 63.66 <sup>a</sup>   | 82.09 <sup>a</sup>   | 99.59 <sup>a</sup>  | 142.22 <sup>a</sup>   |
|                              | D2        | 15.47 <sup>a</sup>       | 25.90 <sup>a</sup>  | 43.64 <sup>ab</sup>  | 61.18 <sup>ab</sup>  | 79.81 <sup>ab</sup>  | 95.13 <sup>b</sup>  | 138.31 <sup>ab</sup>  |
|                              | D3        | 13.91 <sup>a</sup>       | 24.64 <sup>a</sup>  | 42.27 <sup>b</sup>   | 59.89 <sup>b</sup>   | 76.79 <sup>b</sup>   | 94.86 <sup>b</sup>  | 136.41 <sup>b</sup>   |
| Fertilizer (F)               | F1        | 14.91 <sup>a</sup>       | 25.46 <sup>a</sup>  | 41.46 <sup>b</sup>   | 57.09 <sup>b</sup>   | 77.16 <sup>b</sup>   | 91.74 <sup>b</sup>  | 133.32 <sup>b</sup>   |
|                              | F2        | 15.63 <sup>a</sup>       | 26.14 <sup>a</sup>  | 44.10 <sup>a</sup>   | 65.13 <sup>a</sup>   | 81.16 <sup>a</sup>   | 98.77 <sup>a</sup>  | 144.17 <sup>a</sup>   |
|                              | F3        | 14.36 <sup>a</sup>       | 25.27 <sup>a</sup>  | 45.82 <sup>a</sup>   | 62.50 <sup>a</sup>   | 80.38 <sup>ab</sup>  | 99.07 <sup>a</sup>  | 139.46 <sup>ab</sup>  |
| Interaction ( $F \times D$ ) | F1D1      | 15.70 <sup>a</sup>       | 27.87 <sup>a</sup>  | 45.67 <sup>ab</sup>  | 61.97 <sup>abc</sup> | 80.23 <sup>abc</sup> | 96.63 <sup>ab</sup> | 139.53 <sup>ab</sup>  |
|                              | F1D2      | 15.22 <sup>a</sup>       | 25.10 <sup>ab</sup> | 38.57 <sup>d</sup>   | 52.17 <sup>d</sup>   | 77.07 <sup>bc</sup>  | 89.77 <sup>bc</sup> | 131.63 <sup>bc</sup>  |
|                              | F1D3      | 13.82 <sup>a</sup>       | 23.40 <sup>b</sup>  | 40.13 <sup>cd</sup>  | 57.13 <sup>cd</sup>  | 74.17 <sup>c</sup>   | 88.83 <sup>c</sup>  | 128.80 <sup>c</sup>   |
|                              | F2D1      | 16.13 <sup>a</sup>       | 25.70 <sup>ab</sup> | 43.47 <sup>bc</sup>  | 66.83 <sup>a</sup>   | 83.50 <sup>a</sup>   | 100.67 <sup>a</sup> | 145.57 <sup>a</sup>   |
|                              | F2D2      | 16.30 <sup>a</sup>       | 26.97 <sup>a</sup>  | 45.07 <sup>ab</sup>  | 66.50 <sup>a</sup>   | 80.93 <sup>ab</sup>  | 97.27 <sup>ab</sup> | 144.47 <sup>a</sup>   |
|                              | F2D3      | 14.47 <sup>a</sup>       | 25.77 <sup>ab</sup> | 43.77 <sup>abc</sup> | 62.07 <sup>abc</sup> | 79.03 <sup>abc</sup> | 98.37 <sup>a</sup>  | 142.47 <sup>ab</sup>  |
|                              | F3D1      | 14.75 <sup>a</sup>       | 25.40 <sup>ab</sup> | 47.27 <sup>a</sup>   | 62.17 <sup>abc</sup> | 82.53 <sup>ab</sup>  | 101.47 <sup>a</sup> | 141.57 <sup>ab</sup>  |
|                              | F3D2      | 14.90 <sup>a</sup>       | 25.63 <sup>ab</sup> | 47.30 <sup>a</sup>   | 64.87 <sup>ab</sup>  | 81.43 <sup>ab</sup>  | 98.37 <sup>a</sup>  | 138.83 <sup>abc</sup> |
|                              | F3D3      | 13.43 <sup>a</sup>       | 24.77 <sup>ab</sup> | 42.90 <sup>bc</sup>  | 60.47 <sup>bc</sup>  | 77.17 <sup>bc</sup>  | 97.37 <sup>ab</sup> | 137.97 <sup>abc</sup> |
| LSD <sub>0.05</sub>          |           | 3.14                     | 3.37                | 3.77                 | 5.61                 | 6.20                 | 8.11                | 11.78                 |

Note: In the same column, numbers with at least one identical letter are not significantly different at  $p < 0.05$ . LSD-least significant difference. CV-coefficient variation.

inorganic fertilizer, the *Solanum procumbens* would produce more leaves.

Interaction between fertilizer and density (F×D) influenced the number of the leaves of *Solanum procumbens* Lour. At harvesting time (5 months after planting), number of leaves on main stem ranged from 48.47 to 55.77 leaves. Formula F1D1 had the lowest number of leaves on main stem, the highest was formula F3D3 (55.77 leaves) ( $p < 0.05$ ). These results showed that when amount of applied inorganic fertilizer increased comprised with density decreased (sparse planting), number of leaves on main stem increased.

### Effects of density and fertilizer dosage on the number and length of first-level branch

Because *Solanum procumbens* Lour. is a bush and climbing plant, its yield depends greatly on number of branch. Among the branch levels, first-level branch development dynamics depended on the development dynamics of plant height. Because level 2, 3, ... branch was in large numbers growing on first-level branch, many thorns and interwoven, hence, in the scope of this study we could only measure the number and length of first-level branch (Table 3).

**Table 2:** Dynamics of leave development on the main stem of *Solanum procumbens* Lour. in experimental formulas (leaves/main stem).

| Factors             | Formulas | After cultivating (days) |                    |                     |                     |                      |                      | Harvesting           |
|---------------------|----------|--------------------------|--------------------|---------------------|---------------------|----------------------|----------------------|----------------------|
|                     |          | 15                       | 25                 | 35                  | 45                  | 55                   | 65                   |                      |
| Density (D)         | D1       | 11.01 <sup>a</sup>       | 14.14 <sup>a</sup> | 17.41 <sup>b</sup>  | 22.64 <sup>b</sup>  | 29.09 <sup>b</sup>   | 34.16 <sup>b</sup>   | 50.51 <sup>b</sup>   |
|                     | D2       | 11.81 <sup>a</sup>       | 15.26 <sup>a</sup> | 19.70 <sup>a</sup>  | 24.80 <sup>a</sup>  | 31.41 <sup>a</sup>   | 36.71 <sup>a</sup>   | 52.52 <sup>ab</sup>  |
|                     | D3       | 10.64 <sup>a</sup>       | 14.20 <sup>a</sup> | 19.32 <sup>a</sup>  | 25.29 <sup>a</sup>  | 31.17 <sup>a</sup>   | 36.14 <sup>a</sup>   | 53.82 <sup>a</sup>   |
| Fertilizer (F)      | F1       | 10.70 <sup>a</sup>       | 14.01 <sup>a</sup> | 17.39 <sup>a</sup>  | 23.34 <sup>a</sup>  | 29.14 <sup>b</sup>   | 34.03 <sup>b</sup>   | 49.66 <sup>b</sup>   |
|                     | F2       | 12.14 <sup>a</sup>       | 15.72 <sup>a</sup> | 20.51 <sup>a</sup>  | 25.96 <sup>a</sup>  | 32.42 <sup>a</sup>   | 37.62 <sup>a</sup>   | 53.39 <sup>ab</sup>  |
|                     | F3       | 10.62 <sup>a</sup>       | 13.87 <sup>a</sup> | 18.53 <sup>a</sup>  | 23.43 <sup>a</sup>  | 30.10 <sup>ab</sup>  | 35.36 <sup>ab</sup>  | 53.81 <sup>a</sup>   |
| Interaction (F×D)   | F1D1     | 11.50 <sup>ab</sup>      | 14.43 <sup>a</sup> | 16.63 <sup>a</sup>  | 22.87 <sup>ab</sup> | 27.03 <sup>c</sup>   | 32.13 <sup>c</sup>   | 48.47 <sup>c</sup>   |
|                     | F1D2     | 10.80 <sup>ab</sup>      | 14.47 <sup>a</sup> | 17.87 <sup>ab</sup> | 23.20 <sup>ab</sup> | 29.73 <sup>abc</sup> | 34.47 <sup>bc</sup>  | 49.70 <sup>bc</sup>  |
|                     | F1D3     | 9.80 <sup>b</sup>        | 13.13 <sup>a</sup> | 17.67 <sup>ab</sup> | 23.97 <sup>ab</sup> | 30.67 <sup>ab</sup>  | 35.50 <sup>abc</sup> | 50.80 <sup>abc</sup> |
|                     | F2D1     | 11.43 <sup>ab</sup>      | 14.83 <sup>a</sup> | 18.37 <sup>ab</sup> | 23.97 <sup>ab</sup> | 31.03 <sup>ab</sup>  | 36.13 <sup>abc</sup> | 51.10 <sup>abc</sup> |
|                     | F2D2     | 13.10 <sup>a</sup>       | 16.43 <sup>a</sup> | 21.50 <sup>a</sup>  | 26.73 <sup>a</sup>  | 33.27 <sup>a</sup>   | 38.87 <sup>a</sup>   | 54.17 <sup>ab</sup>  |
|                     | F2D3     | 11.90 <sup>ab</sup>      | 15.90 <sup>a</sup> | 21.67 <sup>a</sup>  | 27.17 <sup>a</sup>  | 32.97 <sup>ab</sup>  | 37.87 <sup>ab</sup>  | 54.90 <sup>ab</sup>  |
|                     | F3D1     | 10.10 <sup>ab</sup>      | 13.17 <sup>a</sup> | 17.23 <sup>ab</sup> | 21.10 <sup>b</sup>  | 29.20 <sup>bc</sup>  | 34.20 <sup>b</sup>   | 51.97 <sup>abc</sup> |
|                     | F3D2     | 11.53 <sup>ab</sup>      | 14.87 <sup>a</sup> | 19.73 <sup>ab</sup> | 24.47 <sup>a</sup>  | 31.23 <sup>ab</sup>  | 36.80 <sup>abc</sup> | 53.70 <sup>abc</sup> |
|                     | F3D3     | 10.23 <sup>ab</sup>      | 13.57 <sup>a</sup> | 18.63 <sup>ab</sup> | 24.73 <sup>a</sup>  | 29.87 <sup>abc</sup> | 35.07 <sup>abc</sup> | 55.77 <sup>a</sup>   |
| LSD <sub>0.05</sub> |          | 3.15                     | 4.84               | 4.84                | 4.65                | 3.98                 | 3.76                 | 5.33                 |

Note: In the same column, numbers with at least one identical letter are not significantly different at the  $p < 0.05$  level.

**Table 3:** Number and length of first-level branch of *Solanum procumbens* Lour. at harvesting time in experimental formulas.

| Factors                   | Formulars | No. of first-level branch (branch) | Length of first-level branch (cm) |
|---------------------------|-----------|------------------------------------|-----------------------------------|
| Density (D)               | D1        | 32.56 <sup>b</sup>                 | 115.89 <sup>a</sup>               |
|                           | D2        | 34.51 <sup>ab</sup>                | 113.73 <sup>ab</sup>              |
|                           | D3        | 35.63 <sup>a</sup>                 | 106.14 <sup>b</sup>               |
| Fertilizer (F)            | F1        | 31.11 <sup>b</sup>                 | 108.14 <sup>b</sup>               |
|                           | F2        | 36.18 <sup>a</sup>                 | 117.09 <sup>a</sup>               |
|                           | F3        | 35.41 <sup>a</sup>                 | 110.54 <sup>ab</sup>              |
| Interaction (F×D)         | F1D1      | 31.13 <sup>de</sup>                | 114.31 <sup>abc</sup>             |
|                           | F1D2      | 29.27 <sup>e</sup>                 | 106.97 <sup>bc</sup>              |
|                           | F1D3      | 32.93 <sup>cde</sup>               | 103.13 <sup>c</sup>               |
|                           | F2D1      | 33.87 <sup>bcd</sup>               | 117.27 <sup>ab</sup>              |
|                           | F2D2      | 38.23 <sup>a</sup>                 | 124.20 <sup>a</sup>               |
|                           | F2D3      | 36.43 <sup>abc</sup>               | 109.80 <sup>bc</sup>              |
|                           | F3D1      | 32.67 <sup>cde</sup>               | 116.10 <sup>abc</sup>             |
|                           | F3D2      | 36.03 <sup>abc</sup>               | 110.03 <sup>bc</sup>              |
|                           | F3D3      | 37.53 <sup>ab</sup>                | 105.50 <sup>bc</sup>              |
| LSD <sub>0.05</sub> (F×D) |           | 4.39                               | 13.45                             |

Note: In the same column, numbers with at least one identical letter are not significantly different at the  $p < 0.05$ .

Results showed that when planting density decreased, number of first-level branch increased, but length of branch decreased. The reasons were that when planting at low density, height plant was reduced, node distance was shorted and plant had more space to grow; therefore, number of first-level branch increased. Number of first-level branch increased from 32.56 at D1 density to 35.63 branch at D3 density, the difference was significant at  $p < 0.05$ . Besides, when applied different inorganic fertilizers in formulas F2 and F3, there was insignificant difference in the number and length of first-level branch. However, there was a significant difference compared to the formula without applied inorganic fertilizer F1 ( $p < 0.05$ ). This showed the effectiveness of inorganic fertilizer in formulas F2 and F3 compared to the formula without inorganic fertilizer F1 (control) on number of first-level branch. At the same time, because amount of fertilizer between formulas F2 and F3 was not large enough, difference between these two formulas was not shown.

Interaction between fertilizer and density ( $F \times D$ ) had an effect on number and length of first-level branch of *Solanum procumbens* Lour. Between experimental formulas, number and length of first-level branch were fluctuation and significant difference at  $p < 0.05$  in formulas with and without applied inorganic fertilizers. In which, applied inorganic fertilizer formulas did not have a significant difference in the number of first-level branch. Number of first-level branch ranged from 29.27 to 38.23, of which F1D2 formula had the lowest number of first-level branch (29.27), the highest was the F2D2 formula (reaching 38.23) ( $p < 0.05$ ). This result showed that when inorganic fertilizer applying increased and density decreased, number of first-level branch increased

and impact of fertilizer tended to be stronger than density on the number of first-level branch. Length of first-level branch ranged from 103.13 to 124.20 cm, of which formula F1D3 had the lowest and formula F2D2 had the highest. Thus, increased inorganic fertilizer combined with higher density made first-level branch length longer.

#### Effects of density and fertilizer dosage on individual yield and net yield

Yield is an important indicator of all plants, influenced by many factors of height, number of leaves, stump diameter, number of first-level branch, first-level branch length, in which main factors are plant height, number of leaves, number and length of first-level branch (Lam *et al.*, 2022). After 5 months after planting, *Solanum procumbens* Lour. was harvested. Individual yield and net yield of *Solanum procumbens* Lour. in experimental formulas is shown in Table 4.

As density decreased, productivity tended to increase. Individual productivity in formulas D2 and D3 were significantly higher than that in formula D1 ( $p < 0.05$ ). However, between density formulas D2 and D3, the difference in yield was not meaningful. This result implied that as we choose cultivation with lower density would lead to reduce number of plants, input costs and ultimately increased profits. Formulas F2 and F3 with applied inorganic fertilizers had made individual and net yield significantly higher than that of formula F1 without applied inorganic fertilizers. However, the difference in yield between inorganic fertilizer formulas was not statistically significant ( $p < 0.05$ ). This means we could apply lower amounts of inorganic fertilizer but still ensure yield and profits.

**Table 4:** Individual yield and net yield of *Solanum procumbens* Lour. in experimental formulas.

| Factors                              | Formulas | Individual yield (g per plant) |                     | Net yield (tons per ha) |                     |
|--------------------------------------|----------|--------------------------------|---------------------|-------------------------|---------------------|
|                                      |          | Fresh yield                    | Dried yield         | Fresh yield             | Dried yield         |
| Density (D)                          | D1       | 145.56 <sup>b</sup>            | 35.57 <sup>b</sup>  | 15.64 <sup>b</sup>      | 3.82 <sup>b</sup>   |
|                                      | D2       | 251.67 <sup>a</sup>            | 61.81 <sup>a</sup>  | 19.89 <sup>a</sup>      | 4.88 <sup>a</sup>   |
|                                      | D3       | 261.11 <sup>a</sup>            | 64.20 <sup>a</sup>  | 18.38 <sup>a</sup>      | 4.51 <sup>a</sup>   |
| Fertilizer (F)                       | F1       | 154.44 <sup>b</sup>            | 35.52 <sup>b</sup>  | 11.93 <sup>b</sup>      | 2.74 <sup>b</sup>   |
|                                      | F2       | 247.78 <sup>a</sup>            | 59.47 <sup>a</sup>  | 22.13 <sup>a</sup>      | 5.31 <sup>a</sup>   |
|                                      | F3       | 256.11 <sup>a</sup>            | 66.59 <sup>a</sup>  | 19.84 <sup>a</sup>      | 5.16 <sup>a</sup>   |
| Interaction ( $F \times D$ )         | F1D1     | 103.33 <sup>e</sup>            | 23.77 <sup>e</sup>  | 11.33 <sup>d</sup>      | 2.61 <sup>d</sup>   |
|                                      | F1D2     | 153.33 <sup>de</sup>           | 35.27 <sup>de</sup> | 11.93 <sup>d</sup>      | 2.74 <sup>d</sup>   |
|                                      | F1D3     | 206.67 <sup>cd</sup>           | 47.53 <sup>cd</sup> | 12.53 <sup>d</sup>      | 2.88 <sup>d</sup>   |
|                                      | F2D1     | 186.67 <sup>cd</sup>           | 44.80 <sup>cd</sup> | 20.07 <sup>cd</sup>     | 4.82 <sup>bc</sup>  |
|                                      | F2D2     | 313.33 <sup>a</sup>            | 75.20 <sup>a</sup>  | 25.13 <sup>a</sup>      | 6.03 <sup>a</sup>   |
|                                      | F2D3     | 243.33 <sup>bc</sup>           | 58.40 <sup>bc</sup> | 21.20 <sup>ab</sup>     | 5.09 <sup>abc</sup> |
|                                      | F3D1     | 146.67 <sup>de</sup>           | 38.13 <sup>de</sup> | 15.53 <sup>cd</sup>     | 4.04 <sup>c</sup>   |
|                                      | F3D2     | 288.33 <sup>ab</sup>           | 74.97 <sup>ab</sup> | 22.60 <sup>ab</sup>     | 5.88 <sup>ab</sup>  |
|                                      | F3D3     | 333.33 <sup>a</sup>            | 86.67 <sup>a</sup>  | 21.40 <sup>ab</sup>     | 5.56 <sup>ab</sup>  |
| LSD <sub>0.05</sub> ( $F \times D$ ) |          | 76.21                          | 18.76               | 4.59                    | 1.09                |

Note: In the same column, numbers with at least one identical letter are not significantly different at the  $p < 0.05$ .

The interaction of fertilizer and density (F×D) affected the fresh and dried individual yield of *Solanum procumbens* Lour. Fresh individual yield fluctuated greatly, from 103.33 to 333.33 g per plant. F1D1 formula had the lowest yield. The highest formulas were F3D3 (333.33 g per plant) and F2D2 (313.33 g per plant). Dried individual yield ranged from 23.77 to 86.67 g per plant, of which the lowest yield was formula F1D1 (23.77 g per plant), the highest yield was formula F3D3 (86.67 g per plant). Net dried yield were also different and statistically significant ( $p < 0.05$ ), fluctuating from 11.33 to 25.13 fresh tons per hectare and from 2.61 to 6.03 dried tons per hectare. Among them, formulas F1D1, F1D2 and F1D3 had the lowest, formulas F2D2, F3D3 and F3D2 were the highest in net fresh and dry yields. Thus, increasing amount of fertilizer comprised with decreasing density increased individual and net yield of *Solanum procumbens* Lour. The reasons were due to the effectiveness of applied fertilizer of 20-15-5+TE along with appropriate planting density which helps *Solanum procumbens* Lour. grow better and produce higher yields. The results of this study showed higher yield than studies by Thien *et al.* (2019) and Thanh *et al.* (2018).

## CONCLUSION

Planting density and fertilizer dosage have strong effects on the growth of main stem height, number of leaves on main stem, root diameter, number and length of first-level branches of *Solanum procumbens*; as a result, yield is affected accordingly. When density decreased, tree height and primary branch length decreased, but number of leaves, root diameter, number of primary branches and yield increased and vice versa. Applying inorganic fertilizer (NPK 20-15-5+TE) helps plants grow better, have higher height, increase the number of leaves and first-level branches; as a result, plants give higher yield than the formula without applying inorganic fertilizer.

*Solanum procumbens* grows and yields optimally when planted at a density of 50,000 plants/ha, inorganic fertilized with 1.0 ton of NPK 20-15-5+TE+5 tons of manure +1.5 tons of biofertilizer + 500 kg of lime powder. With such density and fertilizer dosage, after 5 months of planting, *Solanum procumbens* achieved a fresh yield of 25.13 tons/ha (equivalent to 6.03 dry tons/ha) in Central Vietnam.

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## Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any

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## Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

## Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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