HAYATI
Journal of Biosciences

Vol. 31 No. 4, July 2024 750-767
DOI:10.4308/hjb.31.4.750-767
ISSN: 1978-3019
EISSN: 2086-4094

Slow-release Fertilizer Application on Silk (*Falcataria moluccana* Miq.) and Rice (*Oryza sativa* L.) Plant Growth and Yield in Agroforestry System

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ARTICLE INFO

Article history:
Received August 8, 2023
Received in revised form January 3, 2024
Accepted January 12, 2024

KEYWORDS:
Agroforestry,
chitosan,
germination,
NPK fertilizers,
nutrient release

ABSTRACT

The aim of this experiment is to evaluate the impact of chitosan-NPK slow-release fertilizer (CS-NPK SRF) on the germination and growth of silk tree and rice in different planting patterns, as well as to assess the nutrient release rate of the SRF. The germination test followed a complete randomized design, incorporating a single factor (fertilizer type), namely no fertilizer (F_0), SRF CS 0.5% weight 0.03 g (F_1), SRF CS 0.5% 0.01 g (F_2), SRF CS 0.7% 0.03 g (F_3), SRF CS 0.7% 0.01 g (F_4), and conventional NPK fertilizer (F_5). The growth test utilized a 2-factor split-plot design, with the primary factor being the planting pattern (sengon/rice monoculture-SM/RM and *sengon*-rice agroforestry-AF) and the second factor being the fertilizer type. Results indicate that F_2 and F_4 yielded the highest germination and growth values in both plants, although not significantly different from F_0. These findings suggest that CS-NPK SRF has the potential to enhance plant growth. The AF pattern exhibited lower growth compared to SM/RM, attributed to plant competition. CS-NPK SRF demonstrated a slower nutrient release (47.65% N; 85.01% P; 31.80% K) compared to conventional fertilizers. This slow release could potentially reduce nutrient loss to the environment while enhancing plant nutrient absorption.

1. Introduction

Falcataria moluccana, commonly known as the silk tree, is a swiftly developing pioneer tree that falls within the Fabaceae family (Baskorowati 2014). In Indonesia, this plant is known as *Sengon*. *Sengon* is extensively cultivated in plantation forests due to its rapid growth, strong adaptability to diverse soil types, and satisfactory wood quality suitable for the panel and woodworking industries (Julian *et al.* 2019). *Sengon* logs contributed 11.93% of Indonesia's roundwood production (Indonesia's Statistics 2019). *Sengon* wood production is centered on Java Island, with the dominant planting pattern used as monoculture (Syarifuddin *et al.* 2021). The efforts to optimize monoculture *sengon* land can be made by combining *sengon* with intercrops, such as upland rice (*Oryza sativa*), through an agroforestry system.

Upland rice (*Oryza sativa* L.) is cultivated in dryland (Malik 2017). Dryland for upland rice tends to be increasingly widespread throughout the islands of Indonesia while the area of paddy fields is getting smaller (Rejekiningrum *et al.* 2022). The use of superior varieties can enhance upland rice cultivation. An exceptional variety introduced in Indonesia is the IPB 9G variant. The IPB 9G rice demonstrates an average yield of 6.1 tons per hectare and exhibits robust adaptability to fertile soil, dryland conditions, and resistance to drought (Adi *et al.* 2019).

Agroforestry of *sengon* with rice in drylands has a limiting factor on soil fertility. Conventional chemical fertilizers are widely known to enhance plant growth significantly (Firmansyah *et al.* 2017; Budiman and Nurjaya 2021). However, excessive and continuous chemical fertilizers can reduce fertilizer efficiency and harm plants and the environment (Siska and Ismon 2019). A slow-

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release fertilizer (SRF) is a type of fertilizer designed to gradually release nutrients by incorporating them with semipermeable materials (Cole *et al.* 2016). SRF has a significant advantage, namely the efficiency of nutrient absorption through the slow release of nutrients more suited to plant needs, thereby increasing production yields (Liu *et al.* 2021; Ali and Danafar 2015). Chitosan (CS) emerges as a promising material for SRF. Ranking as the second most bioavailable natural fiber following cellulose, CS possesses non-toxic and biodegradable characteristics, ensuring its safe utilization (Sharif *et al.* 2018). Some research results related to CS-SRF in plants indicate slow-release properties, the ability to absorb water, maintain soil moisture, and increase crop production (Handayani 2014; Essawy *et al.* 2016; Nayan *et al.* 2018; Maharani *et al.* 2018; Istiani *et al.* 2020; Pimsen *et al.* 2021; Eddarai *et al.* 2022). CS-SRF experiments on *sengon* and rice planted with different planting patterns must be carried out to identify the highest plant growth. Hence, the objective of this investigation is to examine the impact of SRF on the germination and growth of *sengon* and rice under varied planting patterns. Additionally, the study includes an analysis of the nutrient release levels (N, P, and K) by the SRF and the quantity of nutrients absorbed by the plants.

2. Materials and Methods

2.1. Materials

The utilized materials included *sengon* seeds (from a local provider), IPB 9G upland rice seeds (Department of Agronomy and Horticulture, IPB University, Indonesia), *sengon* seedlings (Dramaga Permanent Nursery, BPDAS Citarum-Ciliwung, Indonesia), chitosan (Department of Fisheries and Marine Science, IPB University), methacrylic acid (MAA) (Himedia Lab., USA), potassium persulphate ($K_2S_2O_8$) (Himedia Lab., USA), urea, superphosphate, KCl, filter paper, distilled water, soil, sand, and compost.

2.2. Synthesis of CS-NPK SRF

The creation of CS-NPK SRF occurred through a two-step process: first, the formulation of chitosan/(poly(methacrylic acid)) (CS/PMAA), and second, the integration of NPK into CS/PMAA. The synthesis method for CS-NPK SRF adhered to the procedure outlined by Corradini *et al.* (2010) and de Moura *et al.* (2008). CS/PMAA was obtained by polymerizing MAA with CS. CS at concentrations of 0.5% and 0.7% (w/v) was dissolved in a 0.5% (v/v) MAA solution with continuous stirring for 12 hours. Following an initial hour of stirring at 70°C, 0.2 mmol of $K_2S_2O_8$ was introduced into the CS/PMAA solution, followed by cooling in an ice bath. Urea, superphosphate, and KCl fertilizers served as the NPK source. The dissolved fertilizer quantities were 0.36 g urea, 0.14 g superphosphate, and 0.09 g KCl. Incorporation of NPK into CS/PMAA involved diluting NPK in 100 m of CS/PMAA with stirring for 6 hours at 25°C. Subsequently, the CS-NPK SRF solution underwent oven drying at 70°C for 24 hours.

2.3. Germination Test

Germination tests were conducted in a 'seed germinator chamber' (a cabinet-shaped machine with controlled conditions, i.e., 24-hour illumination (fluorescent lamp) and aseptic conditions. *Sengon* and IPB 9G rice seeds were chosen by immersing them in water. Seeds that floated were eliminated, and those that sank were selected to enhance seed imbibition through a 24-hour water soaking process. Germination tests were done using Petri dishes covered with filter paper. Each Petri dish contained six seeds. The germination test was structured as a completely randomized design with one factor and four replications. The factor under consideration in this investigation comprises various fertilizer types, each with six levels: no fertilizer/control (F_0), SRF with a CS dosage of 0.5% and a weight of 0.03 g (F_1), SRF with a CS dosage of 0.5% and a weight of 0.01 g (F_2), SRF with a CS dosage of 0.7% and a weight of 0.03 g (F_3), SRF with a CS dosage of 0.7% and a weight of 0.01 g (F_4), and conventional NPK fertilizer (F_5). Fertilizers (F_1-F_5) were applied by placing them in the center of the seed batch. The application dose of F_5 was the same as the amount used in synthesizing SRF. The germination parameters observed included germination rate (GR) (SNI 2019), maximum growth potential (MGP) (Al-Ansari and Ksiksi 2016), mean germination time (MGT) (Ali *et al.* 2020), survival rate (SR) (Christophe *et al.* 2019) and sprout height (SH).

2.4. Growth Test

Growth experiments were carried out in the Greenhouse of the Department of Silviculture, IPB University, Indonesia. The growth test followed a split-plot design with two factors and four replications. The primary factor was the planting pattern, encompassing two patterns: *sengon* monoculture (SM)/rice monoculture (RM) and *sengon* and rice agroforestry (AF). The second factor, as a subplot, involved the type of fertilizer, with six levels (F_0-F_5), mirroring those used in the germination test. Growth tests used 14-day-old upland rice seedlings and 7-month-old *sengon* seedlings with a height of ±50 cm. *Sengon* and rice were planted in pots with an upper diameter of 22.5 cm, base diameter of 15.2 cm, and height of 15.2 cm. The pots employed featured deep and narrow dimensions, aimed at enhancing interactions between plants and between the soil and plants, mimicking conditions found in agroforestry on conventional land (López-Díaz *et al.* 2011). The planting media used a mix of sand, soil, and leaf compost in a ratio of 7:2:1 (Irawan *et al.* 2020). *Sengon* and rice were planted in SM, RM, and AF. One pot consisted of 1 *sengon* seedling and three rice seedlings with different planting holes at a spacing of 15 cm. Fertilizer was applied at planting time by sprinkling it around the plants. *Sengon* growth parameters observed included plant height and diameter (Ikhfan and Wijayanto 2019), number of leaves, plant survival rate, root length and diameter (Ikhfan and Wijayanto 2019) number of root nodules (Pommeresche and Hansen 2017), and plant wet and dry weight (Zulkifli *et al.* 2020). The observed rice growth parameters include height and plant survival rate (Christophe *et al.* 2019), number of tillers and productive tillers, root length, weight of filled grain, hollow grain, and 1,000 grains (Kumoro *et al.* 2019), plant wet and dry weight, and rice production (Firdaus *et al.* 2018). Other parameters, such as meteorological data, were also collected during the growth test in the greenhouse.

2.5. Soil Fertility Analysis

Soil fertility analysis was done twice (before and after growth tests). Soil samples were obtained using the composite method by taking soil samples from test pots with the same treatment and then compositing. Parameters tested included soil acidity (pH H_2O), N-total, P-available, K-potential, exchangeable cations, and cation exchange capacity (CEC).

2.6. SRF Nutrient Release Test

Nutrient release tests were conducted on a laboratory and greenhouse scale. The laboratory test used the shaking method. The shaking method involves the use of distilled water for durations of 15, 30, 45, and 60 minutes (Handayani *et al.* 2016). After watering, the greenhouse scale test uses water from the bottom of the pot (growth test). Greenhouse scale test samples were collected 1, 5, 9, and 15 weeks after fertilizer application (López-Díaz *et al.* 2011). Nitrogen (N) analysis was carried out using a UV-VIS Spectrophotometer by the method of (USEPA 1971). Phosphorus (P) content was determined using a spectrophotometer using the APHA method (1992b). Potassium (K) content was assessed using an atomic absorption spectrometer with the APHA method (1992a).

2.7. Plant Nutrient Uptake Analysis

Plant nutrient uptake analysis was conducted on *sengon* plants using the plant stem. The nutrient uptake analysis used 20 g of stem samples for each treatment. The calculation formula for plant nutrient uptake refers to (Dhlamini *et al.* 2020) as follows:

$$\underset{\text{(mg/pot)}}{\text{Nutrient absorption}} = \%\ \text{nutrient content} \times \text{dry weight (g/pot)}$$

2.8. Data Analysis

Data collected from the germination and growth tests underwent statistical analysis using the computer-based software "RStudio 2022.07.0 (548)" through analysis of variance (ANOVA). Significance in the results was additionally assessed using the Duncan Multiple Range Test (DMRT) at a 95% confidence interval. Graphical representations were generated using the "RStudio 2022.07.0 (548)" software.

3. Results

3.1. Germination Test of *Sengon* and Upland Rice

Over the 21-day observation period, it was evident that the fertilizer type exerted a significant impact ($p<0.05$) on all germination parameters in *sengon* seeds, with the exception of maximum growth potential (MGP) and mean germination time (MGT). Meanwhile, the fertilizer type exhibited a significant effect on all parameters in upland rice seeds (Table 1). Referring to the data provided in Table 1, germination values (germination rate/GR, sprout height/SH, and survival rate/SR) of *sengon* seeds show that F_4 and F_2 fertilizers produce germination values that are not significantly different from F_0. A similar response showed that F_4 and F_2 fertilizers

Table 1. Variance analysis of fertilizer effect on sengon and rice germination test (1–21 days of germination)

Fertilizers type[c]	Parameters[a]				
	GR	MGP	MGT	SH	MGP
Sengon[b]	*	ns	ns	*	ns
F_0	64.58[ab]	83.33	1.57	3.33[a]	83.33
F_1	47.91[bc]	75.00	1.34	1.67[b]	75.00
F_2	56.25[ab]	83.33	1.34	1.65[b]	83.33
F_3	54.16[b]	70.83	1.50	1.40[b]	70.83
F_4	77.08[a]	87.50	1.13	2.50[ab]	87.50
F_5	27.08[c]	54.18	1.06	0.23[c]	54.18
CV	5.72	4.33	0.08	0.29	4.33
R^2	0.73	0.33	0.28	0.70	0.33
Rice[b]	*	*	*	*	*
F_0	77.09[a]	83.33[a]	1.86[c]	5.89[a]	62.5[a]
F_1	41.67[b]	75.00[b]	3.21[ab]	1.91[c]	20.84[cd]
F_2	68.75[a]	87.50[a]	2.45[bc]	4.40[b]	58.34[a]
F_3	39.58[b]	75.00[b]	3.54[a]	2.00[c]	33.34[bc]
F_4	60.42[ab]	83.33[a]	3.50[a]	3.71[b]	45.83[ab]
F_5	14.58[c]	29.17[c]	2.50[bc]	0.02[d]	0.00[d]
CV	5.94	2.88	0.11	0.27	6.39
R^2	0.74	0.71	0.62	0.86	0.73

[a]GR: germination rate, MGP: maximum growth potential, MGT: mean germination time, SH: sprout height; SR: survival rate; [b](ns): no significant effect, (*): significant effect on the test level of 5%; [c]CV: coefficient of variation; R^2: coefficient of determination

produced rice germination values that were not significantly different from F_0 for all parameters except SH. Furthermore, although significantly different and lower than F_0 in the SH parameter, F_4 and F_2 fertilizers produced higher germination values than the other fertilizers (F_1, F_3, and F_5). F_5 fertilizer produced the lowest germination values in all parameters in *sengon* and rice seeds.

3.2. Growth Test of *Sengon* and Upland Rice

Environmental condition measurements were taken at the bottom of the plant canopy. In general, temperature and light intensity parameters decreased as the observation time increased while air humidity increased (Table 2). Every treatment and its respective interaction exhibited a varied impact on the growth parameters of both *sengon* and upland rice (Table 3). The planting pattern had a significant impact ($p<0.05$) solely on the root length of *sengon*, whereas the type of fertilizer significantly influenced the root length of upland rice (Table 3). In addition, the interaction between planting pattern and fertilizer type did not significantly affect either *sengon* or upland rice.

3.2.1. Plant Height

According to the ANOVA, neither the planting pattern nor the fertilizer type significantly ($p<0.05$) affected the plant height of *sengon* and upland rice (Table 3). The average height of *sengon* plants with *sengon*-rice agroforestry/AF planting pattern was 27.06 cm, while upland rice was 12.50 cm (Figure 1). The average was lower than the height of *sengon* and upland rice in monoculture (SM and RM), which were 30.5 cm and 27.37 cm, although the values were not significantly different (Figure 1). The highest *sengon* plant height was produced from the F_1 treatment, followed by the F_3, F_5, and F_4 treatments (Figure 2). The highest height increment of *sengon* produced by F_1 was 34.75 cm, which was higher than F_0 at 24.06 cm, although the difference was not statistically significant. Conversely, the tallest rice plants, reaching 27.77 cm, were observed with the F_0 fertilizer type, which was higher than the other fertilizer types (F_1-F_5) although not significantly different (Figure 2).

3.2.2. Plant Root Length

ANOVA results indicated that the planting pattern had a significant impact only on the root length of *sengon*, with no significant effect observed on rice. Conversely, the type of fertilizer exhibited a significant effect solely on the root length of upland rice, without a notable impact on *sengon* (Table 3). The average root length of *sengon* from AF treatment was 21.31 cm, which was lower and significantly different from the average root length of SM of 25.40 cm (Figures 3 and 4).

Table 2. Recapitulation of meteorological conditions at different planting patterns and times

Parameters	Time[a]	Planting pattern[b]			Open space
		SM	RM	AF	
Temperature (°C)	I	33.33	33.50	33.42	±29-31
	II	30.60	31.87	29.83	
	III	28.87	29.75	28.93	
Humidity (%)	I	63.00	60.50	61.25	±59-70
	II	74.67	66.75	77.33	
	III	87.33	76.75	86.67	
Light intensity (lux)	I	3635 (7.27%)	3393 (6.80%)	3814 (7.63%)	± 50000 (100%)
	II	2714 (5.43%)	2958 (5.92%)	2384 (4.77%)	
	III	2015 (4.03%)	2710 (5.42%)	2297 (4.60%)	

[a]I: 1 week after planting (WAP), II: 7 WAP, III: 13 WAP; [b]SM: sengon monoculture, RM: rice monoculture, AF: *sengon*-rice agroforestry

Table 3. Variance analysis of growth of sengon and upland rice

Parameters	Planting pattern (P)[a]	Type of fertilizers (F)[a]	Interaction (P*F)[a]
Sengon plant			
Plant height	ns	ns	ns
Stem diameter	ns	ns	ns
Number of leaves	ns	ns	ns
Survival rate	ns	ns	ns
Root length	*	ns	ns
Root diameter	ns	ns	ns
Root nodule	ns	ns	ns
Plant wet weight	ns	ns	ns
Plant dry weight	ns	ns	ns
Rice plant			
Plant height	ns	ns	ns
Survival rate	ns	ns	ns
Number of rice tillers	ns	ns	ns
Number of productive tillers	ns	ns	ns
Root length	ns	*	ns
Filled grain	ns	ns	ns
Hollow grain	ns	ns	ns
1,000 grain weight	ns	ns	ns
Plant wet weight	ns	ns	ns
Plant dry weight	ns	ns	ns
Rice production	ns	ns	ns

[a](ns): no significant effect, (*): significant effect on the test level of 5%

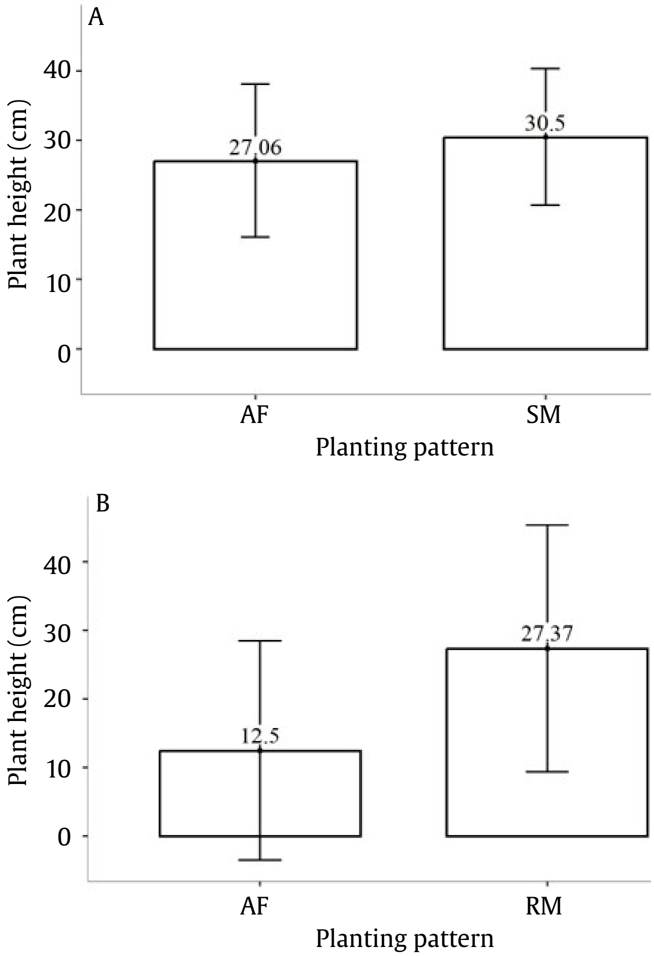

Figure 1. Effect of planting pattern on plant height of sengon (A) and upland rice (B)

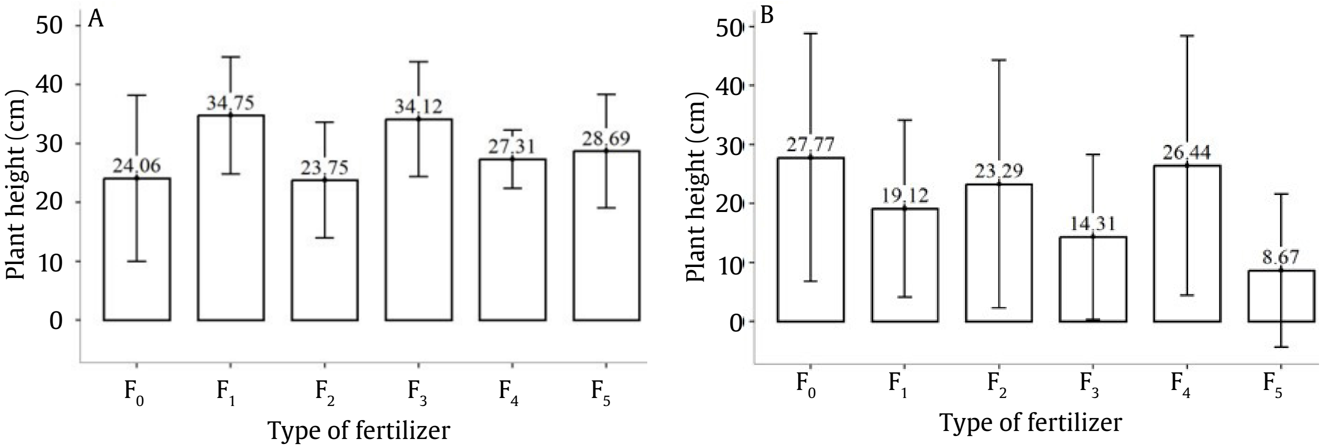

Figure 2. Effect of fertilizer type on plant height of *sengon* (A) and upland rice (B)

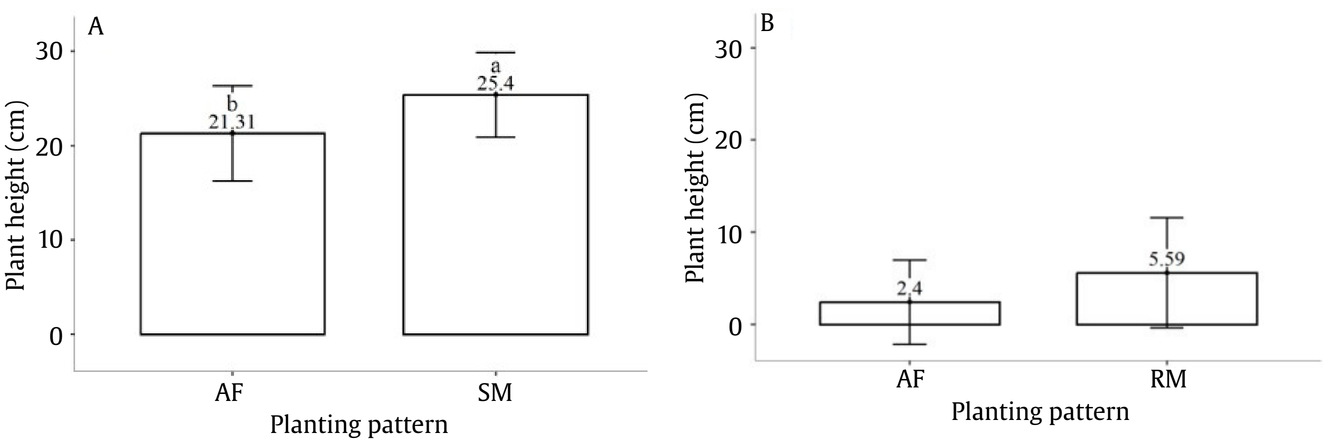

Figure 3. Effect of planting pattern on root length of *sengon* (A) and upland rice (B)

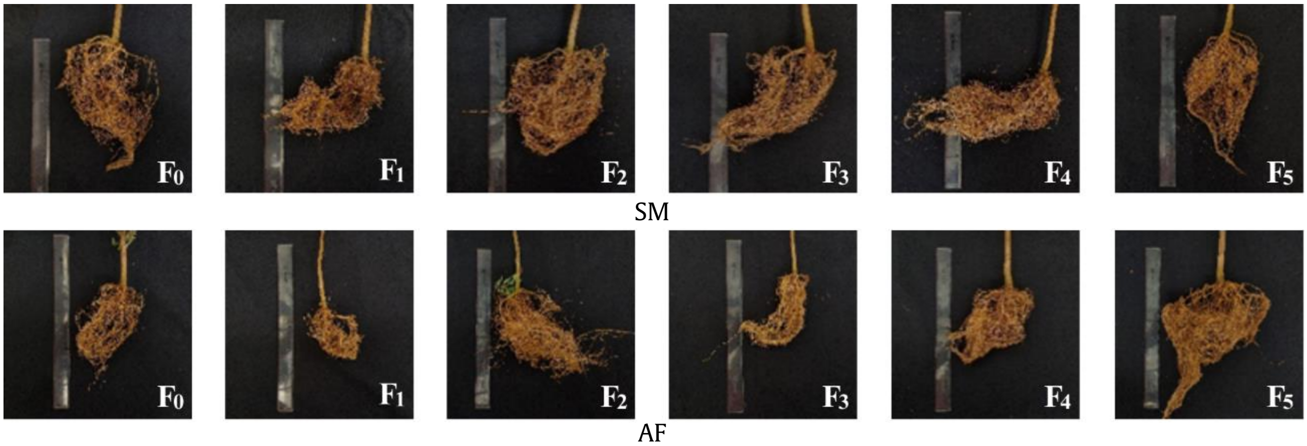

Figure 4 Length of *sengon* roots at 15 WAP

The maximum root length in upland rice was achieved with the F0 treatment, and this was notably different from the outcomes of other treatments, with a value of 8.33 cm. DMRT test on upland rice root length resulted in the following treatment order: $F_0 > F_4 > F_1 > F_2 > F_3 > F_5$ (Figures 5 and 6).

3.2.3. Plant Survival Rate

The results of variance analysis on plant survival rate found that planting pattern and fertilizer type did not significantly affect the survival rate of *sengon* and upland rice (Table 3). The survival rate of *sengon* in two planting patterns, AF and SM, was the same at 100% (Figure 7). On the other hand, the survival rate of upland rice in the RM planting pattern was higher than the AF pattern, although not significantly different. The survival rate values by AF and RM treatments were 20.83% and 56.94%, respectively (Figure 7).

The survival rate of *sengon* after 15 weeks after planting (WAP) with the application of fertilizer types reached 100% in all fertilizer types. On the other hand, the survival rate of upland rice was different among treatments, though not significantly different from each other (Figure 8). The highest survival rate was produced by fertilizer type F_4, followed by F_2, F_0, and F_3.

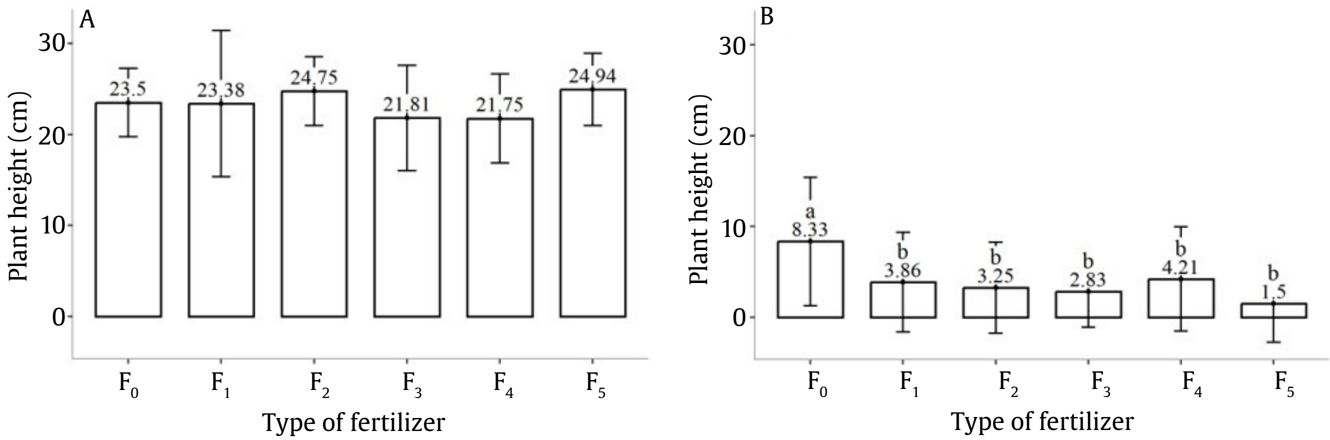

Figure 5. Effect of fertilizer type on root length of *sengon* (A) and upland rice (B)

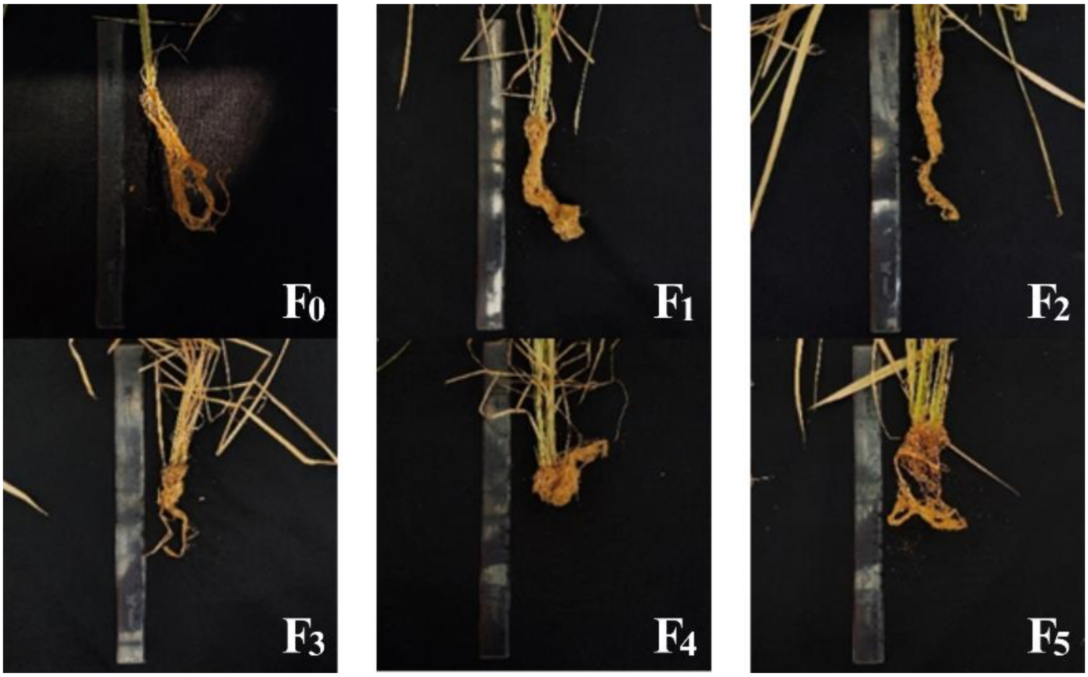

Figure 6 Root length of upland rice at 15 WAP

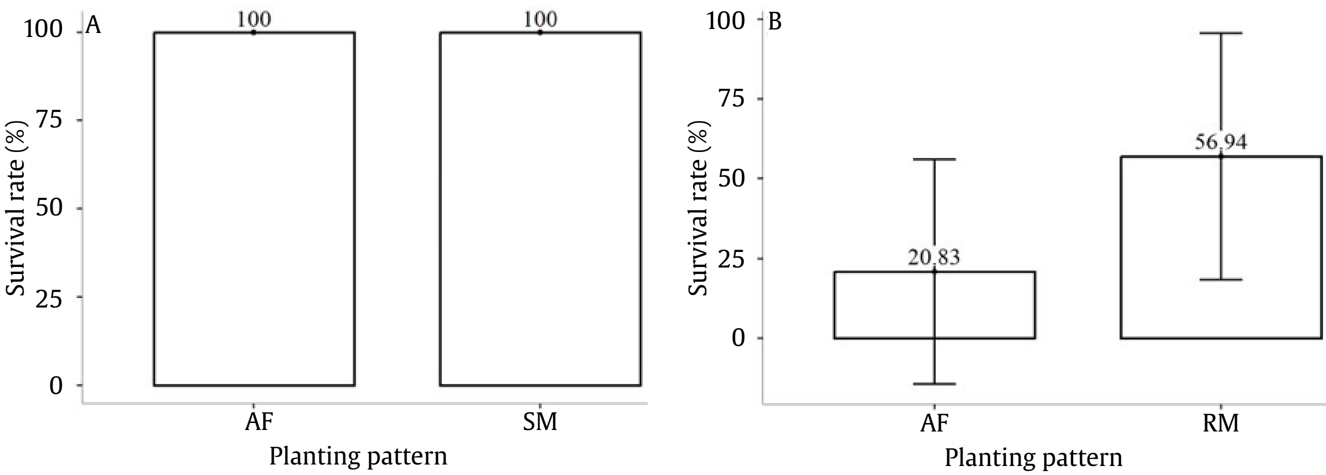

Figure 7. Effect of planting pattern on survival rate of *sengon* and upland rice

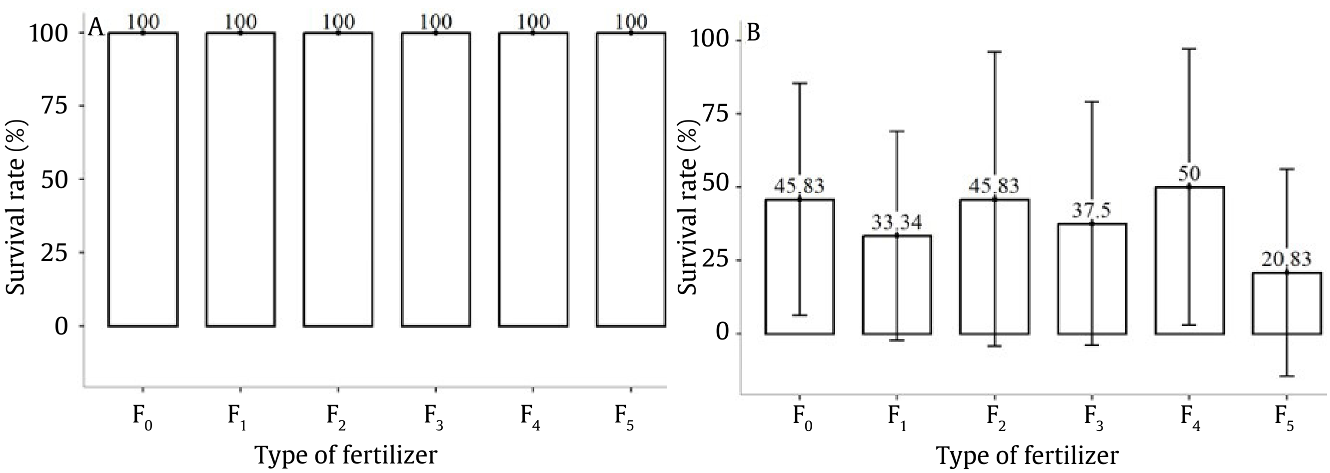

Figure 8. Effect of fertilizer type on survival rate of *sengon* and upland rice

3.2.4. Number of Rice Tillers

Both the planting pattern and fertilizer type did not have a statistically significant impact on the number of tillers in upland rice (Table 3). The quantity of tiller in rice was higher in the RM pattern compared to the AF planting pattern (Figure 9). The value of the number of tillers of each pattern was 0.22 (AF) and 0.97 (RM). The highest value resulted from the type of fertilizer F_0, followed by F_2, F_4, and F_3 (Figure 10).

3.2.5. Plant weight

Plants' wet and dry weights in both *sengon* and upland rice were not significantly affected by the planting pattern, fertilizer type, or their interaction (Table 3). The highest wet and dry weight of plants resulted from the interaction between planting patterns and the type of fertilizer, specifically the combination of RM:F2 treatment. The wet and dry weights of rice were 2.85 g and 2.33 g, respectively (Figure 11). This value indicates that combining monoculture treatment with SRF F_2 can produce the highest plant biomass compared to other treatment combinations.

3.3. Soil Fertility Analysis

In general, the results of soil fertility analysis after 15 weeks with cropping patterns and fertilizer types found a decrease in the value of the parameters N-total, P-available, K-potential, Na-exchangeable (ex), K-ex, Mg-ex, and cation exchange capacity (CEC), and an increase in the value of the soil pH parameter (Table 4).

3.4. SRF Nutrient Release Test

The results of laboratory-scale fertilizer nutrient release showed that conventional fertilizer (F_5) released higher nutrients than CS-NPK SRF in 4 observation times, clearly visible in P and K nutrients, which were 85.68% and 38.16% higher than CS-NPK SRF, respectively (Figures 12B and C). F_5 started to release P and K elements since observation time I (15

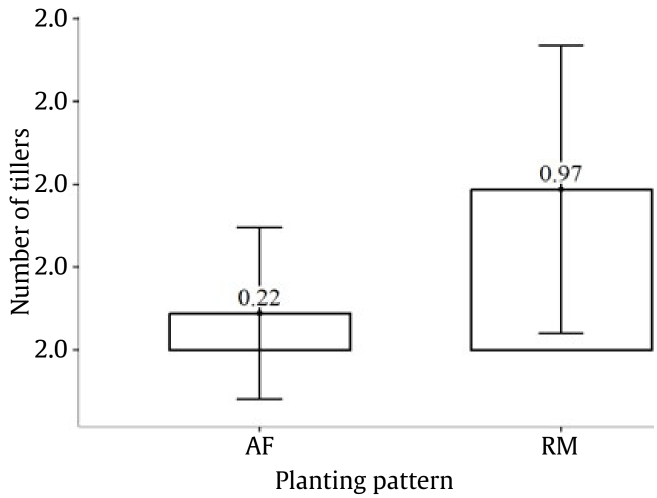

Figure 9. Effect of planting pattern on the number of tillers of upland rice

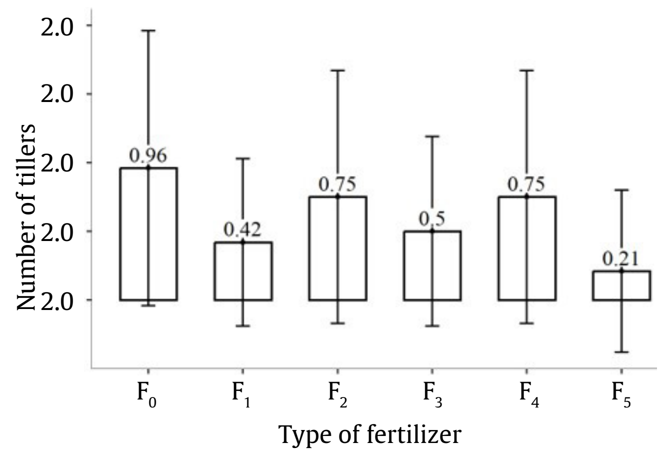

Figure 10. Effect of fertilizer type on the number of upland rice tillers

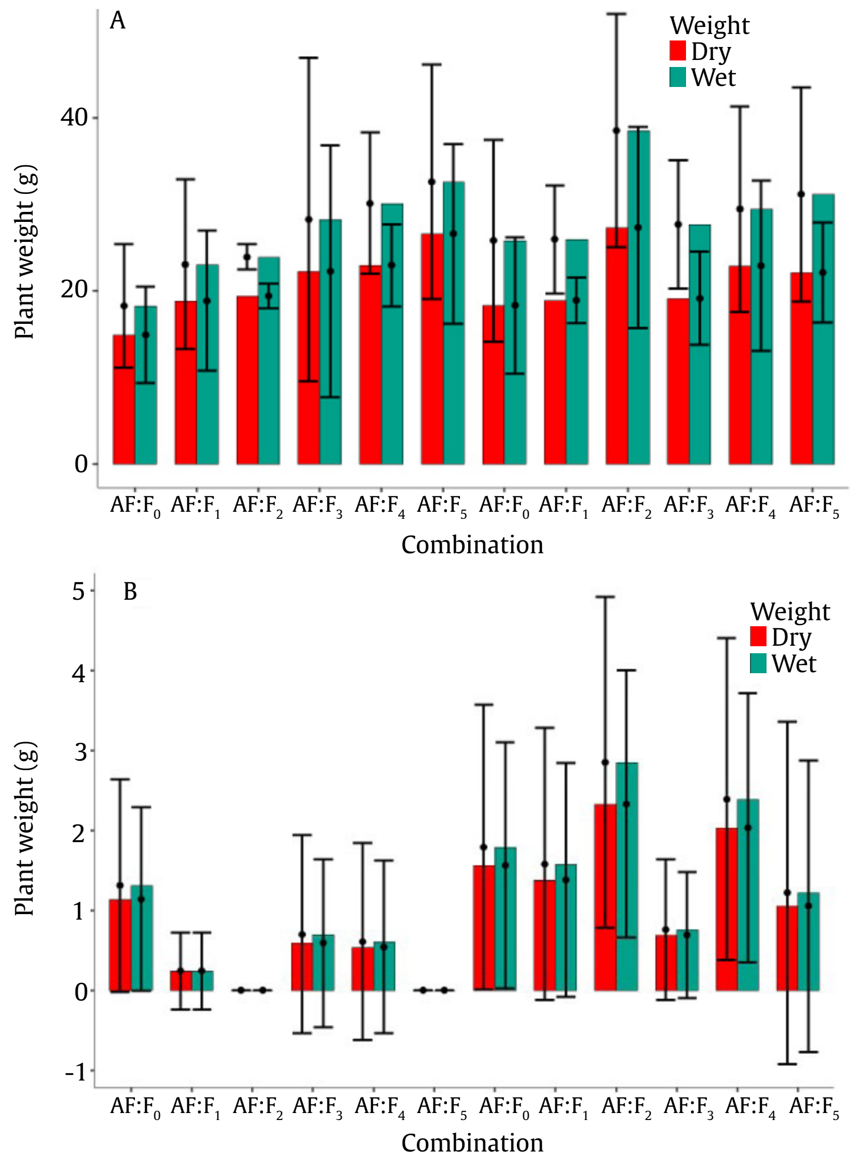

Figure 11. Effect of interaction (cropping pattern and fertilizer type) on wet and dry weight of *sengon* and upland rice plants

Table 4. Recapitulation of soil fertility analysis by planting pattern and fertilizer type

Treatment	Parameter[a]							
	Degree of acidity	Total-N	Available-P	Potential-K	Na-ex	K-ex	Mg-ex	CEC
	pH	%	mg/Kg	mg/100 g	cmol/Kg			
Initial	6.60 (N)[b]	0.14 (L)	135.7 (VH)	86.00 (VH)	0.22 (L)	0.70 (H)	1.80 (M)	11.25 (L)
Planting pattern	7.75 (SA)	0.09 (VL)	51.17 (VH)	54.67 (H)	0.14 (L)	0.40 (M)	1.10 (M)	9.43 (L)
SM	8.03 (SA)	0.07 (VL)	45.53 (VH)	57.50 (H)	0.11 (L)	0.48 (M)	0.99 (L)	8.68 (L)
RM	7.92 (SA)	0.08 (VL)	40.43 (VH)	46.00 (H)	0.13 (L)	0.37 (L)	0.97 (L)	8.34 (L)
AF								
Fertilizer type								
F_0	7.77 (SA)	0.09 (VL)	50.27 (VH)	51.67 (H)	0.10 (L)	0.43 (M)	1.08 (L)	8.94 (L)
F_1	7.87 (SA)	0.08 (VL)	42.10 (VH)	51.67 (H)	0.13 (L)	0.38 (M)	0.98 (L)	8.44 (L)
F_2	8.00 (SA)	0.08 (VL)	41.10 (VH)	49.67 (H)	0.13 (L)	0.36 (M)	1.04 (L)	8.76 (L)
F_3	8.00 (SA)	0.08 (VL)	45.63 (VH)	54.67 (H)	0.13 (L)	0.43 (M)	1.00 (L)	8.75 (L)
F_4	7.93 (SA)	0.08 (VL)	41.80 (VH)	48.00 (H)	0.13 (L)	0.39 (M)	0.97 (L)	8.94 (L)
F_5	7.83 (SA)	0.08 (VL)	53.37 (VH)	60.67 (VH)	0.14 (L)	0.51 (H)	1.03 (L)	9.05 (L)

[a]Soil analysis assessment criteria (Eviati and Sulaeman 2009); [b]N: neutral, SA: slightly acidic, L: low, VL: very low, VH: very high, H: high, M: medium

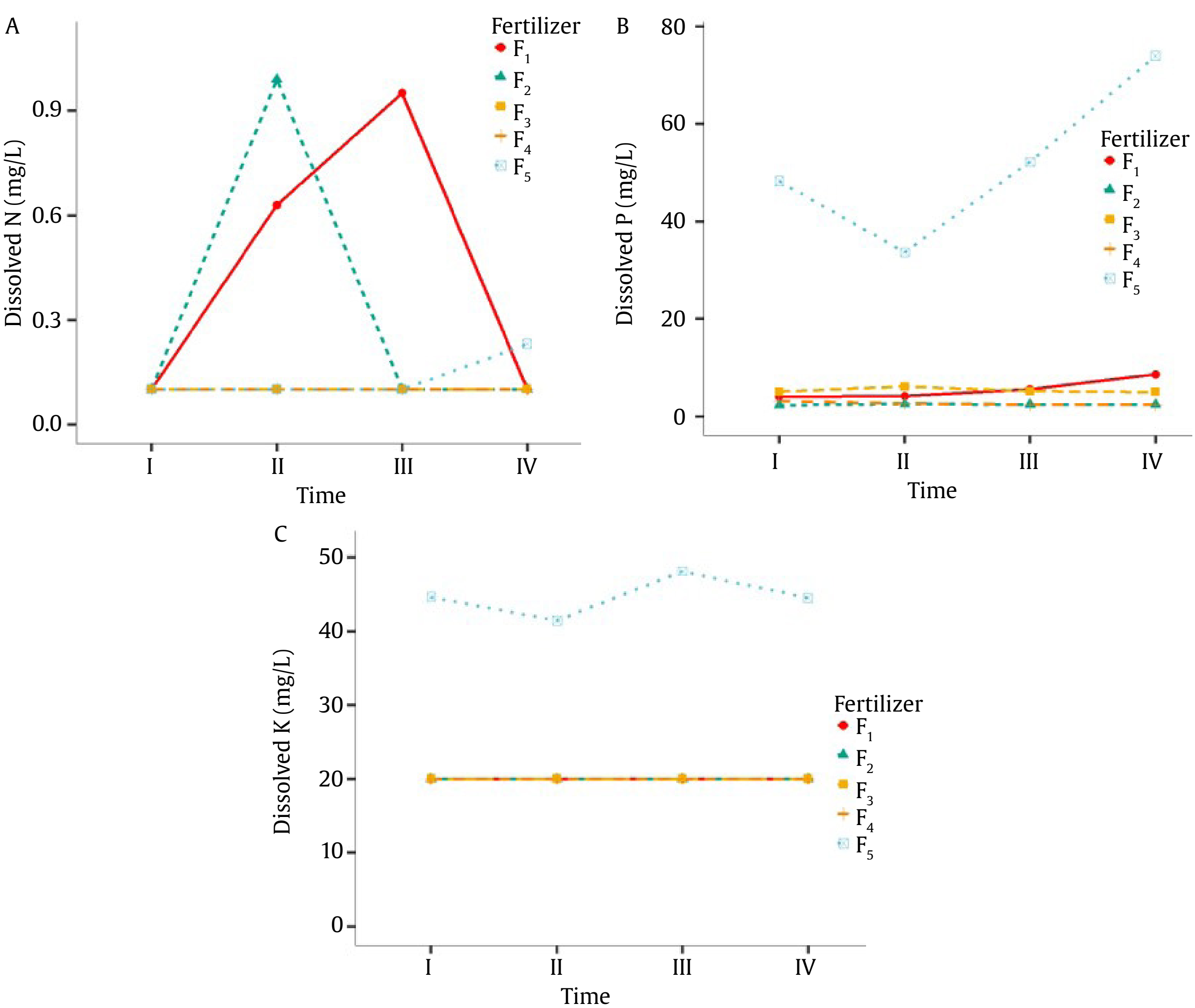

Figure 12. Total dissolved nutrients at 4 observation times in distilled water solvent

minutes) at (48.24 and 44.64 mg/L) and fluctuated until observation time IV (60 minutes) with values of (73.9 and 44.53 mg/L). In contrast to F_5, CS-NPK SRF (F_1-F_4) released lower P element at time I of 2.33 mg/L (F_2), 3.15 mg/L (F_4), 4 mg/L (F_1), 5.07 mg/L (F_3), and fluctuated until time IV of 2.44 mg/L (F_2), 2.44 mg/L (F_4), 5 mg/L (F_3), and 8.57 mg/L (F_1). Furthermore, CS-NPK SRF (F_1-F_4) released lower K than F_5 at 4 observation times with a 20 mg/L reading value.

The greenhouse-scale analysis of fertilizer nutrient release revealed that the quantity of N released by F_5 excedeed the formulated CS-NPK SRF fertilizer. The results of DMRT indicated a significant difference between F5 and the other fertilizer types (F_0-F_4), with a value of 69.31 mg/L at observation time I (Table 5). It is clear from Table 5 that the dissolved N of CS-NPK SRF (F_1-F_4) is lower at observation time I to IV than conventional fertilizer (F_5). However, the value is not significantly different at observation time II-IV. Figure 13 shows the dissolved nutrients from the fertilizers 15 weeks after application. The highest dissolved N value was produced from fertilizer type F5, followed by F_0, F_1, F_3, F_2, and F_4. Different results were shown in the soluble K element, where F_1 and F_3 fertilizer types had higher values than F_5. The value of the P element produced from fertilizer types was relatively low, ranging from 0.21-0.27 mg/L.

3.5. Plant Nutrient Uptake Analysis

The results of plant nutrient uptake in N and P elements were highest in treatment F_2, followed by F_5, F_4, F_3, F_0, and F_1, while the highest K element uptake was obtained from treatments F_2, F_5, F_3, F_0, F_1, and F_4 (Figure 14).

Table 5 Recapitulation of variance of N release in soil at 4 observation times

Time	F-test[a]	Dissolved N [b]					
		F_0	F_1	F_2	F_3	F_4	F_5
I (1 WAP)	*	9.69[b]	12.22[b]	3.38[b]	11.18[b]	11.18[b]	69.31[a]
II (5 WAP)	ns	0.26	0.12	0.34	0.10	0.10	4.83
III (9 WAP)	ns	2.63	1.39	1.36	1.00	1.00	3.96
IV (15 WAP)	ns	15.25	14.63	8.49	9.14	9.14	16.49

[a](ns): no significant effect, (*): significant at the 95% confidence interval; bvalues sharing the same letter within a row indicate that they are not significantly different (DMRT test)

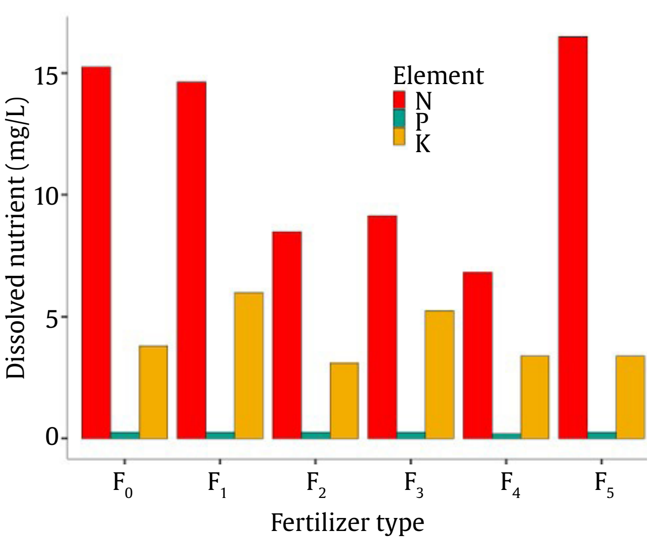

Figure 13. Total dissolved nutrients (NPK) at 15 WAP in the soil

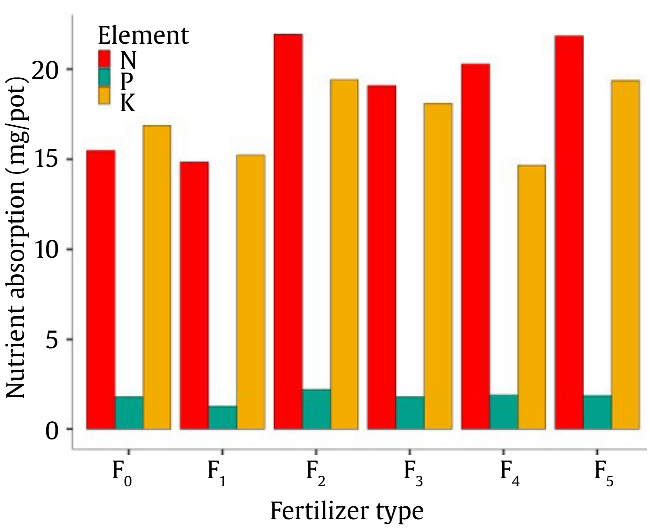

Figure 14. Total plant nutrient uptake with fertilizer at 15 WAP

4. Discussion

4.1. Germination of *Sengon* and Upland Rice

Slow-release fertilizer (SRF) is a type of fertilizer designed to provide plants with nutrients, releasing them gradually to enhance their accessibility and availability to plants. Achieving a slow release of nutrients involves encapsulating the fertilizer material with a protective layer made of water-soluble and semipermeable materials (Trenkel 2010). Research related to SRF with chitosan (CS) coatings on plant growth has been conducted. Handayani (2014) found that CS-NPK SRF provided lower nutrient solubility and increased the growth of acacia (*Acacia crassicarpa*) seedlings. The study found that nutrient release was slower over four months and had better growth in eggplant (*Solanum melongena*) and swamp rice (var. Inpara-2) (Said *et al.* 2018; Hartoyo *et al.* 2023).

While this study did not specifically characterize CS-PMAA-NPK SRF, Corradini *et al.* (2010) reported an average SRF diameter of 78±1.5 nm during the preparations of CS-PMAA-NPK SRF. This value indicates that CS solubilized with MAA can produce CS nanoparticles (1-100 nm). The weakness encountered in research with nano-fertilizers is determining the concentration of nano-fertilizers to be applied to plants (Szőllősi *et al.* 2020). The germination test results indicate that CS-NPK SRF (F_1-F_4) has not demonstrated a significant impact on enhancing the germination of *sengon* and upland rice seeds, as it is not significantly different from the control (F_0) (Table 1). These findings suggest that the use of fertilizer/SRF is not necessary during the seed germination phase. Plant seeds inherently possess nutritional reserves in the endosperm, eliminating the need for supplementary nutrients (Yan *et al.* 2014). The outcomes of this study contrast with the findings of Sharma *et al.* (2020), where they employed chitosan (CS)-copper (Cu)-salicylic acid (SA)-nano fertilizer enhance the vigor index of corn (*Zea mays*) sprouts, showing a difference from the control group. The utilization of SRF with a chitosan base has been reported to enhance plant vigor and bolster resistance against pathogens, as documented by studies such as Sathiyabama and Parthasarathy (2016) and Choudhary *et al.* (2019). Furthermore, chitosan has been found to positively impact seed germination by inducing amylase and protease activities (Saharan *et al.* 2016).

The germination test results reveal an interesting trend, where CS-NPK SRF with lower concentrations (F_2 and F_4) exhibited higher germination values (GR, MGP, SR, SH) compared to high-concentration SRF (F_1 and F_3) and conventional NPK fertilizer. The difference between F_2 and F_4 and F_1 and F_3 is the formula applied to the plants. SRF formulas F_2 and F_4 used an application amount of 0.01 g, while F_1 and F_3 used 0.03 g. According to Saharan *et al.* (2016), they observed a decrease in seed vigor as the concentration of Cu-CS-nano fertilizer increase in corn (*Z. mays*) seeds. In their research, Khalifa and Hasaneen (2018) mentioned that CS-NPK SRF at higher concentrations (0.5 g N; 0.06 P; 0.4 K) led to a reduction in root length and hindered the growth of secondary roots in Pisum sativum seeds. The inhibitory impact on sprout growth observed with high concentrations of CS-NPK SRF is attributed to heightened damage to plant DNA, thereby impeding the seed germination process. Leonardi *et al.* (2021) similarly reported research results indicating that the application of CS-CuO-nano fertilizer failed to enhance the height of kumquat orange (*Fortunella margarita*) sprouts.

Looking at the germination results by conventional NPK fertilizer (F_5), CS-NPK SRF produced better germination than F_5 in all germination parameters for both seed species (Table 1). This result is presumably because conventional NPK fertilizers are composed of non-organic chemicals, which if in direct contact with plants in high amounts, will cause damage and death to plants. NPK fertilizers have the potential to release ammonia (NH_3) and ammonium (NH_4^+), which can be detrimental to seeds due to ammonia toxicity and seed osmotic damage. This is especially true if the fertilizers are directly applied to seeds without a medium Makaza and Khiari (2023). Seed osmotic damage transpires when toxicity disrupts the gradient at the seed surface, impeding water uptake and resulting in the physiological desiccation of the seed (Pereira *et al.* 2012). These results show that conventional NPK fertilizer mixed with CS to become CS-NPK SRF is safer for seeds than conventional NPK fertilizer without a chitosan mixture. Codognoto *et al.* (2019) concluded that prolonged exposure of seeds to direct NPK resulted in decreased seed germination, reduced shoot and root length, and increased seed mortality.

4.2. Growth of *Sengon* and Upland Rice

Studies investigation the impact of CS-NPK SRF application on plant growth have been conducted by researchers such as Abdel-Aziz *et al.* (2016), Hasaneen, *et al.* (2016), Khalifa and Hasaneen (2018), Dhlamini *et al.* (2020), and Elshayb *et al.* (2022). CS-NPK SRF can potentially increase the plant growth parameters of *sengon* and upland rice. The potential for increased growth is seen in plant height, root length, plant survival rate, and number of rice tillers, although similar to the control (Figures 2, 5, 8, 10, and 11). Abdel-Aziz *et al.* (2016), in their study involving the application of CS-NPK SRF on wheat (*Triticum aestivum*) plants in sandy soil, reported a significant increase in plant height growth compared to the control group. Dhlamini *et al.* (2020) reported similar outcomes when using CS-tripolyphosphate-NPK on corn (*Z. mays*) plants, yielding the highest plant height compared to both the control group and conventional NPK fertilizer. CS-NPK SRF was noted to enhance the root length of wheat (*T. aestivum*) and chickpea (*Phaseolus vulgaris*) plants in comparison to both the control and conventional NPK fertilizer, as reported by Abdel-Aziz *et al.* (2016) and Hasaneen *et al.* (2016). In the study conducted by Elshayb *et al.* (2022) using CS-urea SRF, an increase in the number of rice tillers was observed, and this difference was found to be significant compared to conventional NPK fertilizer.

The potential for improved plant growth values by CS-NPK SRF application has been proven. However, the effect on plant growth is still variable. Bhardwaj *et al.* (2022) unveiled that the interaction and response of nano fertilizer formulations did not exhibit a consistent pattern and varied based on plant species, the type of nano formulation, and the stage of plant growth during application. Like the germination test results, on average, the plant growth response in the growth test by CS-NPK SRF F_2 and F_4, produced higher growth values than SRF F_1 and F_3. The mechanism of plant growth inhibition by nanoCS is thought to be due to the accumulation of nanoparticles in plant cells that cause reduced water absorption, gas exchange, and inhibit overall plant tissue (Pereira *et al.* 2017; Khalifa and Hasaneen 2018). The findings align with other research employing CS-NPK SRF, wherein the use of lower concentrations (10% NPK) led to greater plant growth compared to higher concentrations of the formulation (100% NPK), as reported in studies by Abdel-Aziz *et al.* (2016) and Hasaneen *et al.* (2016).

In addition to examining the CS-NPK SRF formula, the study also investigated the planting pattern as another contributing factor. The monoculture pattern of both *sengon* and rice produced higher values in all growth parameters than the *sengon*-rice agroforestry pattern (Figures 1, 3, 7, 9, and 11). The agroforestry of *sengon* with upland rice affected the amount of sunlight received by each plant (Table 2). *Sengon* is a fast-growing and intolerant plant species that grows vertically and horizontally faster than others. *Sengon* has a broad horizontal crown and a double compound leaf shape with small leaves (Krisnawati *et al.* 2011). *Sengon* seedlings aged seven months with a plant height of ±50 cm resulted in reduced light penetration to rice plants under *sengon*. In the agroforestry pattern of *sengon* and upland rice, there is competition for sunlight, nutrients, and water (Dewi *et al.* 2017; Tsaniya *et al.* 2022). In their research findings of Tsaniya *et al.* (2022), it was observed that the height of upland rice plants was lower in agroforestry compared to monoculture rice. Upland rice planted at a smaller distance with *sengon* is hampered by its growth because the *sengon* canopy is large and dense, so sunlight does not reach the rice. In their study on *sengon* and rice agroforestry, Wijayanto and Briliawan (2022) discovered that a dense planting distance (1.5 × 1.5 m) led to lower grain weight and fewer productive tillers in rice compared to those planted with a wider distance (3.0 × 1.5 m). The reduction in the number of tillers is caused by the necessary photosynthate input that cannot meet the needs of plants for the growth of rice tillers evenly (Lestari *et al.* 2020). The deficiency of photosynthate is related to the disruption of the photosynthesis process in plants. Rice is a C3 plant with the Rubisco enzyme, which functions to fix CO_2 in photosynthesis (Lal 2018). When plants receive less sunlight intensity due to shading, the Rubisco enzyme does not work due to the decarbamylation process (sugar-phosphate inhibition) that occurs in plants. This leads to reduced carbon absorption by plants until, finally, the process and results of photosynthesis (photosynthate) cannot meet the needs of plants (Taylor *et al.* (2022). Similar research findings regarding competition for sunlight in agroforestry systems were documented by several studies, including Hairmansis *et al.* (2017), Muhidin *et al.* (2018), Ikhfan and Wijayanto (2019), Satriawan *et al.* (2022), and Wijayanto and Briliawan (2022).

Interactions among plants that compose agroforestry patterns can be positive or negative and may occur above or below ground. Atangana *et al.* (2014) mentioned some negative interactions of agroforestry patterns, such as competition for water and nutrients in the roots, light competition by the plant canopy, changes in microclimate that increase pest and disease attacks on plants, and allelopathic compounds from some plant species that are deadly to other plants in the surrounding area. Agroforestry patterns have a higher density of individuals than monoculture cropping patterns. High plant density has implications for increasing competition between constituent plants (Sopacua *et al.* 2021). The spacing of 15 cm in pots used in the study resulted in competition between plants in obtaining nutrients and water, both in the roots of *sengon* and rice plants. Sarto *et al.* (2022) observed a reduction in water content in sandy soil within the agroforestry pattern involving cattle grass and Eucalyptus. Narrow spacing resulted in lower water content than high spacing and monoculture patterns. Furthermore, Niether *et al.* (2020) found a decrease in cocoa (*Theobroma cacao*) plants' water content and biomass in agroforestry patterns compared to monoculture. Forestry crops planted in agroforestry patterns can reduce land productivity if planted at very high densities (Blaser *et al.* 2018).

4.3. Soil Fertility

The analyzed soil is categorized by neutral to slightly alkaline pH conditions with soil pH values ranging from 6.60-8.00 (Table 4). Kondal *et al.* (2021) found that the nanoCS-urea composite increased pH 90 days after application. The diminished concentration of N, P, and K in the soil resulting from CS-NPK SRF application was attributed to the gradual release properties of the chitosan coating. Similar research results were obtained by Khati *et al.* (2017) using nanoCS applied to sterile and non-sterile soil. They found that the results of nanoCS application did not differ in value from the treatment without fertilizer 30 days after application. Kondal *et al.* (2021) also obtained lower macronutrient values with nanoCS-urea compared to conventional fertilizers 90 days after application. The results of other nutrient analyses (Na, Ca, Mg) are still in the same category for each treatment: Na is low, K is high, and Mg is low (Eviati and Sulaeman 2009). Different results were found by Deshpande *et al.* (2017), who used nanoCS-Zn, which provided higher Zn nutrient release than without fertilizer application at 40 days of observation. There still needs to be a precise time standard related to nutrient release by CS-NPK SRF in its application in soil (Lawrencia *et al.* 2021). Cation exchange capacity (CEC) is a soil chemical property that plays a significant role in influencing soil fertility. A higher CEC value indicates more fertile soil due to higher organic carbon levels (Ritonga *et al.* 2020; Wibowo and Kasno 2021). The CEC values obtained in all treatments were classified as "low". The growing media used in the study was dominated by sand (>70%). The sandy soil texture exhibits a low CEC level owing to its limited organic matter and clay content, which is beneficial for the binding of nutrient cations (Aprile and Lorandi 2012).

4.4. SRF Nutrient Release

In this study, the results of nutrient release by fertilizers at the laboratory and greenhouse scales produced a similar pattern where CS-NPK SRF released lower nutrients (N, P, and K) than conventional NPK fertilizers at several observation times (Figures 12 and 13). This outcome mirrors the findings of Plofino *et al.* (2019), who observed a lower nutrient release with CS-K compared to conventional chemical fertilizer after 1 hour in a water medium. Essawy *et al.* (2016) similarly achieved lower nutrient release results with chitosan-cellulose superabsorbent hydrogels compared to conventional chemical fertilizers after 240 hours of observation in liquid medium. Furthermore, the chitosan-cellulose superabsorbent hydrogels released lower N, P, and K nutrients than conventional fertilizers in soil media for 60 days (Essawy *et al.* 2016). Sathisaran and Balasubramanian (2020) revealed that the media's pH affects chitosan's swelling rate, which has implications for the nutrient release rate. The swelling rate of chitosan was found to increase in conditions with acidic pH. Besides the acidic pH, decreasing the media's ionic strength increases the chitosan coating's swelling rate. The release of N nutrients by conventional fertilizers at the greenhouse scale was easier and faster by 49.10% compared to CS-NPK SRF (Figure 13). Different results were shown in the dissolved K value where F_1 and F_3 were higher than the conventional fertilizer. This result differs from the results of Handayani *et al.* (2016), who found that the amount of soluble K by CS-NPK SRF was lower than in conventional fertilizer. The relatively low value of P in the soil is attributed to the high dissociation rate of the P element, making it prone to conversion into a labile P form. Labile P occurs when phosphorus binds to elements such as aluminium (Al), calcium (Ca), and iron (Fe) in the soil. The bound P becomes unavailable or cannot be absorbed by plants (Bhardwaj *et al.* 2022).

4.5. Plant Nutrient Uptake

The examination of plant nutrient absorption revealed that CS-NPK SRF F_2 led to the maximum uptake of N, P, and K nutrients (Figure 14). The results between plant nutrient uptake, nutrient release by fertilizers, nutrient levels in the soil, and plant growth can be connected to see which fertilizer treatments are absorbed by plants and produce the highest plant growth. The CS-NPK SRF F_2 treatment was found to produce the highest nutrient uptake for N, P, and K (Figure 14) and the lowest amount of water-soluble fertilizer nutrients (4th place) (Figure 13). These results indicate that the nutrients N, P, and K released by CS-NPK SRF F_2 are absorbed mainly by plants and less wasted in the environment (leached). This is in line with the results of *sengon* plant weight in Figure 16A, with the highest *sengon* growth results and low nutrient values in the soil (Table 4). On the other hand, in the conventional fertilizer treatment (F_5), plant nutrient uptake, total soluble nutrients, plant growth, and nutrient levels in the soil showed relatively high values in all four results. This indicates that conventional fertilizer can produce high plant growth from nutrient uptake and high plant growth (Figures 11A and 14) but is followed by high environmental contamination, as seen from the number of soluble nutrients and nutrients in the soil (Figure 13 and Table 4).

CS-NPK SRF significantly affects germination and growth tests of *sengon* and upland rice. The SRF CS dose of 0.7% with a wight of 0.01 g (F_4) exhibited elevated germination values in *sengon* seeds, while SRF CS dose of 0.5% with a weight of 0.01 g (F_2) resulted in increased germination values in upland rice seeds. However, these values did not surpass those of the control (F_0). In addition, other SRF levels (F_1 and F_3) and conventional fertilizer (F_5) tended to produce low germination values in *sengon* and upland rice. However, these results show that conventional fertilizers mixed with chitosan to become CS-NPK SRF are safer to apply to seeds than conventional fertilizers without chitosan. In the growth test, SRF F_2 resulted in improved plant growth for both *sengon* and upland rice, though the outcomes did not show significant differences from F_0. The agroforestry pattern yielded lower values for all growth parameters compared to the monoculture pattern, and this was attributed to interplant competition. CS-NPK SRF exhibits a slower release of nutrients (47.65% N, 85.01% P, and 31.80% K) compared to conventional NPK fertilizers in both laboratory and greenhouse scale tests. This gradual nutrient release characteristic can mitigate nutrient loss to the environment, enhancing the efficiency of nutrient absorption by plants.

Acknowledgements

We are grateful to all those who have assisted in this research. We express our gratitude to the Directorate General of Higher Education, Research, and Technology, as well as the Indonesian Ministry of Education, Culture, Research, and Technology, for providing financial support to this research through the 2023 Higher Education Leading Basic Research Scheme (PDUPT).

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