

Research Article

Nitrogen released from mixtures of sago pulp waste and *Gliricidia sepium* pruning on a Dystrudept of Central Moluccas and its effect on maize growth

June Putinella^{1,2*}, Yulia Nuraini³, Budi Prasetya³

¹ Postgraduate Program, Faculty of Agriculture, Universitas Brawijaya, Jl. Veteran-Malang, 65145, Indonesia

² Faculty of Agriculture, Pattimura University, Jl. Ir. M. Putuhena, Poka Campus, Ambon, Indonesia

³ Department of Soil Science, Faculty of Agriculture, Brawijaya University, Jl. Veteran-Malang, 65145, Indonesia

*corresponding author: putinellajune@gmail.com

Abstract

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The agricultural sector is the mainstay of the economy in Central Moluccas. However, most agricultural soils on the island have low soil fertility. One of the efforts that farmers can make to improve soil fertility is to apply organic matter, which is widely found in Central Moluccas. This study aimed at elucidating the effect of mixing high-quality organic material (*Gliricidia sepium* pruning) with low-quality organic material (sago pulp waste) on the improvement of available nitrogen in an acid soil (Dystrudept) and growth of maize. Two experiments were carried out in a laboratory and a greenhouse. The compositions of the mixtures of sago pulp waste (A) and pruning of *Gliricidia sepium* (G) were A₀G₁₀₀; A₂₀G₈₀; A₄₀G₆₀; A₆₀G₄₀; A₈₀G₂₀, and A₁₀₀G₀. Six treatments and one control (no application of residues) were arranged in a completely randomized design. The results showed that the application of the mixture of 20% and 80% of *Gliricidia sepium* pruning (A₂₀G₈₀) increased the cumulative amount of mineral N in the soil higher than that of the other organic material mixtures, which in turn improved maize growth.

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Introduction

The agricultural sector is the mainstay of the economy in Central Moluccas. However, most agricultural soils on the island have low soil fertility due to low pH (<5) and low nitrogen and organic matter contents. Waas et al. (2016) stated that the Dystrudepts found in Central Moluccas was a very acidic soil reaction (pH<4.5) to acid (pH 5.5-4.5), low to very low organic matter content (<1%). The soil, however, has the potential for the development of superior agricultural commodities, both food crops, horticulture and plantations (Risal et al., 2018). One of the efforts that farmers can make to improve soil fertility is to apply organic matter in the form of sago pulp waste which is widely found in Central Moluccas. The high fibre plant residue from the stems of the sago plant (*Metroxylon sago*) resulting

from the starch extraction process has the potential as a local organic material, which annually produces 26.4 tons of sago pulp waste from 20 trees ha⁻¹ (Alfons and Bustaman, 2005) or 153 t ha⁻¹ of one hectare (Alfons, 2013). Fresh sago pulp waste contains: 26% organic C; total N 0.28%; available P 1.03%; K 0.29%; Ca 3.84%; Mg 0.05% (La Habi et al., 2014); lignin 20.67% (Kiat, 2006); the highest C/N ratio is 70 (Tatipata and Jacob, 2013). Sago pulp waste is allowed to accumulate for years after being decomposed into compost which can provide nutrients for plant growth (Syahtria et al., 2016). Plant residues that are incorporated into the soil will undergo mineralization (Wieder et al., 2013). Plant parameters that control mineralization are nitrogen, carbon, lignin and polyphenol contents (Mafongoya et al., 2011; Castellano et al., 2015),

besides climates and soil microbial activities (Palm et al., 2001). Because sago pulp waste is classified as an organic material of low quality having low nitrogen content (0.82%), high lignin (20.67%) and high C/N ratio (46), its decomposition process takes 4-6 months (Syakir 2005; Alfons, 2013) so that the release of nitrogen from sago pulp waste runs very slowly and is not in synchrony with the plant demand for nitrogen.

In addition to sago pulp waste, organic material that is widely available around agricultural land in Central Moluccas is *Gliricidia sepium* pruning. It has been widely reported that the fresh pruning leaves of *Gliricidia sepium* have 3.5%-4.8% N (Powers and Tiffin, 2010; Gei et al., 2013; Li et al. 2016), C/N ratio of 9.8, 12.5% lignin, and 2.4% polyphenol (Mundus et al., 2008; Powers and Tiffin, 2010). *Gliricidia sepium* pruning decomposes and releases nitrogen very fast into the soil; within seven days, 30% N was released (Kaba et al., 2019), and within 24 weeks, about 60% N was released (Chirwa et al., 2006), so it is not in synchrony with plant demands for nitrogen. Nitrogen-rich plants decomposed much faster than nitrogen-poor plants (Korsaeth et al., 2001). In order to synchronize N released from legume pruning with plant demand for nitrogen, changing the quality of organic materials by mixing high-quality organic matter with low-quality organic matter is a way to accelerate the decomposition and mineralization of N of organic matter to improve plant growth (Mapfumo et al., 2007; Murungu et al., 2011).

This study was aimed at elucidating the effect of mixing organic materials of different qualities, i.e., *Gliricidia sepium* pruning and sago pulp waste, on the improvement of available nitrogen in acid soil and growth of maize.

Materials and Methods

Experiment 1: Mineralization of nitrogen from mixtures of sago pulp waste and Gliricidia sepium pruning (an incubation experiment)

A non-leaching incubation experiment was conducted at the Soil Biology Laboratory, Faculty of Agriculture, Pattimura University. Air-dried sago pulp waste (A) and *Gliricidia sepium* pruning (G) were mixed with the proportions (%w/w): A₀G₁₀₀; A₂₀G₈₀; A₄₀G₆₀; A₆₀G₄₀; A₈₀G₂₀, and A₁₀₀G₀. Each mixture with a dose equivalent to 100 kg N ha⁻¹ was incorporated into 100 g of air-dried soil and placed in a 250 mL plastic bottle. The soil used for this study was Dystrudept collected from Hatu village, West Leihitu Sub-district, Ambon Island. The soil is located in a hilly area, with an altitude of 37 m above sea level and the land use is a mixed garden. The soil has the following characteristics: pH = 5.0, organic C = 1.3%, total N = 0.16 %, C/N ratio = 8, organic matter = 2.01% and clay texture. The sago pulp waste was taken from Tulehu village, Salahutu Sub-district - Ambon Island in fresh condition (1-day harvest). The results of chemical analysis showed that the sago pulp waste contained

45.13% of organic C, 0.56 % of total N, 16.23% of lignin and 6.12% of polyphenol. *Gliricidia sepium* pruning (young twigs and leaves) were obtained from Suli Village, Salahutu Sub-district, Ambon Island. The results of chemical analysis showed that the *Gliricidia sepium* pruning contained 25.93% of organic C, 2.86% of total N, 8.68% of lignin and 2.78% of polyphenol. The chemical composition of sago pulp waste and *Gliricidia sepium* pruning mixtures (A₀G₁₀₀; A₂₀G₈₀; A₄₀G₆₀; A₆₀G₄₀; A₈₀G₂₀ and A₁₀₀G₀) were analyzed for C, N, lignin and polyphenol contents. The plastic bottle containing soil and the organic material mixture was incubated at room temperature (27°C) for 8 weeks. During the incubation period, the water content was maintained at 70% of the water holding capacity. Six treatments and one control were arranged in a completely randomized design with three replications. At 1, 2, 4, 6 and 8 weeks of incubation, soil samples were taken destructively for the determination of soil mineral N (N-NH₄⁺ and N-NO₃⁻) using the Kjeldahl method (Bremer and Mulvaney, 1982). Data obtained were subjected to analysis of variance (ANOVA) followed by the Duncan Multiple Range Test at 5% significant level. Correlation analysis was performed using the SPSS package program.

Experiment 2: Effect of mixtures of sago pulp waste and Gliricidia sepium pruning on maize growth (a pot experiment)

A pot experiment was conducted in a glasshouse of the Faculty of Agriculture, Pattimura University. Each of the mixture of sago pulp waste (A) and *Gliricidia sepium* pruning (G) as for experiment 1 (A₀G₁₀₀; A₂₀G₈₀; A₄₀G₆₀; A₆₀G₄₀; A₈₀G₂₀ and A₁₀₀G₀), applied at a rate equivalent to 100 kg N ha⁻¹, was mixed with 20 kg of soil in a polybag. The basal fertilizers given were 3.74 g urea (N-fertilizer) polybag⁻¹, 0.21 g SP36 (P-fertilizer) polybag⁻¹ and 0.35 g KCl (K fertilizer) polybag⁻¹ (Syafurudin, 2015). After 2 weeks of incubation, one seed of maize of Nakula Sadewa 29 variety was planted. Six treatments and one control were arranged in a completely randomized design with three replications. Soil and plant samples were taken destructively at weeks 1, 2, 4, 6 and 8. Soil samples were analyzed for mineral N using the Kjeldahl method proposed by Bremer and Mulvaney (1982) with the addition of oxidized magnesium and Devarda Alloy. Plant height, stem diameter and root length were also measured. The data obtained were subjected to analysis of variance (ANOVA) followed by the Duncan Multiple Range Test at 5% significance level.

Results and Discussion

Chemical composition of the mixtures of sago pulp waste and Gliricidia sepium pruning

The mixtures of sago pulp waste and *Gliricidia sepium* pruning had various chemical compositions (Table 1). The C content, C/N ratio, polyphenol content, lignin content, polyphenol/N ratio, lignin/N ratio and

(polyphenol + lignin)/N ratio increased in value with the increasing proportion of sago pulp waste in the mixtures, while N content significantly decreased with decreasing proportion of *Gliricidia sepium* in the mixtures.

The lowest C content of 25.97% was observed in the A₀G₁₀₀ mixture, and the highest C content of 45.13% was in the A₁₀₀G₀ mixture. The lowest N content of 0.32% was in the A₁₀₀G₀ mixture, and the highest N content of 2.89% was in the A₀G₁₀₀ mixture. The C/N ratio obtained ranged from 9.18 (A₀G₁₀₀) to 141.03 (A₁₀₀G₀). For rapid decomposition and mineralization, organic material should have an N content higher than the critical value, which is between

1.5% to 2.5% (Palm et al., 2001), with a ratio value C/N of less than 20 (Hadas et al., 2004). Thus, the mixtures of sago pulp waste and *Gliricidia sepium* that have an N content higher than the critical value of N were A₆₀G₄₀ (1.33%), A₄₀G₆₀ (1.85%), A₂₀G₈₀ (2.35%) and A₀G₁₀₀ (2.86%). The lowest values of polyphenol content (2.16%), lignin content (7.97%), polyphenol/nitrogen ratio (9.82), lignin/nitrogen ratio (36.29), and (polyphenol + lignin)/nitrogen ratio (46.08) were observed in the A₀G₁₀₀. To undergo N mineralization, organic material should contain below lignin content 15%, and the polyphenol content is not more than 4% (Palm et al., 2001; Hadas et al., 2004).

Table 1. Chemical composition of mixtures of sago pulp waste and *Gliricidia sepium* pruning.

Mixtures of Organic Materials	Parameters							
	C (%)	N (%)	C/N ratio	Polyphenol (%)	Lignin	Polyphenol /N ratio	Lignin/N ratio	(Polyphenol +Lignin) /N ratio
A ₀ G ₁₀₀	25.93	2.86	9.18	2.16	7.97	9.82	36.29	46.08
A ₂₀ G ₈₀	29.77	2.35	12.67	3.88	9.08	17.07	40.06	57.2
A ₄₀ G ₆₀	33.61	1.85	18.17	6.54	10.05	29.73	45.69	75.43
A ₆₀ G ₄₀	37.48	1.33	33.17	7.42	12.77	29.13	60.79	89.54
A ₈₀ G ₂₀	41.29	0.83	49.75	9.14	15.61	36.53	76.84	113.37
A ₁₀₀ G ₀	45.13	0.32	141.03	6.12	15.24	46.47	82.87	129.34

Notes: A₀G₁₀₀ = 100% *Gliricidia sepium* pruning, A₂₀G₈₀ = 20% sago pulp waste and 80% *Gliricidia sepium* pruning, A₄₀G₆₀ = 40% sago pulp waste and 60% *Gliricidia sepium* pruning, A₆₀G₄₀ = 60% sago pulp waste and 40% *Gliricidia sepium* pruning, A₈₀G₂₀ = 80% sago pulp waste and 20% *Gliricidia sepium* pruning, and A₁₀₀G₀ = 100% sago pulp waste.

Cumulative mineral N in the soil (experiment 1)

The cumulative amount of mineral N in soil amended with sago pulp waste and *Gliricidia sepium* pruning mixtures increased from week 1 to week 4 and then decreased from week 6 to week 8 (Figure 1). The increase in the cumulative mineral N that occurred in week 1 to week 4 was in accordance with the

composition of the mixtures of sago pulp waste and *Gliricidia sepium* pruning, where the higher the proportion of *Gliricidia sepium* pruning in the mixtures, the higher was cumulative of mineral N in the soil. On the contrary, the higher the sago pulp waste in the mixtures, the lower the cumulative mineral N.

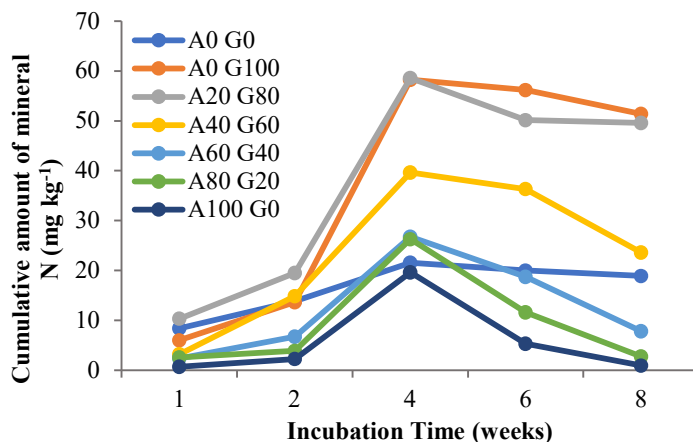


Figure 1. The cumulative amount of mineral N in soil amended with the mixtures of sago pulp waste and *Gliricidia sepium* pruning during 8 weeks incubation. A₀G₁₀₀ = 100% *Gliricidia sepium* pruning, A₂₀G₈₀ = 20% sago pulp waste and 80% *Gliricidia sepium* pruning, A₄₀G₆₀ = 40% sago pulp waste and 60% *Gliricidia sepium* pruning, A₆₀G₄₀ = 60% sago pulp waste and 40% *Gliricidia sepium* pruning, A₈₀G₂₀ = 80% sago pulp waste and 20% *Gliricidia sepium* pruning, and A₁₀₀G₀ = 100% sago pulp waste.

The highest cumulative mineral N of 58.62 mg kg⁻¹ occurred in week 4, which was observed in the A₂₀G₈₀ treatment. The high soil mineral N in the A₂₀G₈₀ treatment was influenced by the low C/N ratio (Seneviratne 2000; Cordovil et al., 2005), so that the mixed material mineralized more quickly (Kamkar et al., 2014; Gaisie et al., 2016; Jiang et al., 2017). Likewise, the polyphenol and lignin contents of the material were still below the decomposition limit (Palm et al., 2001; Hadas et al., 2004).

The decreases in the cumulative mineral N found at week 6 and week 8 were strongly influenced by the composition of the mixture of sago pulp waste and *Gliricidia sepium* pruning. The highest cumulative amounts of mineral N at week 6 and week 8 of 56.20 mg kg⁻¹ and 51.43 mg kg⁻¹, respectively, were found in the A₀G₁₀₀ treatment. Compared to the highest cumulative mineral N at week 4, namely, in the A₂₀G₈₀

treatment (58.62 mg kg⁻¹), or increased 172% compared to the control treatment of 21.53 mg kg⁻¹, the highest cumulative mineral N at week 6 (56.20 mg kg⁻¹) and week 8 (51.43 mg kg⁻¹) decreased, respectively, by 4.13% and 12.27%. The C/N ratio, polyphenol content, and the lignin content of the organic material mixtures have negative relationships with the cumulative mineral N in the soil, while the N content of the organic material mixtures had positive relationships with the cumulative mineral N in the soil (Table 2). Although *Gliricidia sepium* pruning decomposes relatively quickly so that it can contribute nitrogen (Chirwa et al., 2006; Walpola and Arunakumara, 2009; Kaba et al., 2019) as much as 30% within 7 days (Chirwa et al., 2006), the amount of N released from the pruning was not able to increase the cumulative amount of mineral N in the soil at week 6 and week 8.

Table 2. Correlation between the chemical composition of sago pulp waste and *Gliricidia sepium* pruning mixtures with the cumulative amount of N mineralized from the organic material mixtures.

Chemical composition of organic material mixtures	Coefficient of correlation (r)				
	Cumulative mineral N in soil (mg kg ⁻¹)				
	Incubation time (weeks)				
	1	2	4	6	8
C (%)	-0.571**	-0.554*	-0.276	-0.431	-0.492*
N (%)	0.318	0.572**	0.938**	0.900**	0.817**
C/N ratio	-0.670	-0.766**	-0.511*	-0.655**	-0.619**
Polyphenol (%)	-0.778**	-0.702**	-0.373	-0.554**	-0.637**
Lignin (%)	-0.718**	-0.686**	-0.186	-0.404	-0.479*
Polyphenol/N ratio	-0.795**	-0.747**	-0.417	-0.597**	-0.670**
Lignin/N ratio	-0.745**	-0.740**	-0.256	-0.466*	-0.535*
(Polyphenol+Lignin)/N ratio	-0.770**	-0.749**	-0.318	-0.519*	-0.590**

Notes: **significantly different at $p < 0.01$; *significantly different at $p < 0.05$.

N released from the mixtures of sago pulp waste and Gliricidia sepium pruning (experiment 2)

During the vegetative growth of maize, the amount of N released from the mixture of organic materials increased from week 1 to week 4; the increase varied depending on the proportion of sago pulp waste and *Gliricidia sepium* pruning in the mixtures. The higher pruning of *Gliricidia sepium* in the mixture significantly increased the amount of N released from the mixture of organic materials, while the higher the sago pulp waste in the mixtures significantly reduced the amount of N released from the mixtures. The highest amount of N released (82.45 mg kg⁻¹), or 156% higher than that of the control treatment, was observed at week 4 for the A₂₀G₈₀ treatment, while the lowest (3.41 mg kg⁻¹) was observed at week 8 for the A₁₀₀G₀ treatment (Table 3). The amount of N released from the mixtures of sago pulp waste and *Gliricidia sepium* prunings is closely related to the quality of the material (Cayuela et al., 2009). The A₂₀G₈₀ mixture had a high N content of 2.86%, with a low C/N ratio, low

polyphenol content, and low lignin content (Table 1). On the contrary, the A₁₀₀G₀ mixture had a low N content of 0.32%, high C/N ratio, high polyphenol content and high lignin content of 141.03, 6.12% and 15.24%, respectively (Table 1), which hindered the N released from organic materials (Liu et al., 2007; Teklay et al., 2007). Interactive effects of residue mixtures can occur when residues of component types with contrasting residue qualities are mixed (Hoorens et al., 2002). Results of this study showed that the effect of organic matter quality on the decrease in N released from the organic matter was prominent at week 6 and week 8. The decreased amount of N availability could be caused by N uptake by plant roots and the amount of N-mineral used by microbes (Harmsen and Schreven, 2010). Microbial needs for sources of N under conditions of N in plant residues are not sufficient to meet microbial needs, so microbes will use inorganic N present in soil solution, thereby reducing the amount of N available to be absorbed by plants (Walley, 2005; Vadakattu and Gupta, 2016).

Table 3. The amount of N released from the sago pulp waste and *Gliricidia sepium* pruning mixtures during the vegetative phase of maize growth.

Mixtures of organic materials	N released from sago pulp waste and <i>Gliricidia sepium</i> pruning mixtures (mg kg ⁻¹) during the vegetative phase of maize growth (weeks)				
	1	2	4	6	8
A ₀ G ₁₀₀	4.29 c	26.44 b	32.14 d	26.27 c	22.85 cd
A ₀ G ₁₀₀	13.93 a	32.60 a	82.41 a	75.11 b	66.04 b
A ₂₀ G ₈₀	8.57 b	14.12 c	82.45 a	80.85 a	79.85 a
A ₄₀ G ₆₀	3.64 c	7.79 d	44.57 b	37.76 c	26.73 c
A ₆₀ G ₄₀	2.32 cd	5.11 de	39.48 c	32.14 d	21.12 d
A ₈₀ G ₂₀	1.31 d	3.47 e	26.86 e	16.24 f	8.13 e
A ₁₀₀ G ₀	1.21 d	3.52 e	23.16 e	12.40 f	3.41 e

Notes: numbers followed by different letters are significantly different according to the Duncan Multiple Range Test at 5% level. A₀G₁₀₀ = 100% *Gliricidia sepium* pruning, A₂₀G₈₀ = 20% sago pulp waste and 80% *Gliricidia sepium* pruning, A₄₀G₆₀ = 40% sago pulp waste and 60% *Gliricidia sepium* pruning, A₆₀G₄₀ = 60% sago pulp waste and 40% *Gliricidia sepium* pruning, A₈₀G₂₀ = 80% sago pulp waste and 20% *Gliricidia sepium* pruning, and A₁₀₀G₀ = 100% sago pulp waste.

Maize growth (experiment 2)

Plant growth as measured by plant height, stem diameter, and root length increased from week 1 to week 8 (Table 4). The increase was significantly different from the increase in the proportion of *Gliricidia sepium* pruning in the mixtures. In contrast, the decrease was significantly different from the increase in the proportion of sago pulp waste in the

mixtures. Maize growth experiences a vegetative growth phase from week 4 until the plant enters the final vegetative stage at 8 weeks after planting, where the plant's need for nitrogen is very high (Ladan and Jacinthe, 2017). Nitrogen is an essential constituent of amino acids, amides, nucleotides and nucleoproteins, and is essential for cell division, cell enlargement and growth.

Table 4. Effects of the application of sago pulp waste and *Gliricidia sepium* pruning mixture on the growth of maize plant.

Mixtures of organic materials	Parameters of maize plants during the growth (weeks)				
	1	2	4	6	8
Plant Height (cm)					
A ₀ G ₀	23.36 c	35.53 d	48.86 e	84.90 c	107.00 b
A ₀ G ₁₀₀	27.00 a	44.86 b	69.09 b	102.56 b	102.56 c
A ₂₀ G ₈₀	24.87 b	49.20 a	73.73 a	106.87 a	129.16 a
A ₄₀ G ₆₀	23.80 c	44.63 b	65.85 c	102.89 b	128.63 a
A ₆₀ G ₄₀	23.06 c	39.93 d	60.13 d	69.90 c	101.83 c
A ₈₀ G ₂₀	20.83 d	35.23 d	44.83 f	56.10 e	85.03 d
A ₁₀₀ G ₀	19.70 ed	35.36 d	40.00 g	42.83 f	81.46 d
Stem Diameter (cm)					
A ₀ G ₀	0.05 e	0.08 d	0.22 d	0.46 d	1.29 d
A ₀ G ₁₀₀	0.13 b	0.14 b	0.35 b	0.49 c	1.25 e
A ₂₀ G ₈₀	0.15 a	0.17 a	0.44 a	1.05 a	1.65 a
A ₄₀ G ₆₀	0.12 b	0.18 a	0.35 b	0.50 b	1.52 b
A ₆₀ G ₄₀	0.08 c	0.13 b	0.25 c	0.16 e	1.43 c
A ₈₀ G ₂₀	0.06 d	0.10 d	0.20 e	0.12 f	1.24 f
A ₁₀₀ G ₀	0.03 e	0.06 e	0.07 f	0.07 g	0.85 g
Root length (cm)					
A ₀ G ₀	9.50 f	19.92 c	34.03 f	104.49 c	89.03 a
A ₀ G ₁₀₀	21.23 a	25.66 c	81.07 b	129.23 b	95.60 b
A ₂₀ G ₈₀	19.13 b	27.20 b	87.97 a	150.26 a	108.10 a
A ₄₀ G ₆₀	15.60 c	35.13 a	73.04 c	100.66 d	95.90 b
A ₆₀ G ₄₀	12.00 d	19.27 c	66.03 d	85.02 e	93.89 c
A ₈₀ G ₂₀	11.96 d	18.60 cd	36.96 fe	72.15 f	62.99 e
A ₁₀₀ G ₀	11.02 e	15.76 d	27.10 g	48.26 g	53.56 f

Notes: numbers followed by different letters are significantly different according to the Duncan Multiple Range Test at 5% level. A₀G₁₀₀ = 100% *Gliricidia sepium* pruning, A₂₀G₈₀ = 20% sago pulp waste and 80% *Gliricidia sepium* pruning, A₄₀G₆₀ = 40% sago pulp waste and 60% *Gliricidia sepium* pruning, A₆₀G₄₀ = 60% sago pulp waste and 40% *Gliricidia sepium* pruning, A₈₀G₂₀ = 80% sago pulp waste and 20% *Gliricidia sepium* pruning, and A₁₀₀G₀ = 100% sago pulp waste.

Therefore, plant growth is a function of plant uptake of nutrients, especially nitrogen. According to Sakala et al. (2000), mixing different quality organic matter has the potential to manipulate residue decomposition and regulate the timing of nutrient availability, including the availability of N. By developing better root growth, the plant can absorb nutrients to encourage plant growth through increasing plant meristematic and physiological activities (Akongwubel et al., 2012, so that high absorption causes the plant growth component to be also high (Akitan, 2019) as seen in the parameters, plant height 129.16 cm, stem diameter 1.65 cm and root length 150.26 cm

Conclusion

The application of 20% sago pulp waste and 80% of *Gliricidia sepium* pruning (A₂₀G₈₀) increased the cumulative amount of mineral N in an acid Dystrudept of Central Moluccas increased by 172% compared to the control treatment, the amount of N released by 156% higher than the control treatment at 4 weeks, and improved the growth of maize plants in acid soils.

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