GROWTH, AND YIELD CHARACTERISTICS AS WELL AS PESTS AND DISEASES SUSCEPTIBILITY OF CHILI PEPPER (*Capsicum annuum* L.) UNDER DIFFERENT PLANT DENSITIES AND PRUNING LEVELS

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Abstract. The field experiments were conducted at Indonesian Vegetable Research Institute (IVEGRI) West Java, Indonesia during the period of July 2018 to February 2019. The objective of the study was to determine the effect of three plant densities (20,000, 30,000 and 40,000 plants ha^{-1}) and four stem pruning levels (control, 3 stems, 4 stems, and shoot pruning) on growth and yield parameters as well as pest and diseases incidences for chili pepper. Split plot experiment was performed using a randomized block design with three replications. The recommended cultural practices were done for better crop growth and good yields. Results showed no interactions between plant density and pruning for any of the variables measured. Chili pepper growth, yield, and quality and incidence of pest and diseases can be effectively manipulated by plant density and pruning. Increasing of plant population from 20,000 to 30,000 plants ha^{-1} resulted in the increased of total fruit yield to 52.58%, however, total fruit yield declined up to 34.09% at 40,000 plant/ha. Pruning significantly affected fruit yield from 4.65 to 20.33%. Shoot pruning produced higher number of branches, and resulted in maximum yield per ha^{-1} due to higher number of shoots contributing to the production of more number of fruits. Growing chili pepper at a density of 30,000 plant ha^{-1} was better than the conventional methods, and it combination with shoot pruning in nurseries could be used as an alternative method to increase the production of chili pepper.
Keywords: *plant population, branches, susceptibility, fruit quality, production*

Introduction

Chili pepper (*Capsicum annuum* L.) is one of important spices and vegetable crops in the world. FAOSTAT (2020) reported that world production of chili pepper was 42.282 million tons in both dry and green fruits from 3.718 million hectares of land. Indonesia is currently ranked fourth in chili production after China, Mexico and Turkey and account for about 5 percent of global annual chili production (Kementan, 2020). An average production, however, is low (8.46 t ha^{-1}) compared to its potential yields of 12 to 20 t ha^{-1}. It attributed to a combination of various bottlenecks in production constraints such as climate change, poor cultivation practices, high production costs for

seeds, fertilizers, and pesticides, as well as high pests and diseases attacks (Setiawati et al., 2021).

Successful of crop production could be affected by various factors including transplanting age, fertilization, pest and diseases management, pruning and plant density. Plant density and plant arrangement influenced plant development, plant dry weight, stem diameter, plant width, growth and marketable yield of chili pepper. Planting density, which can be maintained by adjusting row spacing and plant spacing, is a strong determinant of yield in various crops, including chili pepper.

Yield of sweet pepper was depended on the number of plants accommodated per unit area of land (Maboko and Plooy, 2008; El Naim and Jabereldar, 2010; Islam et al., 2011). Plant density of chili pepper for double population increased production up to 67%, and plant density of 40,000 plants ha^{-1} increased productivity by 123% compared to the conventional technology (9,570 plants ha^{-1}) (Adams et al., 2001; O'Keefe and Palada, 2002). The chili variety used did not affect the productivity. A number of studies have indicated a linear increase in fruit yield when plant density is increased (Jovicich et al., 2003, 2004; Mavengahama et al., 2009) and then declined as plant population increased up to a point (Akintoye, 2009; Mavengahama et al., 2009).

Chili pepper plants have a branching habit, therefore, fruit development is controlled by restricting the branching pattern to 1, 2, 3 and 4 main branches (Alsadon et al., 2013). The reasons for pruning sweet pepper are to train plant growth to facilitate light penetration throughout the leaf canopy for more efficient interception of light (Jovicich et al., 2004). Pinching of marigold plants resulted in an increased number of branches per plant (Chauhan et al., 2005). Pruning to two or three stems was reported to be effective in increasing yield and reducing fruit size of cherry tomatoes to a more acceptable marketable size (Dasgan and Abak, 2003). Chili pepper plants are commonly infested by numerous insect pests that attack at its various growth stages. Plant density and pruning had a significant effect on the presence of pests. Plant density and pruning are very important for the optimization of plant spacing per unit area (El Naim et al., 2010). Many factors influence the optimum plant population for a crop such as availability of water, nutrients and sunlight, length of growing season, potential plant size, and the plant's capacity to change its form in response to varying environmental conditions (morphological plasticity). By determining optimum plant population under suitable environment, it is possible to get optimum yield.

Majority of the chili growers in Indonesia have little knowledge about the advantage of pruning in chili production. Usually the farmers of Indonesia cultivate chili without pruning and even they do not maintain proper plant density and plant population. Populations vary from 15 000 to 20 000 plants ha^{-1}. The objective of this study was to evaluate the effect of different plant density and pruning systems on the growth and yield characteristics as well as the pest and diseases susceptibility for chili pepper in open field condition.

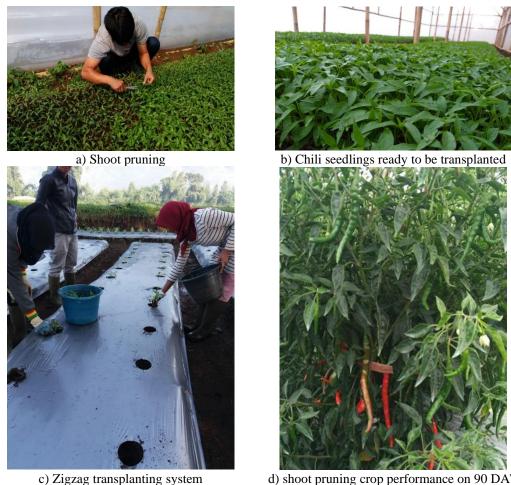## Methodology

Place and time of study

The study was conducted in the research field station of the Indonesian Vegetables Research Institutes (IVEGRI), Lembang, Bandung, West Java Province, Indonesia from July 2018 to February 2019. This site is 1,250 m above sea level and located at 60° 30' S and – 107° 30' E. Soil type in this location is mainly Andisol with the average pH of 5.0

– 6.0. This area experiences average temperature of 19-24ºC, humidity ranges from 34-90% and average rainfall of 2,207 mm/year.

Research design

A complete randomized block with split-plot arrangement and three replications was established up to achieve the goal. The main plot was population density (a) consisting of (a1) 20,000 plants ha^{-1} (one plant per hole), (a2) 30,000 plants ha^{-1} (one and two plants per hole), and (a3) 40,000 plants ha^{-1} (two plants per hole). The pruning system was applied as subplot, and there were four subplots set up in the field i.e. (b1) control or upruned plants, (b2) three branches remaining after pruning, (b3) four branches remaining after pruning, and (b4) shoot pruning or pinching.

The chili pepper variety of Kencana was used in the experiment. Seedlings were raised in the protected nursery to minimize pests and diseases attacks. Seedling pruning for shoot pruning treatment were conducted in the nursery. Three weeks old seedlings were pruned using sterile scissor right under the first leaf shoots. Two weeks after pruning, seedlings were transplanted in to the field as per experiment layout (*Figure 1*). As for other treatments i.e., b2, and b3, five weeks old seedlings were transplanted in to the field and pruned at the base of main stem on the 30 days after transplanting (DAT) to follow the treatments.

a) Shoot pruning

b) Chili seedlings ready to be transplanted

c) Zigzag transplanting system

d) shoot pruning crop performance on 90 DAT

Figure 1. Shoot pruning treatment

An area of 88 m x 136 m was divided into three equal blocks. There were 36 plots altogether in the experiment. The size of each plot was 13 m x 14 m (700 plants per plot) and the plots were arranged in spacing 50 cm x 70 cm in a zigzag system to avoid competition in light, distribution of roots and nutrients contents The distance within blocks and plots were 1 m and 0.5 m, respectively. Organic materials consisting of mature compost were applied as a basal fertilizer along with NPK composite fertilizers. The dose of organic materials and NPK was 30 t ha^{-1} and 1 t ha^{-1}, respectively. The chemical characteristics of Andisol soil and mature compost are presented on *Tables 1 and 2*, respectively.

Tabel 1. Chemical characteristics of Andisol soil

Chemical characteristics*	Analysis values	Criteria
pH (H$_2$O)	5.80	Acid
pH (KCl)	4.70	Acid
C-rganik (%)	5.80	Very high
N-total (%)	0.72	High
C/N	9.0	Low
P$_2$O$_5$ – Bray 1 (ppm)	3.50	Very low
K – Morgan (ppm)	135.50	Medium
Ca (cmol(+)/kg)	2.80	Low
Mg (cmol(+)/kg)	0.27	Very low

*IVEGRI's Integrated Testing Laboratory (2018)

Table 2. Chemical characteristics of mature compost

Chemical characteristics	Mature compost (made of enrichment stable manure + plant residues compost)
pH (H$_2$O)	7.67
pH (KCl)	7.31
Kadar air (%)	48.46
C-organik (%)	10.71
N-total (%)	0.57
C/N	19.0
P$_2$O$_5$ (%)	0.58
K$_2$O (%)	0.45
CaO (%)	0.71
MgO (%)	0.26
Fe (ppm)	8878.0
Mn (ppm)	423.0
Cu (ppm)	32.0
Zn (ppm)	55.0
Pb (ppm)	20.09

*IVEGRI's Integrated Testing Laboratory (2018)

The beds were covered with silvery plastic mulch. The land was cleared manually started with plugging and making beds.

Data analysis

Growth of plant and percentage of plant damage due to pests and diseases attack were recorded. Ten sample plants from each plot were randomly selected in each

observation day. Assessments were conducted throughout the growing season in weekly interval started from 30 Days After Planting (DAP).

Plant damage due to thrips was measured using to follow Equation 1 formula as follow:

$$I = \frac{\sum (n \times v)}{N \times z} \times 100\% \qquad \text{(Eq.1)}$$

Notes:
I, damage levels (%)
v, the value of damage category
n, number of plants that have same v value
Z, the value of highest damage category
N, number of observed plants

Category of plant damage value (v) is determined based on the percentage of leaf area damage i.e.:
  0, if there is no damage leaf area
  1, if there is $> 0 - \leq 20\%$ leaf area damage
  3, if there is $> 20 - \leq 40\%$ leaf area damage
  5, if there is $> 40 - \leq 60\%$ leaf area damage
  7, if there is $> 60 - \leq 80\%$ leaf area damage
  9, if there is $> 80 - \leq 100\%$ leaf area damage.

The incidence of anthracnose was observed from total harvested fruit. The intensity of anthracnose attack on chili fruit was measured using *Equation 2* as follow:

$$Disease\ incidence = \frac{\sum infected\ fruits}{\sum observed\ fruits} \times 100\% \qquad \text{(Eq.2)}$$

Yield assessment: Data collected were fruit length (cm), fruit diameter (cm), individual fruit weight (g). Chili pepper fruit per plot were weighed for each treatment to observe the total yield. Data are presented as expected weight t ha^{-1}. The percent increase in yield over control in various treatments was calculated to follow *Equation 3*.

$$\%\ of\ increasing\ yield = \frac{yield\ in\ treatment - yield\ in\ control}{yield\ in\ control} \times 100\% \qquad \text{(Eq.3)}$$

Statistical analysis

The data were subjected to two ways ANOVA (SAS Program). Significantly different means (P < 0.05) were separated using Duncan Multiple Range Test (DMRT) at 5% probability. Count data were transformed by square root of (x + 0.5), and transformation of percentage data by arcsine-square root.

Results and Discussion

There was no significant interaction between plant density and pruning for all parameter observed (p ≥0.05), showing that these factors took action independently on variables of plant height, number of flowers per plant, fruit length, fruit diameter, number of fruits per plant, individual fruit weight, pest and diseases, and chili yield.

Vegetative growth parameters

Plant density and pruning system gave significant effects on chili plant height (p ≤0.05). The plant height ranged between 63.03 and 71.41 cm. Plant height increased linearly in response to increased plant densities at all observations (*Table 3*). This was due to intra-specific competition for the sunlight (El Naim, 2010; Edgar et al., 2017). Plant height showed significant variation at different days after transplanting (DAT) due to pruning. At 93 DAT the maximum plant height (69.34 cm) was obtained from (b3) which was statistically similar to b0 and b1, while the minimum (65.30 cm) was recorded from (b4). This was probably caused to the fact that competition between plants for available water, nutrients and light was less in one branch system than in 3 or 4 branches systems. Shoots pruning/pinching (b4) significantly reduced the plant height in comparison with the other treatments. Decreased plant height and increased number of branches could reduce vertical plant growth, resulting in translocation of photosynthates to leaf axils, hence increased number of axillary (Kumar et al., 2014; Singh et al., 2015; Setiawati et al., 2021).

Table 3. *The average of plant height on chili pepper at different treatments*

Treatments	(Plant height at plant ages) ………. (DAP)									
	30	37	44	51	58	65	72	79	86	93
Population density										
a1.20,000 plants ha^{-1}	10.02[b]	12.96b	16.43b	19.81c	26.71c	34.18c	43.03c	51.64c	57.46c	63.03b
a2.30,000 plants ha^{-1}	11.18[a]	13.98b	17.92ab	22.76b	29.48b	38.12b	47.90b	57.11b	62.45b	69.25a
a3.4,000 plants ha^{-1}	12.20[a]	15.69a	19.31a	25.15a	34.82a	43.87a	53.82c	60.58a	65.82a	71.41a
LSD 5%	1.05	1.46	1.95	1.84	2.63	2.96	3.16	2.34	2.36	2.53
Pruning system										
b1. Control (upruned plants)	11.63a	14.73a	18.00a	23.19a	31.73a	39.70a	49.22a	56.92a	61.71ab	69.29a
b2. Three branches remaining	11.87a	14.51a	18.71a	23.39a	30.82a	39.56a	49.16a	57.04a	62.42ab	67.90ab
b3. Four branches remaining	11.09a	16.57a	20.5a	25.38a	33.11a	41.81a	50.96a	58.09a	63.90a	69.34a
b4. Shoot pruning	9.21b	12.47b	15.41b	19.80b	27.08b	35.33b	45.37b	54.20b	60.16b	65.30b
LSD 5%	1.21	1.69	2.26	2.13	3.04	3.42	3.65	2.70	2.73	2.92

Means followed by the same letter in the column are not significantly different according to Duncan's Multiple Range Test at α = 0.05

Pests and diseases incidence on chili pepper

The lowest plant damage occurred in plant density of 20,000 plants ha^{-1}, followed by density of 30,000 and 40,000 plants ha^{-1}. In the pruning treatment, the lowest plant damage occurred in shoot pruning (b4), followed by b1, b2 and highest was presented in b3. There was no significant effect of plant density on the plant damage in most of observation days. However, on the 44 until 93 DAP plant damage due to thrips attack in the 40,000 plants ha^{-1} plot were significantly higher compared to other treatments (*Table 4*). Other studies suggested that there might be an inverse relationship between the attack rates and the number of branches. Shivute (2005) reported that pruned tomatoes were less prone to pest attack than those, which were not pruned.

Tabel 4. Plant damage (%) due to thrips attack

Treatments	Plant damage (%) at DAP									
	30	37	44	51	58	65	72	79	86	93
Populations density										
a1. 20,000 plants ha^{-1}	0.00	1.48a	1.02ab	2.50a	6.02b	7.32b	6.39a	12.96a	5.83a	4.54a
a2. 30,000 plants ha^{-1}	0.00	1.57a	0.83b	3.24a	7.13ab	8.33b	6.39a	12.59a	4.72a	4.91a
a3. 40,000 plants ha^{-1}	0.00	0.93a	1.94a	2.50a	9.28a	11.39a	6.21a	13.24a	4.81a	4.81a
Pruning system										
b1.Control (upruned plants)	0.0	1.23a	0.99a	2.47a	6.67bc	9.88a	6.42a	12.84a	4.57b	4.69ab
b2. Three branches remaining	0.0	0.99a	1.11a	3.21a	8.15ab	8.64ab	6.05a	13.09a	4.94ab	4.20b
b3. Four branches remaining	0.0	3.21a	2.22a	3.33a	9.88a	11.48a	6.67a	13.83a	6.05a	5.43a
b4. Shoot pruning	0.0	0.86a	1.11a	1.97a	5.21c	6.05b	6.30a	12.22a	4.94ab	4.32b

Means followed by the same letter in the column are not significantly different according to Duncan's Multiple Range Test at α = 0.05

Plant density and pruning had a significant effect on incidence of anthracnose diseases. Plant density of 20,000 plants ha^{-1} and pruning (b1 and b4) had decreased the incidence of this diseases compared to the other treatments (*Table 5*). Pruning made the sunlight freely illuminates the parts of plants and the leaves more productive in carbohydrates production, this situation provides benefits to the plant because it could reduce the infestation level of pests and diseases (Setiawati et al., 2021).

Table 5. Effects of populations density and pruning on total yields incidence of Anthracnose diseases on fruit of chili pepper

Treatments	Total fruit yield (t ha^{-1})	% Increasing yield	% Incidence of Anthracnose diseases on fruit
Populations density			
a1. 20,000 plants ha^{-1}	12.38 [c]	-	37.17 [b]
a2. 30,000 plants ha^{-1}	18.89 [a]	52.58	37.29 [b]
a3. 40,000 plants ha^{-1}	16.60 [b]	34.09	38.82 a
Pruning system			
b1.Control (upruned plant)	15.05 [b]	-	37.97 [a]
b2. Three branches remaining	16.01 [b]	6.38	35.77 [c]
b3. Four branches remaining	15.75 [b]	4.65	37.97 [a]
b4. Shoot pruning	18.11 [a]	20.33	35.90 [b]

Means followed by the same letter in the column are not significantly different according to Duncan's Multiple Range Test at α = 0.05

Physical fruit characteristics

Number of fruits plant[-1] and number flower plant[-1] increased significantly with the increase of plant density. Different plant densities showed significant variation on number of fruits plant[-1] and number flower plant[-1]. The highest number of fruits plant[-1]

and number flower plant^{-1} was found from a2 which was followed by a3 and the lowest number was found for a1. This is a direct effect of plant competition. Green pepper fruit number and weight per hectare increased as plant population as well (Buler and Mika, 2009).

Different levels of pruning showed significant variation on fruits plant^{-1} and number flower plant^{-1}. The highest number of fruits plant^{-1} and number flower plant^{-1} (445.45) was observed for b4 which was followed by b2 (406.24), b3 (405.04) and the lowest number (381.02) was found for b1 (no stem pruning) (*Table 6*). Number of fruits per plant affected by pruning (Thakur et al., 2005). Fruit size parameters such as weight, length and diameter fruit of chili were affected by pruning as well. An influence on a number of tree physiological processes connected with the growth, yield and quality of fruits (Buler and Mika, 2009). Pruning decreased total yield, yield plant^{-1}, plant weight and number of fruits plant^{-1}, but it increased fruit weight. Branch numbers plant^{-1} ranged from 11.27 to 14.37, by which significant differences in branch numbers plant^{-1} occurred between the plant density of 20,000 plants ha^{-1} and two others (30,000 and 40,000 plants ha^{-1}). Generally, an increase in plant densities led to significantly lower branching. Low density resulted in an increased number of branches plant^{-1}. This was consistent with the findings of Islam et al. (2011) who reported that there is a relationship between the number of branches and plant population density. The denser the plant population, the less the number of branches produced and will delay the flowering time of plants (Karuppaiah and Krishna, 2005; Mane et al., 2006). Generally, increasing the plant population increased competition among plants for soil moisture, nutrient, light and carbon dioxide (El Naim and Jabereldar, 2010).

Table 6. Yield components of chili pepper

Treatments	Branch number / Plant	Flower number / Plant	Fruit number / Plant	Fruit length (cm)	Fruit weight (g)	Fruit diameter (cm)
Populations density						
a1. 20,000 plants ha^{-1}	14.37[a]	151.43[b]	216.02[b]	13.10 [a]	5.04 [a]	0.85 [a]
a2. 30,000 plants ha^{-1}	11.42[b]	166.75[ab]	278.63[a]	13.42 [a]	4.97 [a]	0.83 [a]
a3. 40,00 plants ha^{-1}	11.27[b]	180.37[a]	235.12[b]	13.32 [a]	5.10 [a]	0.83 [a]
Pruning system						
b1. Control (upruned plants)	12.31[a]	150.31[b]	230.71[b]	12.85 [b]	4.86 [b]	0.80 [b]
b2. Three branches remaining	12.62[a]	163.53[ab]	242.71[ab]	13.51 [a]	5.16 [a]	0.85 [a]
b3. Four branches remaining	12.13[a]	171.51[a]	233.53[b]	13.48 [a]	5.03 [ab]	0.84 [a]
b4. Shoot pruning	12.33[a]	179.38[a]	266.07[a]	13.29 [a]	5.10 [ab]	0.82 [a]

Means followed by the same letter in the column are not significantly different according to Duncan's Multiple Range Test at $\alpha = 0.05$

Yield characteristics

Yield increase as plant density increased (*Table 5*). The highest total yield obtained was 18.89 t ha^{-1} from the second highest plant density (30,000 plants ha^{-1}) and 18.11

t ha^{-1} from shoots pruning in nursery while the lowest yield per hectare (12.38 t ha^{-1}) was recorder at density 20,000 plants ha^{-1}. Increasing plant densities resulted in a greater yield of hot chili pepper and bell pepper (Jovicich et al., 2004), and "Spanish" pepper, Jalapeno chili peppers and other plants (Russo, 2003; Jovicich et al., 2003; Khasmakhi-Sabet et al., 2009; Mavengahama et al., 2009).

This was probably due to the increasing in the number of plants per unit area, which might contribute to the production of extra yield per unit area leading to the high yield. However, as plant population was increased to 40,000 plants ha^{-1}, total fruit yield was decreased up to 34.09%. The production per plant doubled when one and two plants per hole left (30,000 plant ha^{-1}) compared with two plants per hole (40,000 plant ha^{-1}). This shows that the yield per plant lost when was two plants were left per hole was offset by another plant in the same hole.

Yield per unit area tends to increase as plant density increase up to a point and then declines (Akintoye et al., 2009), however, Aminifard et al. (2010) reported that yield per unit area tends to increase as plant density increase. This may be due to better availability of nutrients and better translocation of photosynthesis, such as competition for various environmental resources, availability of water, nutrients and sunlight (Mavengahama, 2009). Plant population increased from 20,000 up to 30,000 plants/ha, total fruit yield was also increased to 52.58%, however, yield declined up to 34.09% at 40,000 plant/ha. Pruning significantly affected fruit yield from 4.65 to 20.33%. Shoot pruning produced more number of branches resulted in maximum yield per ha due to more number of shoots contributed in producing more number of fruits. Planting chili pepper at plant density of 30,000 plant/ ha was an optimum plant density which was better than the two others (20,000 and 40,000 plants ha^{-1}). Plant density of 30,000 plant/ ha and together with shoot pruning in nurseries increased total fruit yield productivity of chili pepper.

Conclusions

Chili pepper growth, yield and quality, as well as the pest and diseases incidence can be effectively managed through plant density and pruning manipulation. The fruit yield can be increased up to 52.58% by adding plant population from 20,000 up to 30,000 plants/ha. However, adding plant population up to 40,000 plant ha^{-1} reduced 34.09% of yield. Pruning could significantly improve yield from 4.65 to 20.33%. Shoot pruning can add more branches on the plant and consequently more fruits can be produced to eventually resulting maximum yield ha^{-1}. The plant density of 30,000 plant ha^{-1} with zigzag transplanting system and shoot pruning/pinching in nursery application was considered as powerful method to boost higher productivity and quality. Therefore, this pruning technology practice could be recommended to chili farmers to obtain higher marketable yield in chili pepper. There is further research needed to determine the upper limit for plant population, particularly on the basis of economic viability.

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