PREPRINT

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Effect of Leaf Pruning and Additional Fertilizer on Growth and Young Pods Yield of Winged Beans

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ABSTRACT

Winged bean (*Psophocarpus tetragonolobus* L.) exhibits luxuriant foliage, making leaf pruning essential to enhance sunlight interception. Additionally, supplementing with additional fertilizer helps offset the impact of gradual harvesting. Therefore, this research aimed to determine the effect of leaf pruning and additional fertilizer on the growth and yield parameter of winged beans in the Institut Pertanian Bogor (IPB) experimental station at Leuwikopo, IPB University, Bogor, Indonesia. A randomized complete block design was used with two factors and three replications, namely leaf pruning intensities (0, 15, and 30% leaf pruning) and rates of additional fertilizer (0, 6.25, 12.5, and 18.5 g NPK 16-16-16/plant). The observed variables were plant height, leaf number, root length, leaf nutrient, auxin content, nutrient uptake, and young pods yield. The findings revealed that the interaction of pruning intensities and additional fertilizer rates significantly influenced leaf number and root length. Specifically, plants receiving a treatment combination without pruning and 6.25 g of additional fertilizer/plant exhibited the highest leaf number. In contrast, those subjected to 15% leaf pruning showed the greatest root length. Leaf nutrient levels, auxin content, and nutrient uptake exhibited noticeable improved with the addition of fertilizer. Meanwhile, a higher phosphorus and organic carbon content was observed in the 15% pruning treatment, and the young pods yield were not affected because the Fairuz variety reached its potential yield. Based on the results, the most recommended treatment is a combination without leaf pruning, supplemented with 6.25 g of additional fertilizer/plant.

Keywords: Leaf nutrient, legumes, root length, phosphorus, vegetables

ARTICLE INFO

Article history:
Received: 23 June 2023
Accepted: 08 September 2023
Published: 17 April 2024

DOI: https://doi.org/10.47836/pjtas.47.2.02

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ISSN: 1511-3701
e-ISSN: 2231-8542

INTRODUCTION

Psophocarpus tetragonolobus L., winged beans, are legume species frequently consumed as a vegetable (Calvindi et al., 2020; Eagleton, 2020). The young pod, leaves, and tuber of winged beans are suitable for vegetable consumption (Bassal et al., 2020). Furthermore, 100 g of the young pod contains 1.9–4.3 g of protein, 0.1–3.4 g of fat, and 0.9–3.1 g of fiber, with 300–900 IU of vitamin A and 205–381 mg of potassium (Mohanty et al., 2020). The winged beans boast 157.6 and 107.8 mg of gallic acid equivalent (GAE) total phenolic and flavonoid compounds, respectively (Calvindi et al., 2020). In Southeast Asia, the young pod is consumed as a main dish or appetizer by eating fresh, boiled, or steamed (Mohanty et al., 2020). Winged beans can also treat diseases like diabetes and asthma, and strengthen the immune system. The species can boost the immune system by having 140–167 µmol antioxidant capacity (TE)/100 g FW (Calvindi et al., 2020). The nutritional quality and production make winged beans a potential tropical commodity candidate to be developed (Bassal et al., 2020) through the improvement of the techniques related to production systems (Anjos et al., 2021).

The winged bean plant is made of vines (Calvindi et al., 2020) and has lush leaves (Eagleton, 2020). Plants with lush leaves have high leaf humidity, which accelerates the development of pest and disease growth. Several pests and diseases pose a threat to these plants, including *Mylabris pustulata*, the black bean aphid (*Aphis craccivora*), necrotic mosaic virus, and the false rust disease caused by *Synchytrium psophocarpi*. Plants affected by leaf rust exhibit orange pustules on their leaves, pods, or stems. In the case of plants infected by *Synchytrium psophocarpi*, the size of the sporangia measures 20.69 µm, with a diameter of 2.02 µm and a length of flagella at 10.75 µm. The necrotic mosaic virus of winged beans infects approximately 9% of young plants and is responsible for causing yield losses ranging from 10 to 20% (Bassal et al., 2020).

Genetic and environmental conditions can affect a plant's growth and production (Asefa et al., 2021). Fairuz IPB variety is one of the winged beans developed by IPB University. The productivity of Fairuz IPB up to 23 weeks after transplanting (WAT) can reach 2.53 tons of dry seeds/ha (44.31 g of dry seeds/plant) and 5.06 tons of young pods/ha (88.63 g of young pods/plant). Fairuz IPB has a green-colored pod and starts at 65 days after transplanting (Laia, 2019). One limitation of this variety is its dense foliage, making it highly vulnerable to leaf rust attacks, ultimately reducing production (Susanti et al., 2022). In plants exhibiting abundant foliage, it becomes imperative to optimize sunlight absorption and humidity reduction by employing pruning techniques to trim the lush leaves (Samira et al., 2014). Pruning is needed to reduce humidity, risk of pests, disease attacks (Tsegaye & Struik, 2000), and transpiration (K.-T. Li et al., 2016), as well as strengthen growth and increase crop production (Maudu et al., 2010).

Leaf pruning can inhibit the generative phase (Susanto et al., 2013); additional fertilization may be needed to cope with this problem. One of the fundamental environmental conditions conducive to plant growth is the availability of complete nutrients, which can be supplied through fertilization (Nahed et al., 2010), primarily through inorganic fertilizers (Owolabi et al., 2016). There are two phases of fertilizer application in plants, namely basic and additional fertilizer. Basic fertilizers are given at the end of land preparation, while additional fertilizers are administered during plant growth. This additional fertilization is essential, specifically for plants with long growth phases, such as tomatoes (Maillard et al., 2015), tobacco (Iskandar et al., 2020), cauliflower (Sofian & Susila, 2018), and winged bean (Ishthifaiyyah et al., 2021).

A continuous supply of nutrients is crucial to sustain its growth, fruit quality, and productivity (Kueklang et al., 2021). The winged bean plant can be harvested more than seven times in six months (Ishthifaiyyah et al., 2021); sufficient nutrients are needed for its development and growth. Essential macronutrients for plant growth and development, such as nitrogen, phosphorus, and potassium, can be supplied by compound fertilizers (Prajapati & Modi, 2018). Applying these nutrients increases soil nutrient levels, fostering enhanced plant growth and productivity (Owolabi et al., 2016). Additionally, it can positively impact various aspects, such as sucrose content or carbon-nitrogen ratio (Kamhun et al., 2022), morphological and physiological traits of crops (Mahmoodi et al., 2020), and overall yield quality (Cano-Reinoso et al., 2022). Compound fertilizers are inorganic fertilizers that can increase plant growth and are more efficient than single fertilizers (Betty et al., 2021).

Leaf pruning serves the purpose of mitigating plant transpiration and curtailing the proliferation of pests and diseases. However, it impedes generative growth, necessitating the application of additional fertilization to expedite the generative phase. The basic fertilizer recommendations for winged bean plants are 50 kg urea/ha, 90 kg SP-36/ha, and 150 kg MOP/ha (Laia, 2019). Combining leaf pruning and additional fertilization will increase young-winged beans' growth and production. Therefore, this research was conducted to determine the effect of leaf pruning intensities and additional fertilizer rates on winged beans' growth and yield parameters.

MATERIALS AND METHODS

Field Condition and Materials

The experiment was carried out on Latosol soil at IPB Leuwikopo experimental station (latitude 6° 33' 45.2" S, longitude 106° 43' 11.7" E), IPB University, Bogor, West Java, Indonesia from June to December 2021. Fairuz IPB variety was used as plant material. Compound fertilizers (NPK 16-16-16, NPK Mutiara, Indonesia), dolomite, chicken manure, and bamboo stalks were used as nutrients, ameliorants, and plant support sources as used as the material of this study.

Climate Data

The recorded data for the given period indicates an average temperature between 25 and 26°C, with minimum and maximum values of 21 and 32°C, as shown in Table 1. Additionally, the average relative humidity fluctuated between 77 and 86%, and the sun intensity measurements show values varying between 383 and 553 Cal/cm^2.

Table 1
Climate data in Darmaga station in Bogor, Indonesia

Month	Temperature (°C)			Rainfall (mm)		Rainy days	8 hours of sunshine (%)		Relative humidity (%)	Light intensity (Cal/cm^2)
	Average	Max	Min	Average	Total		Average	Total		
June	25.8	31.7	22.0	12.4	311.1	18.0	47.6	1429.1	86.2	383.1
July	26.0	32.1	21.3	11.5	115.6	3.0	76.5	2371.8	79.7	459.9
August	25.9	32.0	21.7	13.3	399.5	16.0	74.0	2294.5	81.8	459.7
September	26.3	32.3	22.0	10.5	317.3	18.0	75.1	2254.0	81.0	520.9
October	26.4	32.6	22.1	18.2	566.5	18.0	71.0	2202.0	77.1	553.7
November	26.4	31.6	22.7	6.1	183.6	17.0	42.4	1359.0	83.7	381.8
December	26.1	31.5	22.2	9.0	279.1	20.0	45.3	1316.0	85.2	399.7

Experimental Design

The research was elaborated using a randomized complete block design (RCBD) with two factors and three replications. The first factor was leaf pruning intensities (0, 15, and 30%), while the second was rates of additional fertilizer (0, 6.25, 12.5, and 18.5 g NPK fertilizer (16-16-16) per plant applied five times (7, 9, 11, 13, and 15 WAT). This fertilizer was administered by pouring 250 ml of the solution of NPK fertilizer (16-16-16) plants at 7, 9, 11, 13, and 15 WAT, and leaf pruning was carried out in 11 WAT, as shown in Table 2.

Table 2
The treatment details employed in the experiment

Factor	Description
Factor 1 (Pruning)	1. 0% leaf pruning
	2. 15% leaf pruning (at 11 WAT)
	3. 30% leaf pruning (at 11 WAT)
Factor 2 (Additional fertilizer)	1. 0 g/plant
	2. 6.25 g/plant (from 7, 9, 11, 13, and 15 WAT)
	3. 12.5 g/plant (from 7, 9, 11, 13, and 15 WAT)
	4. 18.75 g/plant (from 7, 9, 11, 13, and 15 WAT)

WAT = Weeks after transplanting

Land Preparation, Planting, and Harvest

After land preparation, each plot size was 1 m x 5.7 m, and the land was applied with 2 t lime/ha and 10 t chicken manure/ha as an ameliorant three weeks before planting. All plots were added with 50 kg urea/ha (PT Pupuk Indonesia, Indonesia), 90 kg SP-36/ha (Petrokimia Gresik, Indonesia), and 150 kg KCl/ha (MerokeMOP®, Indonesia) (Laia, 2019) at 2 weeks before planting. The winged bean seeds were soaked in warm water overnight to ease seed germination. Furthermore, they were planted in a seedling tray for two weeks, then transplanted in an experimental plot with two plants/hole and (a 50 cm x 30 cm planting distance). The winged beans were harvested eight days after anthesis when Fairuz IPB was considered to achieve its optimal physicochemical characteristics for future consumption (Susanti et al., 2022). The harvesting time was carried out every week until 24 WAT.

Assessments and Measures

Measurement of Plant Growth Parameter. The plant growth parameter includes plant height (cm), leaf number, and root length (cm), measured at 5, 10, and 15 WAT. Each plant height sample was observed from the ground (root base) to the highest shoot. The leaf number was calculated from the number of open trifoliate leaves in one plant, while the root length was observed from the root base to the tip of the longest root in the sample plant taken. Because the leaf pruning was conducted at 11 WAT, the intensity's effect was statistically analyzed for the data of 15 WAT onwards. Meanwhile, the effect of rates of additional fertilizer was evaluated on the variables observed of plants since 5 WAT.

Measurement of Leaf Nutrient and Auxin Content in the Shoot. Fresh leaf samples were taken at 11 WAT, dried overnight in the air, and at 80°C for 48 hr. The dry samples were ground with a blender to pass a sieve with 40 mesh. The measurements on leaf tissue were organic carbon (spectrophotometry method), nitrogen (Kjeldahl method), phosphorus (spectrophotometry method), and potassium (atomic absorption spectrophotometry [AAS] method) (Bhandari, 2018). Auxin analysis on shoots was conducted by taking plant shoots after one week of pruning (12 WAT), drying them overnight in the air, and then dried with an oven at 80°C for 48 hr. The dry samples were ground to pass a sieve with 40 mesh, and CAMAG® thin layer chromatography (TLC) Visualizer 3 (Switzerland) was used to analyze auxin (Porfírio et al., 2016). The nutritional analysis of leaves and shoot auxin was conducted in the Indonesian Medicinal and Aromatic Crops Research Institute (IMACRI) laboratory.

Measurement of Yield Parameter. Young pods were harvested eight days after anthesis (Susanti et al., 2022), and the period was 13–24 WAT. Harvesting was done by cutting the ready-to-harvest pods and measuring the weight/plot of 5.7 m^2 weekly until the plants were 24 WAT.

Statistical Analysis

The data analysis was conducted using the analysis of variance (ANOVA) method, and statistically significant differences were determined by applying Duncan's multiple range test (DMRT) at a significance level of 5%. The statistical software utilized for this analysis was Statistical Analysis System (SAS, version 9.4), and principal component analysis (PCA) was performed using the *R* software.

RESULTS AND DISCUSSION

Plant Growth

In this research, there was an interaction between leaf pruning intensities and additional fertilizer rates on plant growth variables such as leaf number and root length at 15 WAT (Tables 3 and 4). The results showed that the combination treatment without leaf pruning and 6.25 g additional fertilizer/plant was the highest leaf number but did not differ from the combination of 15% pruning and additional fertilizer (6.25 and 18.75 g), as well as 30% pruning and additional fertilizer (0, 6.25, 12.5, and 18.75 g). Furthermore, implementing a 30% leaf pruning approach led to an increase in leaf number, which increased by 20-44% compared to the control group.

Pruning aids the plant in eliminating deceased and unproductive branches, enhancing its vigor and overall growth (Dufour et al., 2019). Additionally, it fosters the development of new branches and vegetative growth (Shashi et al., 2022), leading to increased productivity compared to plants subjected to pruning (Valdes-Rodriguez et al., 2020). Pruning increases shoots and biomass in subsequent growth (Mediene et al., 2002), reduces transpiration (K.-T. Li et al., 2016), and increases the root-shot ratio (Carrillo et al., 2011). The application of additional fertilizer at a rate of 6.25 g/plant resulted in a significant increase in the number of leaves at 15 WAT (weeks after treatment) and root length at 10 WAT. Therefore, the rate of 6.25 g of fertilizer/plant effectively enhanced the leaf number.

The interaction between pruning intensities and additional fertilizer rates significantly influenced the root length at 15 WAT. The longest root length was observed in plants treated with a combination of 15% pruning and 6.25 g of additional fertilizer, and this result was not significantly different from the combination of 30% and 0 g. On the other hand, the shortest root length was recorded in plants subjected to a combination of 15% pruning and 18.75 g of additional fertilizer. The result showed that higher additional fertilizer rates treatment could decrease a root length (Table 4). In conditions of low soil nutrition, roots take longer to acquire the necessary nutrients from the soil. Roots are crucial in plant growth and absorb nutrients and water for metabolism. Roots need to spread widely in the field to enhance nutrient absorption, ensuring a well-distributed supply of nutrients to all plant parts. Therefore, a well-developed root system is vital for optimal plant health and growth (Nugroho et al., 2017).

Table 3
The effect of pruning and additional fertilizer on plant height and leaf numbers of winged bean plant

Treatment	Plant age (WAT)			Plant age (WAT)		
	5	10	15	5	10	15
	Plant height (cm)			Leaf numbers		
Pruning (P)						
0%	24.16 ± 1.37	169.58 ± 16.15	199.00 ± 8.44	10.0 ± 0.71	37.5 ± 3.18	50.3 ± 3.79
15%	26.33 ± 1.58	150.33 ± 12.98	202.75 ± 10.68	9.9 ± 0.93	35.0 ± 2.41	52.2 ± 3.19
30%	23.33 ± 1.01	180.58 ± 14.52	278.00 ± 8.01	9.5 ± 0.57	38.7 ± 4.14	58.2 ± 2.31
p-value	0.30	0.36	0.42	0.87	0.72	0.08
Additional fertilizer (F)						
0 g/plant	25.05 ± 1.62	180.89 ± 20.14	195.11 ± 13.50	10.2 ± 0.92	32.7 ± 427	49.6 ± 4.19
6.25 g/plant	25.27 ± 1.17	143.22 ± 14.70	201.78 ± 11.09	10.3 ± 1.12	33.3 ± 2.31	59.5 ± 2.85
12.5 g/plant	24.66 ± 1.98	155.00 ± 16.42	200.33 ± 8.50	9.4 ± 0.67	40.5 ± 4.93	51.6 ± 4.01
18.75 g/plant	23.44 ± 1.59	188.22 ± 13.83	309.11 ± 11.47	9.1 ± 0.47	41.7 ± 2.39	53.5 ± 3.46
p-value	0.85	0.23	0.40	0.70	0.23	0.11
P×F						
0%, 0 g	27.16 ± 3.98	108.00 ± 39.71	180.7 ± 12.19	9.00 ± 1.25	39.00 ± 11.71	43.00 ± 8.62 c
0%, 6.25 g	23.00 ± 2.46	127.33 ± 15.01	212.3 ± 25.46	11.50 ± 2.25	38.67 ± 4.66	67.00 ± 1.52 a
0%, 12.5 g	25.33 ± 2.60	154.00 ± 35.94	220.3 ± 10.91	10.33 ± 1.42	33.33 ± 6.35	43.00 ± 4.35 c
0%, 18.75 g	21.16 ± 1.58	189.00 ± 26.63	182.7 ± 5.78	9.33 ± 0.83	39.00± 3.51	48.33 ± 5.20 bc
15%, 0 g	24.33 ± 2.72	129.67 ± 26.99	216.0 ± 36.8	11.16 ± 2.45	32.33 ± 5.04	48.67 ± 6.76 bc
15%, 6.25 g	27.83 ± 1.48	162.67 ± 43.02	206.0 ± 24.17	8.83 ± 2.94	32.00 ± 4.04	50.67 ± 4.91 abc
15%, 12.5 g	27.33 ± 5.34	148.33 ± 26.02	195.7 ± 17.90	8.16 ± 1.20	38.67 ± 7.44	49.33 ± 7.42 bc
15%, 18.75 g	25.83 ± 3.65	160.67 ± 10.20	193.3 ± 9.20	9.83 ± 0.60	37.33 ± 3.75	60.33 ± 7.42 ab
30%, 0 g	23.66 ± 2.24	185.00 ± 24.33	188.7 ± 18.35	10.66 ± 1.16	27.00 ± 4.50	57.33 ± 6.22 abc
30%, 6.25 g	25.00 ± 1.52	139.67 ± 13.33	187.0 ± 8.32	10.83 ± 1.42	29.33 ± 3.75	61.00 ± 1.73 ab
30%, 12.5 g	21.33 ± 1.64	162.67 ± 34.89	185.00 ± 10	9.83 ± 0.88	39.66 ± 0.67	62.67 ± 4.25 ab
30%, 18.75 g	23.33 ± 3.03	215.00 ± 27.31	251.3 ± 32.23	8.33 ± 1.01	39.00 ± 3.05	52.00 ± 4.93 abc
p-value	0.69	0.23	0.26	0.66	0.34	0.04

Note. Means ± SE values with different letters indicate significant ($p < 0.05$) differences by Duncan's multiple range test; WAT = Weeks after transplanting

Table 4
The effect of pruning and additional fertilizer on root length of winged bean plant

Treatment	Plant age (WAT)		
	5	10	15
	Root length (cm)		
Pruning (P)			
0%	8.16 ± 0.38	15.91 ± 2.71	18.50 ± 1.54
15%	7.95 ± 0.46	19.16 ± 0.12	24.08 ± 3.20
30%	7.79 ± 0.62	16.83 ± 1.68	23.08 ± 2.78
p-value	0.88	0.45	0.21
Additional fertilizer (F)			
0 g/plant	7.55 ± 0.51	20.55 ± 2.65	23.88 ± 3.28
6.25 g/plant	8.88 ± 0.61	13.44 ± 1.72	24.66 ± 3.90
12.5 g/plant	7.33 ± 0.57	19.77 ± 2.24	20.33 ± 2.53
18.75 g/plant	8.11 ± 0.48	15.44 ± 1.59	18.66 ± 2.19
p-value	0.30	0.08	0.35
P×F			
0%, 0 g	6.67 ± 0.44	19.33 ± 7.53	18.67 ± 3.48 bc
0%, 6.25 g	9.00 ± 0.57	19.33 ± 2.84	18.00 ± 1.00 bc
0%, 12.5 g	8.16 ± 0.83	21.67 ± 6.33	18.00 ± 3.60 bc
0%, 18.75 g	8.83 ± 0.60	13.33 ± 3.17	21.33 ± 4.37 bc
15%, 0 g	8.66 ± 1.09	16.33 ± 2.40	22.33 ± 4.05 bc
15%, 6.25 g	9.00 ± 11.54	20.33 ± 0.33	37.67 ± 4.97 a
15%, 12.5 g	6.50 ± 0.28	22.00 ± 2.64	22.33 ± 6.17 bc
15%, 18.75 g	7.67 ± 0.44	18.00 ± 2.30	14.00 ± 1.00 c
30%, 0 g	7.33 ± 0.88	22.00 ± 4.50	30.67 ± 7.96 ab
30%, 6.25 g	8.67 ± 1.69	14.67 ± 3.75	20.33 ± 5.04 bc
30%, 12.5 g	7.33 ± 1.58	15.66 ± 0.66	20.67 ± 4.63 bc
30%, 18.75 g	7.83 ± 1.36	15.00 ± 3.05	20.67 ± 4.63 bc
p-value	0.72	0.77	0.05

Note. Means ± SE values with different letters indicate significant ($p < 0.05$) differences by Duncan's multiple range test; WAT = Weeks after transplanting

Nutrient Leaf and Auxin Value

The interaction of leaf pruning intensities and additional fertilizer rates had no significant effect on nutrient leaf, auxin value (Table 5), and nutrient uptake (Table 6). Leaf pruning affected leaf nutrients phosphorus and C organic concentration, as shown in Table 5. The leaf pruning intensity is directly related to the phosphorus content. A 30% leaf pruning treatment gave the highest phosphorus content (0.67 ppm), although it was not significantly different from 15% pruning (0.61 ppm), and the control treatment was 0.42 ppm of leaf P content. It was in line with previous research that pruning increased nutrient P in mango plants

Table 5
The effect of pruning and additional fertilizer on the leaf nutrient contents at 11 WAT and auxin concentration in the shoot of winged beans at 12 WAT

Treatment	Nitrogen (%)	Phosphorus (ppm)	Potassium (ppm)	C-organic (%)	C/N ratio	Auxin (%)
Pruning (P)						
0%	6.50 ± 0.15	0.42 ± 0.02 b	2.16 ± 0.17	29.43 ± 0.81 b	4.54 ± 0.81	0.023 ± 0.02
15%	6.14 ± 0.21	0.61 ± 0.01 a	1.63 ± 0.16	36.35 ± 1.00 a	6.01 ± 1.00	0.021 ± 0.02
30%	6.10 ± 0.24	0.67 ± 0.02 a	1.96 ± 0.11	31.66 ± 1.12 b	5.28 ± 1.12	0.022 ± 0.02
p-value	0.29	<0.001	0.06	<0.001	0.007	0.83
Additional fertilizer (F)						
0 g/plant	5.75 ± 0.20	0.52 ± 0.05	1.71 ± 0.13	33.71 ± 1.43	5.94 ± 0.31 a	0.017 ± 0.02 b
6.25 g/plant	6.30 ± 0.22	0.54 ± 0.04	1.86 ± 0.24	32.84 ± 1.69	5.30 ± 0.41 ab	0.018 ± 0.02 b
12.5 g/plant	6.31 ± 0.23	0.58 ± 0.05	2.18 ± 0.19	33.20 ± 1.19	5.27 ± 0.11 ab	0.025 ± 0.02 ab
18.75 g/plant	6.63 ± 0.23	0.62 ± 0.03	1.90 ± 0.14	30.17 ± 0.79	4.60 ± 0.23 b	0.027 ± 0.03 a
p-value	0.07	0.13	0.31	0.09	0.01	0.02
P×F						
0%, 0 g	5.97 ± 0.05	0.34 ± 0.01	1.61 ± 0.34	28.11 ± 0.65	4.70 ± 0.10	0.016 ± 0.003
0%, 6.25 g	6.81 ± 0.09	0.42 ± 0.00	2.37 ± 0.28	27.87 ± 2.08	4.08 ± 0.25	0.020 ± 0.006
0%, 12.5 g	6.40 ± 0.48	0.39 ± 0.01	2.46 ± 0.46	32.07 ± 1.08	5.04 ± 0.23	0.027 ± 0.005
0%, 18.75 g	6.84 ± 0.04	0.53 ± 0.09	2.19 ± 0.07	29.67 ± 1.79	4.33 ± 0.27	0.027 ± 0.006
15%, 0 g	5.74 ± 0.65	0.61 ± 0.05	1.48 ± 0.25	29.27 ± 0.55	7.05 ± 0.94	0.019 ± 0.004
15%, 6.25 g	6.19 ± 0.27	0.56 ± 0.03	1.21 ± 0.42	37.89 ± 1.38	6.16 ± 0.47	0.016 ± 0.001
15%, 12.5 g	6.64 ± 0.17	0.64 ± 0.02	2.07 ± 0.31	36.53 ± 1.28	5.50 ± 0.11	0.026 ± 0.002
15%, 18.75 g	5.98 ± 0.53	0.63 ± 0.01	1.75 ± 0.25	31.71 ± 1.42	5.35 ± 0.28	0.022 ± 0.005
30%, 0 g	5.54 ± 0.27	0.63 ± 0.07	2.03 ± 0.13	33.76 ± 3.51	6.07 ± 0.49	0.017 ± 0.001
30%, 6.25 g	5.91 ± 0.53	0.65 ± 0.08	2.01 ± 0.28	32.76 ± 1.78	5.68 ± 0.77	0.017 ± 0.002
30%, 12.5 g	5.89 ± 0.49	0.71 ± 0.02	2.01 ± 0.25	30.99 ± 2.39	5.27 ± 0.18	0.021 ± 0.003
30%, 18.75 g	7.07 ± 0.15	0.70 ± 0.00	1.78 ± 0.31	29.14 ± 0.72	4.12 ± 0.16	0.032 ± 0.009
p-value	0.36	0.59	0.46	0.14	0.26	0.72

Note. Means ± SE values with different letters indicate significant ($p < 0.05$) differences by Duncan's multiple range test; WAT = Weeks after transplanting

Table 6
The effect of pruning and additional fertilizer on nutrition uptake of winged beans

Treatment	Nitrogen (g/kg)	Phosphorus (mg/kg)	Potassium (mg/kg)	C-organic (g/kg)	C/N ratio
Pruning (P)					
0%	84.56 ± 12.59	5.41 ± 0.77	28.24 ± 5.28 a	390.03 ± 61.33	60.54 ± 9.76
15%	54.61 ± 6.98	5.48 ± 0.68	14.87 ± 2.47 b	328.51 ± 48.07	55.40 ± 9.67
30%	72.62 ± 11.15	8.03 ± 1.17	23.07 ± 3.38 ab	367.39 ± 51.55	59.89 ± 7.61
p-value	0.12	0.63	0.04	0.68	0.89
Additional fertilizer (F)					
0 g/plant	65.97 ± 13.55	5.70 ± 0.99 ab	18.36 ± 2.79 b	376.73 ± 60.92	67.21 ± 10.24
6.25 g/plant	49.77 ± 9.49	4.17 ± 0.73 b	15.14 ± 3.41 b	254.71 ± 50.45	40.38 ± 8.02
12.5 g/plant	90.83 ± 12.79	8.25 ± 1.11 a	33.18± 6.65 a	474.67 ± 61.68	75.09 ± 8.69
18.75 g/plant	75.82 ± 10.47	7.11 ± 1.08 ab	21.57 ± 2.88 ab	341.81 ± 40.23	51.76 ± 5.69
p-value	0.11	0.03	0.02	0.09	0.08
P×F					
0%, 0 g	89.25 ± 39.52	4.96 ± 1.99	21.41 ± 7.32	414.6 ± 176.47	69.78 ± 29.89
0%, 6.25 g	64.35 ± 20.52	3.96 ± 1.20	22.37 ± 7.90	272.7 ± 101.58	39.74 ± 14.46
0%, 12.5 g	106.63 ± 31.07	6.59 ± 1.80	44.36 ± 17.86	532.7 ± 143.47	82.97 ± 19.44
0%, 18.75 g	78.00 ± 7.79	6.14 ± 1.53	24.82 ± 1.70	340.2 ± 46.09	49.68±6.72
15%, 0 g	47.41 ± 15.38	5.14 ± 1.77	11.29 ± 2.89	342.4 ± 144.52	66.75 ± 34.73
15%, 6.25 g	47.42 ± 19.28	4.33 ± 1.76	10.03 ± 4.39	293.2 ± 130.83	47.88 ± 22.46
15%, 12.5 g	69.07 ± 17.38	6.61 ± 1.54	22.37 ± 7.72	381.3 ± 96.84	56.78 ± 13.43
15%, 18.75 g	54.56 ± 2.55	5.85 ± 0.56	15.80 ± 1.00	292.2 ± 24.45	50.21 ± 7.88
30%, 0 g	61.25 ± 15.98	6.99 ± 2.13	22.38 ± 5.87	318.2 ± 99.33	65.09 ± 14.22
30%, 6.25 g	37.54 ± 10.23	4.21 ± 1.38	13.01 ± 4.10	198.3 ± 24.97	33.53 ± 2.56
30%, 12.5 g	98.78 ± 17.84	1.56 ± 1.04	32.81 ± 5.56	510.0 ± 95.07	85.55 ± 9.75
30%, 18.75 g	94.89 ± 28.95	9.35 ± 2.78	24.09 ± 8.41	393.0 ± 118.99	55.39 ± 16.48
p-value	0.84	0.78	0.93	0.93	0.91

Note. Means ± SE values with different letters indicate significant ($p < 0.05$) differences by Duncan's multiple range test

(Singh et al., 2010). Phosphorus is mobile in the phloem and can be transported from source to sink, from old to young leaves, to grow and develop young leaves. Therefore, pruning can affect the plant's transport and distribution of mineral nutrients. The current study shows that leaf P concentrations increase significantly due to pruning. Y. Liu et al. (2022) state that leaf pruning in tea (young leaf pruning) prevents phosphorus distribution from older to younger leaves via phloem connections because the young leaf has been removed.

Meanwhile, in the current study, old (mature) leaves were pruned, and other plant organs covered the leaves, so the distribution of P leaf can be transported from old to young leaf. Furthermore, the treatment of 15% leaf pruning increased the C-organic by 23%. The leaf pruning treatment was conducted in the 11 WAT or flowering stage, so the nutrient in the leaf was increasing at peak nutrient status. As growth progressed, nutrients increased from the vegetative stage to the peak generative stage and gradually declined from pod production to the harvesting stage, with significant variation between each other (Hari Prasath et al., 2017). In this study, the leaf nutrients increased organic C and P because pruning was carried out when the plants were flowering (Yan et al., 2021).

The additional fertilizer treatment affected the C/N ratio and auxin levels (Table 5) and phosphorus and potassium uptake (Table 6). The result showed that the increased rate of additional fertilizer decreased the C/N ratio. It is similar to previous research, where fertilization reduces the C/N ratio in the flag leaves of lowland rice plants. It was possible because adding fertilizer increased leaf nutrient content such as N, P, and potassium and decreased the C/N ratio (Yin et al., 2020). The results indicated that the additional fertilizer significantly increased the plant growth regulators (auxin level). The fertilizer was rich in nutrients, specifically phosphorus and nitrogen. The elements entered the protein synthesis enzymes, nucleic acids, DNA, and RNA, which stimulated the formation of cytokines, as well as containing humic acid in the potassium hydroxide, preventing indole acetic acid (IAA) from breaking down IAA-oxidase (Toman et al., 2020). Table 5 shows that the additional fertilizer did not have a statistically significant effect on nitrogen, phosphorus, and potassium levels. It was possible because of the application of inorganic and organic fertilizers (chicken manure) before planting as basic fertilizers, which were enough for plant growth.

Increasing rates of additional fertilizer increase the phosphorus and potassium nutrition uptake significantly at 12.5 g fertilizer/plant. Therefore, the plants responded well to the additional fertilizer by uptaking the soil nutrients. Suitable climates supported the availability of soil nutrients during plant growth when there was enough rainfall and sunlight from August to October 2021, as shown in Table 1. Climate conditions affected ecosystems, specifically plants and soils (G. J. Kim et al., 2023). During vegetative growth, many nutrients are needed (Nahed et al., 2010; Owino & Sigunga, 2012; Prajapati & Modi, 2018). Macronutrients are also essential for plant growth when absorbed by the roots in the soil (Feng et al., 2020). Fertilizer application improved the soil nutrients, and the increased levels also enhanced plant growth (Owolabi et al., 2016) with a carbon-nitrogen ratio (Kamhun et al., 2022). Furthermore, plants conducted physiological processes properly with sufficient nutrient conditions (Yong et al., 2010). The additional fertilizer did not affect the nitrogen level (Table 5) and the uptake (Table 6) because legume plants formed a symbiosis with rhizobium to bind N_2 from the atmosphere, which served as a source of nutrition essential for plant growth and development (Zahran, 1999). Therefore, nitrogen absorption becomes less significant in legume plants, relying on the nitrogen-fixing ability of rhizobium to meet their requirements.

Yield

This research harvested winged beans until 24 WAT, equivalent to 13 harvests. The interaction between leaf pruning and additional fertilizer did not significantly affect the yield, as shown in Table 7. Even though the treatments did not show significant differences, a 30% leaf pruning resulted in a 9% higher yield than the control (Table 7). The application of higher-intensity leaf pruning is expected to provide advantages for the plant, particularly considering the dense canopy and abundant leaves of Fairuz IPB. The dense canopy can impede light distribution within the plant, and leaf pruning emerges as a suitable method to improve the distribution. The positive effects of pruning on fruit trees have been previously reported in the context of peach cultivation (Samira et al., 2014).

Additionally, pruning offers the benefit of reducing air humidity around the plant canopy, lowering the risk of plant disease incidence, such as leaf rust. Consequently, this can lead to an increase in bean production, and this finding aligns with Bassal et al. (2020), who also reported similar outcomes. Previous research elucidated that pruning serves the purpose of controlling the size and shape of the plant, promoting accelerated and robust growth, and enhancing the quality and quantity of production. The young leaves at the top can absorb the most solar radiation to have a high rate of carbon dioxide (CO_2) assimilation and translocate most assimilated to other plant parts. Furthermore, leaves positioned at the lowermost stratum and overshadowed by those above will exhibit a diminished rate of CO_2 assimilation due to reduced sunlight exposure. Consequently, they contribute insignificantly to assimilating other plant parts (Santanoo et al., 2020; T. Liu et al., 2011).

The pod yield was not significantly different among pruning intensities and additional fertilizer rates treatments, probably because the pod yield (10.83–13.99 young pods/plant) was above the potential yield (8.35–10.42 young pods/plant) according to the Indonesian Ministry of Agriculture (Kementerian Pertanian

Table 7
The effect of pruning and additional fertilizer on the total young pod yield of winged beans

Treatment	Yield per plant		Yield per plot (5.7m^2)		Yield per ha
	Number of pods	Weight of pod (g)	Number of pods	Weight of pod (kg)	Weight of pod (kg)
Pruning (P)					
0%	11.9 ± 0.85	139.33 ± 13.18	416.50 ± 29.83	4.87 ± 0.46	8555 ± 809.76
15%	12.9 ± 1.01	144.46 ± 10.52	453.25 ± 35.49	5.05 ± 0.36	8870 ± 464.00
30%	12.7 ± 0.75	148.85 ± 11.20	447.00 ± 26.58	5.20 ± 0.39	9140 ± 687.98
p-value	0.63	0.85	0.63	0.85	0.85
Additional fertilizer (F)					
0 g/plant	12.65 ± 0.80	144.83 ± 11.05	442.78 ± 28.25	5.06 ± 0.42	8893 ± 730.13
6.25 g/plant	11.98 ± 0.75	141.09 ± 13.42	419.33 ± 26.29	4.93 ± 0.46	8663 ± 824.15
12.5 g/plant	13.44 ± 1.36	150.27 ± 18.62	470.44 ± 47.77	5.25 ± 0.65	9227 ± 1143.71
18.75 g/plant	12.08 ± 0.76	140.66 ± 8.92	423.11 ± 26.74	4.92 ± 0.31	8637 ± 548.08
p-value	0.69	0.95	0.69	0.95	0.95
P×F					
0%, 0 g	10.83 ± 0.69	122.98 ± 13.64	379.33 ± 24.36	4.30 ± 0.47	7552 ± 837.53
0%, 6.25 g	11.72 ± 1.49	143.27 ± 28.06	410.33 ± 52.41	5.01 ± 0.98	8798 ± 1723.1
0%, 12.5 g	13.76 ± 3.56	161.30 ± 48.57	481.67 ± 12.46	5.64 ± 1.70	9904 ± 2982.6
0%, 18.75 g	11.27 ± 0.87	129.75 ± 8.04	394.67 ± 30.60	4.54 ± 0.28	7967 ± 493.73
15%, 0 g	13.12 ± 1.84	137.44 ± 22.21	459.33 ± 64.67	4.81 ± 0.77	8439 ± 1363.8
15%, 6.25 g	11.67 ± 1.77	130.77 ± 32.68	408.33 ± 62.14	4.57 ± 1.14	8030 ± 2006.7
15%, 12.5 g	13.58 ± 1.29	155.52 ± 17.86	475.33 ± 45.17	5.44 ± 0.62	9549 ± 1097
15%, 18.75 g	13.42 ± 2.00	154.11 ± 18.12	470.00 ± 70.16	5.39 ± 0.63	9463 ± 1113
30%, 0 g	13.99 ± 1.12	174.06 ± 19.26	489.67 ± 39.47	6.09 ± 0.67	10688 ± 1182.8
30%, 6.25 g	12.55 ± 1.08	149.22 ± 14.75	439.33 ± 38.11	5.22 ± 0.51	9162 ± 905.89
30%, 12.5 g	12.98 ± 2.80	133.99 ± 35.74	454.33 ± 98.09	4.69 ± 1.25	8228 ± 2194.8
30%, 18.75 g	11.56 ± 0.92	138.12 ± 20.24	404.67 ± 32.35	4.83 ± 0.70	8481 ± 1242.8
p-value	0.87	0.72	0.87	0.72	0.72

Note. Means ± SE values

Republik Indonesia [Kementan RI], 2020). The climatology environment of this study was similar to the previous research, where the winged beans grow well in environmental conditions with sufficient sunlight, nutrients, and water (Eagleton, 2020; Ishthifaiyyah et al., 2021). The growth of plants during the rainy season is facilitated by a sufficient water supply, thereby leading to higher yields compared to the sunny season (Feng et al., 2020; Prajapati & Modi, 2018).

There are several reasons why the additional fertilizer rates did not significantly affect the yield, as shown in Table 7. The experiment benefited from favorable climate conditions with exceptionally high sunlight intensity, elevated air humidity, and rainfall. These conditions facilitated robust plant growth, which is evident from the increasing leaf nutrient concentrations (Table 5) and uptake (Table 6). Despite these favorable factors, a substantial increase in the pod yield was not reported. Firstly, before planting, a soil analysis showed that the soil possessed relatively favorable properties such as pH 4.56, 1.86 ppm C-organic, 0.22% N, 61.7 ppm P, and 334.2 ppm potassium. Secondly, adding 10 t chicken manure/ha as a basic fertilizer for all experiments improved soil structure, added nutrients, and enhanced availability. Thirdly, inorganic fertilizer was also applied as a basic fertilizer.

The initial presumption that the winged bean plant, with its non-simultaneous flowering and susceptibility to pruning effects, would necessitate additional fertilizer has not been carried out. However, this level was insufficient for proper physiological plant processes, and the fertilizer treatment did not lead to an increased yield. It was similar to the previous study stating that an adequate fertilizer application rate enhanced nutrient levels, promoting plant growth and yield, as supported by previous research (Nahed et al., 2010; Prajapati & Modi, 2018). Adequate fertilizer rates are essential to ensure the proper execution of physiological processes in plants (Taiz & Zeiger, 2002). The fourth reason was that the plant in this study produced young pods similar to the yield potential stated in the description of the Fairuz variety, so the plant cannot increase its production beyond its potential yield.

Based on the PCA analysis of several observed variables, PC1 (28.9%) and PC2 (22.2%) can explain 50.1% of the total variance. Figure 1 shows that some observed variables can be divided into four quadrants. The first quadrant consists of nutrient uptake root length and yield (number and weight of pods). The second quadrant comprises plant height, auxin, N content, and leaf potassium. The third quadrant comprises the number of leaf variables, while the fourth comprises organic C and C/N leaves. Variables adjacent and exhibiting positive correlation share a common description, while those in opposing positions or showing negative correlation possess distinct explanations. The PCA can determine the correlation between the observed variables, which is substantial when the value is $r \geq 0.75$ (Limpawattana & Shewfelt, 2010).

The correlation matrix shows a significant positive correlation between

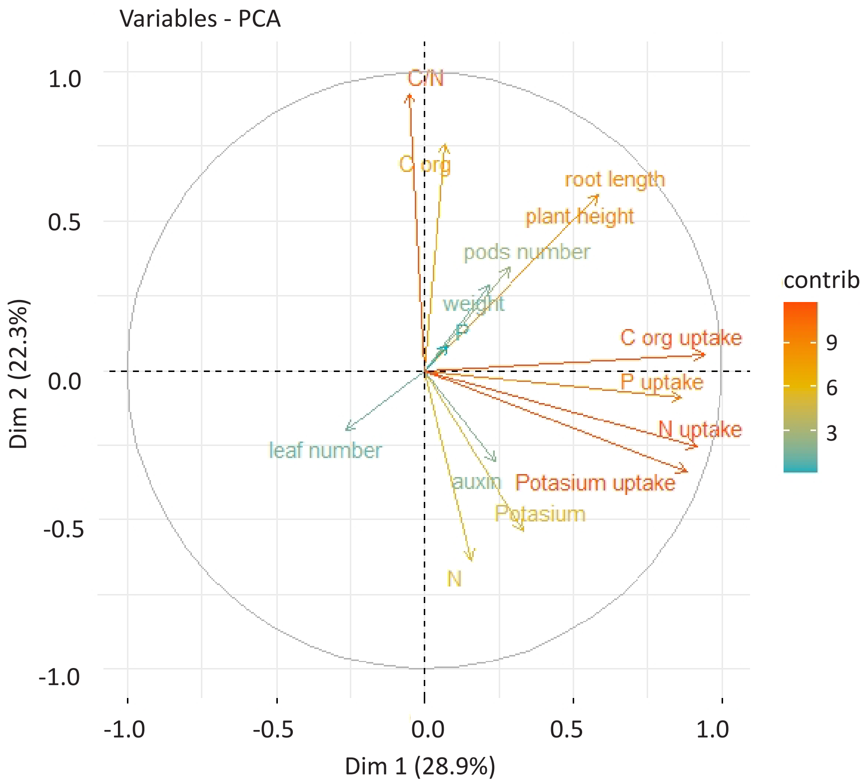

Figure 1. Principal component analysis of variables observed in winged bean

auxin and potassium values, phosphorus value and root length, and pod number and weight (yield). The analysis reported a positive correlation between potassium and auxin levels, indicating that the level increases with the auxin in the leaves. This observation aligns with prior research indicating that the expression of potassium transporter plays a role in regulating auxin levels (Tenorio-Berrío et al., 2018), and the potassium channel AKT1 is involved in auxin-related processes (J. Li et al., 2017).

A positive correlation was also shown by phosphorus nutrient leaf and root length. Previous research has shown that P deficiency enhanced root length in wheat (Shen et al., 2018). An increase in P concentrations can improve the biomass of both roots and flowers. This results in a higher root-to-shoot ratio, with P-deficient plants exhibiting the longest root length when grown in lower P concentrations. Root biomass has been found to correlate positively with the P level, affecting the number of storage roots in cassava (Omondi et al., 2019) and *Lantana* (H.-J. Kim; K.-T. Li, 2016). P deficiency has been shown to enhance root length, a phenomenon co-regulated by DNA replication, transcription, protein synthesis, degradation, and cell growth, as shown by Shen et al. (2018). This increase in root length enables the roots to reach nutrients more effectively, supporting overall plant growth (Qazizadah et al., 2023).

Furthermore, a positive correlation exists between the number of pods and their weight (yield), indicating that an increase in pods leads to a higher yield. This finding aligns with previous research by Bakal et al. (2020), where an increase in peanut pods directly corresponds to a higher peanut plant yield. Figure 1 shows the first quadrant, encompassing nutrient uptake, root length, and yield variables. Some variables exhibit significant relationships, particularly between adjacent lines, such as weight, number of pods, P content, and root length variables. There is a corresponding augmentation in the plant yield, encompassing the weight and number of pods when the P content and root length experience an increase. This observation underscores the significance of elongated plant roots in enhancing nutrient absorption from the soil, promoting optimal photosynthesis, and increasing pod yield and weight. Moreover, previous research reported a positive correlation between P value and favorable root conditions, encompassing root density and length (He et al., 2021).

CONCLUSION

Pruning and additional fertilizer treatment interaction significantly affected the winged bean's leaf number and root length. Without pruning and 6.25 g, additional fertilizer/plant treatment had increased leaf number. The P and C organic content increased with 15% leaf pruning intensity. The effects of additional fertilizer rates were found in auxin content, potassium, and phosphorus uptake, showing the increase of those variables with the additional fertilizer. Still, the additional fertilizer rates did not affect the yield. The young pods yield of this study reached the potential yield of the Fairuz variety.

ACKNOWLEDGEMENTS

The authors thank the Indonesian Ministry of Finance (The Indonesia Endowment Funds for Education [LPDP] Scholarship) with LPDP Scholarship ID Number: 201908211415339 for financial support and Prof. Dr. Ir. Soedarsono for improving this manuscript.

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