AGRIWAR JOURNAL
MASTER OF AGRICULTURAL SCIENCE WARMADEWA UNIVERSITY
E-ISSN: 2808-1137, **P-ISSN**: 2808-1323
Vol. 6, **No.** 1, **Jun 2026**, **Page** 1-7
DOI: https://doi.org/10.22225/aj.6.1.2026.1-7

Weed Management by Acacia Organic Mulch In Soybean For Sustainable Agriculture And Food Security

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Abstract
The application of organic mulch derived from plants containing allelopathic compounds, which can suppress weed growth in soybean fields. This study aims to evaluate the effectiveness of reduced acacia organic mulch dosages as an adaptive and efficient weed management innovation that contributes to sustainable agriculture practices and reinforces national food security.The study was conducted in Lawe Sagu Hulu Village, Lawe Bulan Sub-district, Southeast Aceh Regency, Indonesia, from August to December 2024. The experimental design employed a single-factor Randomized Complete Block Design (RCBD) with five treatment levels of acacia organic mulch dosage: 0, 4.8, 9.6, 14.4, and 19.2 tons ha^{-1}, each replicated four times. The acacia litter used as organic mulch was cut into 10 cm pieces and spread evenly on the soil surface according to the treatment dosage. Observed parameters included weed cover percentage, number of species, and fresh weed biomass, plant height and number of leaves, number of pods, seeds, and dry seed yield per plant. Data were analyzed quantitatively using SPSS version 16. When significant effects were detected, mean separation was conducted using DNMRT at a 5% significance level. The application of acacia organic mulch at a dosage of 4.8 tons ha^{-1} reduced weed cover percentage at 20, 30, 40, and 50 days after planting and increased plant height at 30 days as well as the number of pods per soybean plant. The dosage of 9.6 tons ha^{-1} of acacia organic mulch decreased weed fresh weight at 30 and 50 days after planting.

Keyword: *weed management; organic mulch; Acacia; allelopathy; soybean.*

1. Introduction

Weeds are one of the major constraints in soybean cultivation as they compete for light, water, and nutrients, leading to significant yield reduction [1], [2], [3]. The use of chemical herbicides has long been considered a conventional, effective, and efficient method; however, it contributes to environmental pollution, weed resistance, and soil residue accumulation [4], [5], [6]. According to the implementation of environmentally friendly agricultural practices is essential to support global food security [7]. This effort emphasizes the need for crop cultivation systems that maintain ecosystem balance, reduce dependency on chemical inputs, and optimize the utilization of local resources effectively and efficiently.

One recommended approach is the application of organic mulch derived from plants containing allelopathic compounds, which can suppress weed growth in soybean fields. Organic mulch also contributes to soil conservation, moisture retention, and improvement of soil physical, chemical, and biological properties [8], [9]. In line with the policy direction of the Government of the Republic of Indonesia through the Sustainable Agriculture and National Food Security Strategy 2045, the adoption of ecology-based technologies, including the use of local organic inputs as substitutes for chemical inputs, is strongly encouraged [10], [11]. This policy aims to strengthen the cultivation systems of strategic food crops such as soybeans, which are highly susceptible to weed competition during early growth stages.

Among plant species containing allelopathic compounds, *Acacia* species exhibit strong potential as organic mulch for weed management while simultaneously improving soil quality.

According to [12], the application of acacia-based organic mulch at planting time reduced the density of *Portulaca oleracea* by more than 50%, indicating the potential of invasive biomass utilization as a natural weed control material in sustainable agricultural systems. Furthermore reported that applying acacia organic mulch at a thickness of 5 cm m^{-1} reduced weed inhibition percentage by 54.22%, with broadleaf weeds showing the most significant suppression [13]. The study also revealed that acacia mulch altered weed composition, decreasing the dominance of broadleaf species. Similarly, [14] explained that applying acacia organic mulch at 28 tons ha^{-1} significantly suppressed the emergence of broadleaf weeds without negatively affecting maize growth or soil microbial activity. The effectiveness of this treatment, however, varies depending on weed species and environmental conditions, with the most substantial control observed on *Portulaca oleracea* and *Amaranthus retroflexus*.

The use of *organic acacia mulch as a weed management strategy in soybean cultivation remains underexplored, creating a research gap in advancing* sustainable agriculture. Previous studies demonstrated that applying 28 tons ha^{-1} of acacia organic mulch effectively suppressed weed growth in maize; however, such a dosage is considered less efficient. Therefore, this study aims to evaluate the effectiveness of reduced dosages of organic acacia mulch as an adaptive and efficient weed management innovation that contributes to sustainable agricultural practices and reinforces national food security.

2. Materials and Methods

The study was conducted in Lawe Sagu Hulu Village, Lawe Bulan Sub-district, Southeast Aceh Regency, Indonesia, from August to December 2024. The experimental site was located on flat topography at an elevation of approximately 245 meters above sea level, characterized by Alfisol soil type. The tools used included measuring cylinders, hoes, raffia strings, label paper, an oven, and an analytical balance. The materials consisted of soybean variety Grobogan, *acacia* litter, deltamethrin insecticide, urea, SP-36, and KCl fertilizers.

The experimental design employed a single-factor Randomized Complete Block Design (RCBD) with five treatment levels of acacia organic mulch dosage: 0, 4.8, 9.6, 14.4, and 19.2 tons ha^{-1}, each replicated four times. Land preparation involved soil tillage and plot establishment measuring 2.5 × 2.5 m. The acacia litter used as organic mulch was cut into 10 cm pieces and spread evenly on the soil surface according to the treatment dosage.

Observed parameters included weed characteristics (weed cover percentage, number of species, and fresh weed biomass), soybean growth traits (plant height and number of leaves), and yield components (number of pods, seeds, and dry seed yield per plant). Data were analyzed quantitatively using SPSS version 16. When significant effects were detected, mean separation was conducted using Duncan's New Multiple Range Test (DNMRT) at a 5% significance level.

3. Results and Discussion

Weed Characteristics

Table 1 shows that the application of 4.8 tons ha^{-1} of acacia organic mulch effectively reduced weed cover percentage at 20, 30, 40, and 50 days after planting (DAP). This indicates that the mulch thickness was sufficient to suppress weed seed germination by preventing light penetration to the soil surface. The microclimatic conditions beneath the thick mulch layer became more humid and cooler, creating an unfavorable environment for weed germination. Furthermore, allelopathic compounds contained in acacia plants such as phenolics, flavonoids, and tannins play a role in inhibiting enzymatic activity and early root growth of weeds. The combination of physical inhibition due to mulch thickness and allelopathic activity released during decomposition results in a complex and synergistic weed control mechanism. The simultaneous interaction of these factors suppresses weed growth through physical space limitation and physiological disturbances during germination and vegetative development. This finding is consistent with several studies that report adequate mulch thickness acts as a barrier that limits light penetration

DOI: https://doi.org/10.22225/aj.6.1.2026.1-7

to the soil surface, thereby inhibiting weed seed germination dependent on light intensity for initiation [15], [16]. Furthermore, mulch layers also create a microclimate unfavorable for germination and early weed growth [17], [18], [19], while allelopathic compounds in acacia have been shown to inhibit root growth with a germination rate reduction of more than 80% in several weed species [12], [20].

Table 1. Mean percentage of weed cover, number of weed species, and weed fresh weight at 20, 30, 40, and 50 days after planting as influenced by various doses of acacia organic mulch in soybean cultivation.

Treatment of Acacia Organic Mulch	Percentage of Weed Cover (%)			
	20	30	40	50
0 t ha^{-1}	99.50a	100.00a	100.00a	100.00a
4.8 t ha^{-1}	41.42b	43.25b	57.50b	61.05b
9.6 t ha^{-1}	26.17b	37.00b	63.00b	62.50b
14.4 t ha^{-1}	28.16b	40.00b	54.75b	59.25b
19.2 t ha^{-1}	26.08b	34.25b	54.75b	66.78b
	Number of Weed Species			
0 t ha^{-1}	9.75	9.25	9.00	9.50
4.8 t ha^{-1}	8.25	7.75	8.25	5.75
9.6 t ha^{-1}	7.75	8.00	8.50	6.75
14.4 t ha^{-1}	6.25	7.00	6.50	5.75
19.2 t ha^{-1}	7.75	7.75	6.50	7.25
	Weed Fresh Weight (g)			
0 t ha^{-1}	79.52	163.01a	140.24	261.44a
4.8 t ha^{-1}	63.61	114.48ab	112.57	202.08ab
9.6 t ha^{-1}	41.04	92.61b	99.30	184.25bc
14.4 t ha^{-1}	23.69	77.95b	102.55	166.45bc
19.2 t ha^{-1}	21.18	75.60b	89.76	113.56c

Note: The average value followed by the same letter in the same treatment and column different, not significant at 5% DNMRT test level.

Although weed cover percentage decreased, the number of weed species remained relatively unchanged following acacia organic mulch application. This can be explained by the fact that the mulch dosage primarily suppresses weed growth and dominance rather than altering weed community composition. Some weed species can adapt to mulched conditions, while acacia's allelopathic effect is selective effectively suppressing only certain species without uniformly affecting all weed types. Changes in weed diversity within agricultural lands generally occur gradually after several growing seasons, along with increased organic matter and shifts in soil pH [21]. Therefore, a single application of organic mulch is insufficient to significantly modify weed community structure. These results are supported by previous researchers who noted that the presence of a soil seed bank acts as a buffer, allowing weed species to persist [22], [23], [24], thus preventing changes in total weed species number.

Table 1 also demonstrates that the application of 9.6–19.2 tons ha^{-1} of acacia organic mulch significantly reduced weed fresh weight at 30 and 50 DAP. This finding confirms that a thicker mulch layer increases both physical barriers and soil allelopathic concentrations, thereby inhibiting root development, photosynthesis, and weed biomass accumulation. Consequently, competition for nutrients, water, and light particularly among short-lived weed species becomes limited. Allelopathic compounds can inhibit root cell division and elongation, disrupt protein, ATP, and hormone synthesis, resulting in thickened, shortened roots that struggle to absorb nutrients, ultimately restricting growth [25], [26], [27]. These findings are in line with [28], which reported that mulch thickness is inversely proportional to weed biomass accumulation. The reduction in fresh weed weight also indicates the effectiveness of mulch in minimizing competition with soybean plants. As the weed cover percentage declines, the resulting weed biomass consequently decrees.

Soybean Growth Characteristics

Table 2. Mean plant height and number of leaves of soybean at 20, 30, 40, and 50 days after planting as affected by various doses of acacia organic mulch.

Treatment of Acacia Organic Mulch	Plant Height (cm)			
	20	30	40	50
0 t ha^{-1}	15.19	17.00a	27.00	51.75
4.8 t ha^{-1}	17.50	21.79b	40.25	52.25
9.6 t ha^{-1}	18.38	23.13b	41.00	63.75
14.4 t ha^{-1}	18.69	24.25b	41.00	62.75
19.2 t ha^{-1}	20.28	31.38c	45.25	52.50
	Leaves of Soybean			
0 t ha^{-1}	11.70	15.88	19.75	29.25
4.8 t ha^{-1}	11.00	15.75	21.50	36.00
9.6 t ha^{-1}	12.38	16.00	25.25	32.75
14.4 t ha^{-1}	11.00	11.33	22.75	36.50
19.2 t ha^{-1}	10.63	14.50	26.25	36.50

Note: The average value followed by the same letter in the same treatment and column different, not significant at 5% DNMRT test level.

Table 2 indicates that the application of acacia organic mulch at a dosage of 4.8 tons ha^{-1} significantly increased soybean plant height at 30 days after planting (DAP), although it did not significantly affect the number of leaves. This result reflects the optimal availability of macronutrients such as nitrogen and phosphorus, which support root physiological activity. The suppression of weed competition through allelopathic mulch not only enhances crop access to light and growth space but also inhibits weed proliferation via the release of secondary metabolites that interfere with cell division and elongation in weed roots. Consequently, the allocation of resources for stem elongation and root system development becomes more efficient [29], [30]. Furthermore, the initial decomposition of organic material promotes soil microbial activity, which contributes to nutrient mineralization, improves soil structure, and enhances water retention capacity all of which collectively support plant morphological adaptation, including stem elongation and root system expansion [31]. Nevertheless, the number of leaves did not show a significant response, as plants tend to prioritize vertical growth under abundant light conditions. Nitrogen released from mulch decomposition was likely insufficient to induce new leaf formation. The genetic characteristics of the soybean variety also contribute to the stability of leaf number, while organic mulch primarily modulates photosynthetic efficiency rather than leaf quantity. These findings are consistent with [32], who reported that vegetative growth, particularly stem elongation and photosynthetic efficiency, is more responsive to mulch application than leaf number.

Yield Components Characteristics

Table 3 indicates that the application of acacia organic mulch at a dosage of 4.8 tons ha^{-1} significantly contributed to the increase in the number of soybean pods, primarily by mitigating weed competition and allowing plants to access light, water, and nutrients more efficiently. The gradual decomposition of acacia litter releases essential nutrients, particularly macronutrients, which enhance pod formation and development. *Allelopathic* compounds contained in the mulch also suppress weed proliferation, thereby improving nutrient use efficiency by soybean plants. A more controlled environment, free from excessive weed interference, supports the formation of a greater number of uniform pods.

Table 3. Mean number of pods, seeds, and dry seed yield of soybean at 20, 30, 40, and 50 days after planting as affected by different doses of acacia organic mulch.

Treatment of Acacia Organic Mulch	Number of Pods	Number of Seeds	Dry Seed Yield
0 t ha^{-1}	11.44a	20.29	165.44
4.8 t ha^{-1}	26.28b	50.69	259.07
9.6 t ha^{-1}	37.81b	68.86	492.14
14.4 t ha^{-1}	27.78b	50.16	259.52
19.2 t ha^{-1}	33.90b	58.16	332.87

Note: The average value followed by the same letter in the same treatment and column is different, not significant at 5% DNMRT test level.

This finding aligns with the reports of those who observed that organic mulch dosage did not significantly influence the number of seeds or dry yield [33], [34], likely due to limited nutrient availability during the seed-filling phase, the slow decomposition rate of organic material, and complex interactions between environmental factors and interspecific plant competition. The effectiveness of organic mulch tends to increase with continuous application, as the accumulation of organic matter and the enhancement of soil microbial activity require time to generate a measurable impact on land productivity [35], [36].

4. Conclusion

The application of acacia organic mulch at a dosage of 4.8 tons ha^{-1} reduced weed cover percentage at 20, 30, 40, and 50 days after planting and increased plant height at 30 days as well as the number of pods per soybean plant. The dosage of 9.6 tons ha^{-1} of acacia organic mulch decreased weed fresh weight at 30 and 50 days after planting.

Acknowledgments

The authors sincerely thank the Ministry of Higher Education, Kementerian Pendidikan Tinggi Riset dan Teknologi, for providing research funding through the Beginner Lecturer Research Program (Afirmasi), Batch II, 2024.

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