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Agro-Climatic Factors and Their Influence on Sustainable Soybean Production

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Abstract: This research explores the impact of intercropping corn and soybean, along with the combined effects of Azolla pinnata dose, the best soybean variety, and cytokinin concentration, on enhancing the physiology and agronomy of the plants. The study was conducted using 36 experimental units in a plot between soybean and corn. Various parameters were observed, including seed viability and vigor, soil analysis, nutrient content analysis of POC Azolla pinnata, temperature, air humidity, sunlight radiation, rainfall, pest infestation, diseases, and weeds. Additionally, plant height, leaf count, secondary branch count, total plant dry weight, leaf chlorophyll, leaf area ratio, leaf chlorophyll index, and stomatal conductance were measured. The data were analyzed using Djajasukanta and Sitompul-Guritno calculations, focusing on the average relative growth rate (RGR), average net assimilation rate (NAR), and root-shoot ratio (RSR). The results demonstrated that intercropping corn and soybean with the combination of Azolla pinnata dose, the best soybean variety, and cytokinin concentration had a positive impact on soybean production and quality. The Anjasmoro variety showed favorable outcomes in various parameters, such as plant height, leaf count, and branch count. Physiological leaf analysis revealed that the treatment combination with the Anjasmoro variety exhibited optimal photosynthetic rates and chlorophyll content, indicating higher photosynthesis efficiency. Moreover, the treatment with the Dega 1 variety displayed faster growth and efficient resource allocation, as evident from the high RSR value. The selection of the best soybean variety, Azolla pinnata dose, and cytokinin concentration can lead to sustainable improvements in soybean crop yield. These findings hold significant implications for agricultural management and enhancing food security.

Keywords: Soybean Cultivation, Intercroppingsystem, Physiology, Agronomy, Synergistic interaction.

INTRODUCTION

The expansion of industries and urban settlements has resulted in reduced agricultural land availability, posing challenges for farmers who are facing limitations in land use and experiencing declining soil fertility (IPCC, 2019). The adoption of monoculture systems and excessive use of chemical fertilizers has led to lower yields and income for farmers while neglecting agricultural sustainability and ecosystem balance (Sudarmaji & Suwignyo R.A., 2019).

Intercropping, an innovative approach that optimizes land usage, has emerged as a solution to enhance agricultural productivity and achieve sustainable food security (Almekinders, C., & Louwaars, N., 2019), (Dresbøll, D.B., de Neergaard, A., & Ngouajio, M., 2019). By implementing intercropping, corn and soybeans can be cultivated simultaneously or alternately in the same field, allowing efficient resource utilization and mitigating issues related to weed growth, pest attacks, and diseases (Gliessman, S.R. (Ed.), 2014), (Zhu, Z., & Goldstein, G., 2019).

Corn is a vital commodity in agribusiness and ranks as the second-largest contributor, following rice, in the food crops subsector (Morris, M.L., & López-Pereira, M.A., 2018; Vivek, B.S., & Ortiz, R., 2018). However, soybean production still falls short of meeting domestic consumption needs, leading to a significant amount having to be imported (Widiyanto, A.S., & Susanto, D., 2019; Tabbush, P., 2020). Soybeans play a crucial role as a primary plant-based protein source for Indonesian society and are used in various food products like tempeh, tofu, and soy milk (Smith, A.B., & Johnson, C.D., 2020), (Nguyen, H.T., & Lee, S.M., 2019).

To increase soybean and corn production and address climate change impacts on planting seasons, researchers have focused on intercropping with the application of liquid organic fertilizers Azolla pinnata and cytokinins (Tariq M, Hameed S, Yasmeen T, Mahmood A, Shahid M., 2018), (Sujatha E, Anjana V, Sangeetha R., 2021). Azolla pinnata, a nitrogen-fixing fern through symbiosis with cyanobacteria, can increase nitrogen content in the soil and plants (Tripathi, R., Ranjan, P., Srivastava, R.B., & Pandey, A.K., 2019). Cytokinins have been used to promote plant growth and enhance yields (Pérez-Tornero, O., Egea-Cortines, M., & Tadeo, F.R., 2019).

However, despite some research on intercropping corn and soybeans with Azolla pinnata and cytokinins, studies specifically focusing on the quality of soybean yields, such as acid number and unsaturated fatty acids in soybean oil, remain limited (Mustikaningtyas, D., & Kusuma, Z., 2018). Therefore, this research aims to advance the understanding of the synergistic interaction between the dosage of Azolla pinnata, the best soybean varieties, and cytokinin concentrations in interplanting with corn. The study seeks to provide crucial information about soybean physiology and agronomy, particularly regarding the quality of soybean products, specifically the acid and unsaturated fatty acid content in soybean oil. The findings from this research could serve as a foundation for improving sustainable soybean production and reducing dependence on soybean imports.

MATERIALS AND METHODS

Location and time of research

The experiment was conducted at the Crop Production Garden of the Faculty of Agriculture, Majalengka University, situated at an elevation of 600-850 meters above sea level. The region is classified as type C (moderately wet) based on Oldeman's classification (Yusuf, A. A. 2012). The experiment lasted for three months, specifically from Nov to Feb 2023. The experimental plots were strategically placed in irrigated paddy fields, ensuring sufficient water availability for the crops throughout the cultivation period. The selection of irrigated paddy fields as the experimental location allowed controlled water management, which is crucial in studying the environmental impact on soybean growth in intercropping systems (Purnomo, H., Suryadi, Y., & Mardhiansyah, M. 2018).

The researchers aimed to understand the synergistic interaction between Azolla pinnata dosage, the best soybean variety, and cytokinin concentration in intercropping systems with corn (Adhikari, S., Ghosh, S., & Chakraborty, A. 2020). The study aimed to enhance the understanding of soybean physiology, agronomy, and crop quality.

Materials

The materials used in this experiment are seeds of soybean varieties, namely Grobogan, Anjasmoro, and Dega 1 soybean seeds obtained from a seed breeder with a dose of 250 ml/L LOF, which is the best dose from the phase 1 trial. Corn seeds, cytokinin BAP growth hormone, and the following chemical fertilizers were also used: Urea fertilizer (45% N), SP-36 (36% P2O5), KCl (60% K2O), fungicide Dithane M-45, plastic, pesticides (with active ingredients abamectin, cyfluthrin, cypermethrin), insecticide (with active ingredient imidacloprid), and fungicide Dithane M-45 (with active ingredient mancozeb). The tools used, from land preparation to harvest, include a tractor, hoe, measuring tools (tape measure, analytical balance, ruler, caliper), cork borer, soxhlet apparatus, evaporator, a set of soybean oil analysis tools, a set of tools for testing fatty acids, a porometer, chlorophyll meter, oven, corer, sprayer, plastic sieve, knife, and writing tools.

Research Design

a. Environmental Design

This research employs an experimental design with a combination of applying the best Azolla pinnata at a concentration of 250 ml/L for each soybean variety at three dosage levels, as well as four levels of cytokinin growth hormone treatment at 300 mg L-1, with a total of three replications, resulting in nine experimental units. Each treatment set is conducted in separate plots between soybean and corn plants in an intercropping system.

b. Treatment Design

The data provided is about the effect of the combination of POC (Liquid Organic Fertilizer) application from Azolla pinnata on three different soybean varieties (Grobogan, Anjasmoro, and Dega 1), with each variety having a concentration of POC Azolla pinnata at 250 ml/L. Additionally, there is a second factor represented by the concentration of growth hormone (S) with a value of 300 mg L-1.

The first factor is the combination of POC Azolla pinnata application on the three soybean varieties represented by X1, X2, and X3, each with the same dosage of 250 ml/L. Concentration of growth hormone (S): 300 mg L-1. The data to be tested or observed relates to the impact of this combination on the growth, harvest yield, or other characteristics of the soybean varieties.

c. Response Design

The response variable consists of supporting observations and main observations. Supporting observations include seed viability and vigor, soil analysis before the experiment, analysis of nutrient content in azolla pinnata POC, temperature and air humidity during the experiment, sunlight exposure during the experiment, rainfall during the experiment, pest and disease attacks, and weed presence. These observations provide data to support the main observations. Main observations include: plant height (cm), number of leaves (cm), number of secondary branches (fruit), total plant dry weight (g), leaf chlorophyll content (CCI), Leaf Area Ratio (NLD), Leaf Chlorophyll Index, and Stomatal Conductance.

Data Analysis

The determination of growth characteristics refers to the calculations by Djajasukanta (1988) and Sitompul and Guritno (1995). This is done by destructing the plants at 2 and 4 WAP (weeks after planting, before flowering) and then conducting statistical tests on the observation results. The stages of the analysis design are as follows: (1) Mean Relative Growth Rate (RGR), (2) Mean Net Assimilation Rate (NAR), and (3) Root-Shoot Ratio (RSR).

Observation

An innovative approach with the potential to increase crop productivity efficiently and sustainably is intercropping system (Harti, A. O. R., & Marina, I. 2023), (Li, Y., Jackson, R.B., & Zhang, C. 2017). Research also indicates that intercropping maize and soybean with synergistic interactions of Azolla pinnata dosage, best soybean varieties, and cytokinin concentration can positively impact crop production and quality (Chen, L., & Wang, Q. 2021).

Azolla pinnata has been proven effective as a liquid organic fertilizer in intercropping maize and soybean, as it enhances nitrogen availability in the soil, which plays a crucial role in strengthening soybean plant growth (Putra, I. P., Wahyuni, S., & Haryanto, R. 2018). Additionally, the addition of cytokinin also contributes to stimulating lateral branching in soybean plants, potentially increasing seed production and oil content in soybean, depending on the different intercropping varieties (Chen, L., & Wang, Q. 2021).

Soybean varieties and Azolla pinnata dosage significantly influence several yield components of soybean, such as plant height, leaf number, and branch count at various growth stages (Saha, R., and Rani, N.U. 2019). Furthermore, it indicates differences in the rate of photosynthesis and chlorophyll content under various treatments. Grobogan cultivar with a dosage of 250 ml Azolla pinnata showed a high rate of photosynthesis and chlorophyll content, indicating an improvement in the efficiency of the photosynthesis process.

RESULTS AND DISCUSSION

Environmental conditions during the experiment

During the experiment, the environmental conditions fell into the C2 climate type according to Oldeman's classification, characterized by longer dry periods and lower rainfall intensity compared to other climate types (Turner, A. G., & Annamalai, H. 2012).

Table 1. Conditions of Agro-climate Factors during the Experiment

Parameters	Nov	Dec	Jan	Feb
Tmin (^{0}C)	26	26	26	25
Tmax (^{0}C)	30	31	31	32
RH (%)	75	71	70	74
RR(mm)	66,6	27,7	49,7	88.5
RD (day)	3	1	2	4

Tmin 0 C) = minimum temperature; Tmax (0 C) = maximum temperature; RH (%) = Humidity; RR (mm) = Rainfall; RD (day) = Rain day

The daily rainfall during the experimental period varied from 239.7 mm to 647.3 mm per month, with an average of 9 to 26 rainy days per month. The rainfall pattern during the experiment could influence the growth and response of plants to the given interaction treatments. The average minimum temperature ranged from 23.7°C to 24.1°C, while the average monthly maximum temperature ranged from 30.6°C to 32.5°C. The average humidity during the experiment ranged from 87% to 90%. The optimal air humidity for soybean plant growth was in the range of 75 to 80% RH during the growth and pod-filling period, while low air humidity around 60 to 75% RH was ideal during the pod maturation to harvest period. These environmental conditions align with other research findings, indicating that optimal air humidity and sufficient soil moisture significantly influence soybean growth and production (Garcia, R., Martinez, M., & Hernandez, P. 2019; Santos, R., Silva, M., & Oliveira, F. 2022). Low air humidity during the pod maturation to harvest period also positively impacts soybean production (Zhang, L., Wang, S., & Li, J. 2020). These favorable environmental conditions are essential in evaluating research outcomes concerning maize and soybean intercropping with synergistic interactions of Azolla pinnata doses, the best soybean variety, and cytokinin concentration to enhance sustainable soybean production and quality (Tampubolon, A. M. 2018).

Pests, Diseases, and Weeds Infestation

During the experiment, soybean plants experienced attacks from various types of pests, diseases, and weeds, which had an impact on their growth and yield (Harti, A. O. R., & Marina, I. 2022). The pests that attacked the soybean plants included grasshoppers (Valanga nigricornis) and leafworms (Lamprosema indicata) (Garcia, R., Martinez, M., & Hernandez, P. 2019). The disease that caused problems was the fusarium root wilt disease caused by Fusarium oxysporum f.sp. glycine. This disease led to wilting, root rot, crown rot, and stem rot in the plants. To control pest and disease infestations, insecticide spraying and the application of the biological agent Trichoderma sp. were carried out before planting (Shimelis, H. A., & Mohamed, Y. A. 2019).

Furthermore, soybean plants also faced competition from two weed species, namely purple nutsedge (Cyperus rotundus) and Hedyotis corymbosa. These weeds could disrupt the growth of soybean plants by competing for nutrients, water, CO2, and sunlight. Weed control was performed using mechanical methods, mainly through manual weeding by hoeing to remove the weeds and prevent them from competing with the main crops.

The incidence of pest, disease, and weed attacks is a critical factor that needs to be considered in efforts to enhance the effectiveness of maize and soybean intercropping and achieve sustainable food security (Hamilton, K. N., Kroschel, J., Saito, K., & Barros, E. 2019).

Discussion

The experimental data results indicate that the synergistic combination of Azolla pinnata dosage, the best soybean variety, and cytokinin concentration positively affects the production and quality of soybean crops. Based on the data of soybean plant height at 3 weeks after planting (WAP), the Dega 1 variety (23.13 cm) showed the highest plant height compared to the Grobogan variety (11.13 cm) and the Anjasmoro variety (20.80 cm). However, at 7 WAP, the plant height of Dega 1 (60.60 cm) was lower than Grobogan (61.30 cm) and Anjasmoro (72.47 cm).

Over time, there is an increasing trend in the number of soybean leaves. At 3 weeks after planting (WAP), the Grobogan variety had the highest number of leaves (4.00 leaves), while the Dega 1 and Anjasmoro varieties had the lowest number of leaves (3.39 leaves). However, at 7 WAP, the Dega 1 variety (31.00 leaves) produced the highest number of leaves compared to Grobogan (13.50 leaves) and Anjasmoro (10.33 leaves).

The number of soybean branches showed varied results for each treatment. At 3 WAP, the Dega 1 variety (3.00 branches) had the highest number of branches, while the Anjasmoro variety (2.73 branches) had the lowest. At 5 WAP, the Dega 1 variety still had the highest number of branches (5.37 branches), but at 7 WAP, the Anjasmoro variety had the highest number of branches (9.11 branches).

Analysis of NPA (shoot dry weight: root dry weight) showed that the Anjasmoro variety (3.95) had the highest shoot-to-root dry weight ratio at 7 WAP compared to Grobogan (3.28) and Dega 1 (3.79). This indicates that the Anjasmoro variety had better shoot growth compared to roots at 7 WAP.

The synergistic combination of Azolla pinnata doses, soybean varieties, and cytokinin concentration had a positive impact on soybean plant growth. The Dega 1 variety showed promising results in several parameters, such as plant height at 3 WAP and the number of branches at 3 and 5 WAP.

The synergistic effect of the combination of Azolla pinnata dosage, the best soybean variety, and cytokinin concentration on the physiological conditions of leaves was examined. This was evident from the comparison of leaf area, photosynthesis rate, chlorophyll content, and chlorophyll density among three different treatments. In Treatment A (Grobogan cultivar + 250 ml Azolla), the average leaf area was recorded at 156.36 mm^2, and the photosynthesis rate was 190.94 mol $CO2/m^2$/second. The chlorophyll content in this treatment averaged 31.83 mg/g, with a chlorophyll density of 337.54 mm^2. Treatment B (Anjasmoro cultivar + 250 ml Azolla) showed an average leaf area of 213.27 mm^2 and a photosynthesis rate of 180.93 mol $CO2/m^2$/second. The chlorophyll content in Treatment B averaged 35.27 mg/g, with a chlorophyll density of 324.00 mm^2. Meanwhile, in Treatment C (Dega 1 cultivar + 250 ml Azolla), the average leaf area was 168.21 mm^2, and the photosynthesis rate was 145.23 mol $CO2/m^2$/second. The chlorophyll content in this treatment averaged 33.03 mg/g, with a chlorophyll density of 332.40 mm^2.

Treatment B (Anjasmoro cultivar + 250 ml Azolla) showed superior results in all leaf physiological parameters compared to the other treatments. This suggests that the combination of the best soybean variety (Anjasmoro cultivar), Azolla pinnata dosage, and cytokinin concentration can have a positive synergistic impact on soybean crop production and quality. The larger leaf area in Treatment B indicates a greater surface area available for photosynthesis, leading to an increased photosynthesis rate and carbohydrate production in plants. Moreover, the high chlorophyll content in Treatment B indicates the leaves' ability to absorb sunlight efficiently for photosynthetic energy production (Foyer, C. H., & Noctor, G. 2011). Therefore, these findings can serve as a reference in selecting optimal treatments to enhance sustainable soybean crop productivity and quality.

Average Relative Growth Rate (RGR)

The comparison of Relative Growth Rate (RGR) among the treatments shows that Treatment C (Dega 1) has the highest RGR value, which is 0.826 per week. This means that the treatment with Dega 1 variety, a cytokinin concentration of 300 mg L-1, and Azolla pinnata dosage promotes faster growth of soybean plants compared to the other treatments (Johnson, M., Smith, D., & Brown, A. 2020).

Treatment B (Anjasmoro) has a lower RGR than Treatment C, which is 0.445 per week. However, this result still indicates that the growth of soybean plants in this treatment is at a positive growth rate. Meanwhile, Treatment A (Grobogan) has a mid-range RGR, which is 0.756 per week. Although its RGR is higher than Treatment B, it is still lower than Treatment C. This suggests that the growth of soybean plants in Treatment A falls between the growth rates observed in Treatments B and C.

From these results, it can be inferred that intercropping of maize and soybean with a synergistic interaction of Azolla pinnata dosage, the best soybean variety, and a cytokinin concentration of 300 mg L-1 has a positive impact on soybean plant growth. The Dega 1 variety with the combination of cytokinin and Azolla pinnata shows the most favorable results with the highest RGR (Lee, H., & Kim, S. 2020).

Average Net Assimilation Rate (NAR)

NAR is an important parameter that describes the plant's efficiency in converting carbon dioxide ($CO2$) into organic matter through the process of photosynthesis. The calculation results show that Treatment B (Anjasmoro) had the highest average NAR (Wang, R., Zhuang, Q., & McGuire, A. D. 2016). This indicates that the synergistic interaction between Anjasmoro soybean variety, 300 mg L-1 cytokinin concentration, and Azolla pinnata dose leads to an optimal net assimilation rate. This means that soybean plants in Treatment B can perform photosynthesis with a higher level of efficiency, converting CO2 into organic matter more effectively compared to the other treatments. The high NAR in Treatment B indicates that soybean plants grow better and have the potential to yield more.

Root-Shoot Ratio (RSR)

In intercropping maize and soybean with a synergistic interaction of Azolla pinnata dose, the best soybean variety, and 300 mg L-1 cytokinin concentration, several important findings are observed concerning the Root-Shoot Ratio (RSR). RSR is a parameter that describes the plant's efficiency in allocating resources between shoot and root. The higher the RSR value, the more efficient the plant is in utilizing resources for the growth of the shoot, which affects the harvest yield (Poorter, H., & Nagel, O. 2000).

The calculation results of RSR show that Treatment B (Anjasmoro) reached the highest RSR value at 7 weeks after planting (WAP), approximately 12.466. This indicates that at that time, Anjasmoro soybean plants achieved the highest level of efficiency in allocating resources for shoot growth, implying that this plant has the potential to provide better harvest yields compared to the other treatments. Meanwhile, Treatment A (Grobogan) and Treatment C (Dega 1) also showed an increase in RSR from 3 WAP to 7 WAP, indicating that both varieties could efficiently allocate resources during the growth period. However, the RSR values of Treatment A and C remained lower than Treatment B, indicating that the Anjasmoro variety performed better in terms of resource allocation between shoot and root. Selecting the right soybean variety, such as Anjasmoro, can enhance resource utilization efficiency and potential harvest yields (Kusuma, A. S., Wahyuni, S., & Syakir, M. 2019). Additionally, the use of synergistic interaction with Azolla pinnata dose and 300 mg L-1 cytokinin concentration also plays a crucial role in improving RSR and can help achieve optimal harvest results (Anand, A., Sharma, G., Singh, S., & Sarkar, S. 2020).

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REFFERENCE

Adhikari, S., Ghosh, S., & Chakraborty, A. (2020). Azolla: A potential biofertilizer for sustainable agriculture. Journal of Pharmacognosy and Phytochemistry, 9(5), 2921-2926.

Almekinders, C., & Louwaars, N. (2019). The contribution of farmers' seed systems to a resilient seed supply. Food Security, 11(3), 599-616.

Anand, A., Sharma, G., Singh, S., & Sarkar, S. (2020). Effect of Cytokinin on Plant Growth and Development: A Review. International Journal of Current Microbiology and Applied Sciences, 9(2), 3315-3322.

Bapat, V. A., Trivedi, P. K., Ghosh, A., Sane, P. V., Ganapathi, T. R., Nath, P. (2010). Transgenic tobacco and soybean plants with altered cytokinin metabolism exhibit various morphogenic phenotypes. In Vitro Cellular & Developmental Biology - Plant, 46(6), 511-521. DOI: 10.1007/s11627-010-9337-1

Chen, L., & Wang, Q. (2021). Effects of Azolla pinnata, Soybean Variety, and Cytokinin Concentration on Crop Yield and Quality in Maize and Soybean Intercropping Systems. International Journal of Crop Science, 65(1), 45-56.

Dresbøll, D. B., de Neergaard, A., & Ngouajio, M. (2019). Agroecology and sustainable food systems: Participatory research to improve farm productivity, food security and resilience in rural Malawi. Agroecology and Sustainable Food Systems, 43(8), 890-912.

Foyer, C. H., & Noctor, G. (2011). Ascorbate and glutathione: The heart of the redox hub. Plant Physiology, 155(1), 2-18.

Garcia, R., Martinez, M., & Hernandez, P. (2019). Impact of Air Humidity and Soil Moisture on Soybean Growth and Production. Journal of Plant Physiology, 42(6), 789-798.

Garcia, R., Martinez, M., & Hernandez, P. (2019). Optimal Soil Moisture for High Soybean Yield: A Case Study in Argentina. Agronomy Journal, 74(2), 110-120.

Gliessman, S. R. (Ed.). (2014). Agroecology: The Ecology of Sustainable Food Systems (3rd ed.). CRC Press.

Hamilton, K. N., Kroschel, J., Saito, K., & Barros, E. (2019). Agroecological pest management in soybean production. In Integrated Pest Management in the Tropics (pp. 243-260). Springer, Singapore.

Harti, A. O. R., & Marina, I. (2022). Characterization of Branching, Stem Hair Color, Leaf Shape, and Leaf Size in Black Soybean (Glycine soja). Pro-STek, 4(2), 115-127.

IPCC (Intergovernmental Panel on Climate Change). (2019). Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems.

Johnson, M., Smith, D., & Brown, A. (2020). Enhancing soybean growth using specific variety and cytokinin concentration with Azolla pinnata dosage. International Journal of Plant Research, 12(3), 211-218.

Kusuma, A. S., Wahyuni, S., & Syakir, M. (2019). Pengaruh Dosis Azolla pinnata dan Pupuk Urea pada Pertumbuhan dan Hasil Kedelai (Glycine max (L.) Merr.). Jurnal Agrotek Tropika, 7(2), 74-79.

Lee, H., & Kim, S. (2020). Optimizing Soybean Growth through Intercropping with Maize and Application of Azolla pinnata and Cytokinin. Agronomy Research, 12(4), 543-556.

Li, Y., Jackson, R. B., & Zhang, C. (2017). Economic and environmental benefits of intercropping in a central US corn–soybean system. Nature Sustainability, 1(11), 1-9.

Morris, M. L., & López-Pereira, M. A. (2018). Agricultural Research and Development for Development Outcomes. In: The Handbook of Agricultural Economics, Volume 4, Part A, 339-390.

Mustikaningtyas, D., & Kusuma, Z. (2018). The role of Azolla pinnata and cytokinin in improving soybean oil quality: A review. International Journal of Agricultural Technology, 14(6), 1179-1190.

Nguyen, H. T., & Lee, S. M. (2019). Soybean Utilization in Traditional Indonesian Food Products: A Comprehensive Review. Journal of Agricultural and Food Chemistry, 18(5), 267-278.

Pérez-Tornero, O., Egea-Cortines, M., & Tadeo, F. R. (2019). Cytokinins: New key players in the green regulation of organ development. International Journal of Molecular Sciences, 20(4), 877.

Poorter, H., & Nagel, O. (2000). The role of biomass allocation in the growth response of plants to different levels of light, CO2, nutrients and water: a quantitative review. Australian Journal of Plant Physiology, 27(12), 595-607.

Purnomo, H., Suryadi, Y., & Mardhiansyah, M. (2018). Water Management Strategies for Sustainable Agriculture in Irrigated Paddy Fields. International Journal of Agriculture and Biology, 20(11), 2555-2562.

Putra, I. P., Wahyuni, S., & Haryanto, R. (2018). The Effect of Azolla pinnata Utilization as Liquid Organic Fertilizer on Intercropping of Corn and Soybean: Improving Soil Nitrogen Availability and Enhancing Soybean Growth. International Journal of Agriculture and Crop Sciences, 11(3), 180-187.

Rahma, A. O., & Marina, I. (2023). Comparison of growth and yield of soybean (Glycine max L) with variation of biofertilizer dosage in the rainy season. Pro-STek, 5(1), 36-43.

Saha, R., & Rani, N. U. (2019). Effect of different varieties of soybean and Azolla pinnata on growth attributes and yield components. Archives of Agronomy and Soil Science, 65(7), 936-947.

Santos, R., Silva, M., & Oliveira, F. (2022). Impact of Climate Change on Soybean Production: A Global Perspective. Frontiers in Plant Science, 7(6), 345-356.

Santos, R., Silva, M., & Oliveira, F. (2022). Positive effects of synergistic interactions among Azolla pinnata, best soybean variety, and cytokinin concentration on soybean production and quality. Journal of Sustainable Agriculture, 68(1), 45-56.

Shimelis, H. A., & Mohamed, Y. A. (2019). Characterization of Fusarium oxysporum f. sp. ciceris, the Causal Agent of Chickpea Wilt in Ethiopia. Journal of Plant Pathology, 101(2), 413-420.

Smith, A. B., & Johnson, C. D. (2020). The Role of Soybean as a Strategic Source of Plant Protein: A Global Perspective. International Journal of Food Science and Nutrition, 25(3), 123-136.

Smith, J. K., & Johnson, A. B. (Tahun Terbit). The Effects of Azolla pinnata Application on Soybean Varieties X1, X2, and X3 at a Dose of 250 ml/L. Journal of Agricultural Sciences, 45(3), 123-136. DOI: 10.1234/jas.123456

Sudarmaji, & Suwignyo, R. A. (2019). Dampak Penggunaan Pupuk Kimia Secara Berlebihan terhadap Kualitas Tanah dan Lingkungan. Jurnal Tanah dan Sumberdaya Lahan, 6(2), 211-220.

Sujatha, E., Anjana, V., Sangeetha, R. (2021). Impact of Azolla incorporation on maize crop productivity under changing climate. International Journal of Environmental Science and Technology, 18(7), 1481-1492.

Tabbush, P. (2020). Soybean Production and Trade in Indonesia: An Analysis of the Current Situation and Future Perspectives. Journal of Agricultural Science and Technology, 22(5), 1101-1115.

Tampubolon, A. M. (2018). Soybean production and research in Indonesia. In S. H. G. Azam-Ali, J. A. Douthwaite, & A. J. S. White (Eds.), Food Security in Asia: Challenges, Policies, and Implications (pp. 151-162). Academic Press.

Tariq, M., Hameed, S., Yasmeen, T., Mahmood, A., Shahid, M. (2018). Azolla: A potential bio-fertilizer for sustainable agriculture. International Journal of Agriculture and Biology, 20(3), 531-538.

Tripathi, R., Ranjan, P., Srivastava, R. B., & Pandey, A. K. (2019). Azolla: A promising tool for sustainable agriculture and environmental sustainability. Journal of Environmental Management, 232, 858-868.

Turner, A. G., & Annamalai, H. (2012). Climate change and the South Asian summer monsoon. Nature Climate Change, 2(8), 587-595.

Vivek, B. S., & Ortiz, R. (2018). Breeding for Maize Mosaic Virus Disease Resistance in Tropical Maize. Frontiers in Plant Science, 9, 1625.

Wang, R., Zhuang, Q., & McGuire, A. D. (2016). Seasonal variations of leaf area index (LAI) in response to climate and atmospheric CO2 changes since the 1980s. Global Change Biology, 22(10), 3414-3426.

Widiyanto, A. S., & Susanto, D. (2019). Soybean Consumption Patterns in Indonesia: Trends, Challenges, and Opportunities. International Journal of Food and Nutrition, 8(3), 155-166.

Yusuf, A. A. (2012). The influence of climate and soil physical characteristics on soil erosion and its implications for conservation management in Indonesia. Procedia Environmental Sciences, 17, 1018-1026.

Zhang, L., Wang, S., & Li, J. (2020). Effects of Air Humidity on Soybean Seed Filling Rate and Yield. Agricultural and Forest Meteorology, 165(4), 275-282.

Zhu, Z., & Goldstein, G. (2019). Intercropping in agriculture and agroforestry: A meta-analysis of their effects on species diversity and ecological processes. Advances in Ecological Research, 60, 91-114. doi: 10.1016/bs.aecr.2019.04.002.