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Original Article

Under-Shade Microclimate Study of Coffee-Based Agroforestry Productivity (Coffea sp.) Pujon, Malang, East Java, Indonesia

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Abstract: *The effect of microclimate on coffee plant productivity in the agroforestry model has not been studied by farmers. Based on these problems, it is necessary to carry out research aimed at analyzing the influence of microclimate on the productivity of agroforestry based on coffee plants under shade. The research was carried out in Pujon Malang, East Java, Indonesia. The research method was direct observation of farmers using purposive sampling; data was analyzed by regression. Microclimatic conditions, average temperature between 21-22 ^{0}C, average humidity 92%. Average rainfall is 95.5mm/month. The average wind speed of 1.64 m/s indicates that the wind is not too strong. The results of the multiple regression analysis were significant for coffee under pine shade with a Luminous intensity of 0.000 < 0.05, and in lamtoro shade, the temperature was also significant at 0.043 < 0.05. Coffee productivity under the shade of pine is 9-10 kg/tree, production under the shade of lamtoro is 8-10 kg/tree and production under the shade of durian is 6-7 kg/tree.*

Keywords: *Agroforestry, Microclimate, Productivity, Shade.*

I. INTRODUCTION

The agroforestry system is an effort to use land optimally and sustainably by combining forestry, agriculture, livestock plantations and fisheries activities in one land management unit by paying attention to the physical, social, economic and cultural environmental conditions of the community [1]. Agroforestry is a land management option that still maintains ecological and economic aspects [2]. Agroforestry based on coffee commodities has the potential to increase (economic) income and conserve environmental change. The agroforestry system is an effort to use land optimally and sustainably by combining forestry, agriculture, livestock plantations and fisheries activities in one land management unit by paying attention to the physical, social, economic and cultural environmental conditions of the community [1]. Agroforestry is a land management option that still maintains ecological and economic aspects [2]. Agroforestry based on coffee commodities has the potential to increase (economic) income and conserve environmental change [3], [4]. The advantage of coffee plants is that they can grow well according to the type and geographical location, especially when supported by the presence of shade trees, which function to regulate the microclimate, thus changing management patterns [5]. The density of shade trees and coffee bushes shows the great importance that ecosystem variation has in regulating the environmental microclimate [6].

Climate components are important for the life of flora and fauna; until now farmers do not clearly know the influence of climate on coffee production in agroforestry patterns [7]. The research objective is to analyze the influence of microclimate on the productivity of coffee plant-based agroforestry. Agroforestry can play an active role in efforts to save and preserve land and forests [8]. Rescue and sustainability are carried out with agroforestry patterns that have different plant compositions, which ultimately have the potential to provide income [9], [10].

Climate is a composite of day-to-day weather conditions and atmospheric elements in a particular area over a long period of time. Considering that coffee plants do not require direct light, coffee cultivation is very good if the planting pattern is carried out using an agroforestry system [11]. Tree canopies can provide energy-saving benefits, reduce carbon dioxide and reduce the rate of global warming [5]. Arabica coffee has a distinctive taste with a caffeine content that is not too high compared to Robusta coffee [12]. The lamtoro plant (Leucaena sp.) is a productive shade tree for coffee plants, has economic value and market opportunities, has a canopy structure that is easy to regulate, and its litter is a source of organic material [13], [14]. Shade trees are also efficient as a countermeasure against the danger of erosion, the main effect of shading coffee plants is to reduce air temperature by 2-3°C reduce wind speed to prevent flower fall [15], [16]. The Luminous intensity required by coffee plants is around 60-80% [17]. The level of shade is closely related to Luminous intensity, while Luminous intensity is closely related to canopy strata of vegetation types and plant photosynthesis processes [18]. Coffee plant leaves that are shaded have more total chlorophyll content than leaves that are not shaded. This condition is a physiological adaptation mechanism so that the leaves are still able to absorb long-wave radiation with more chlorophyll for photosynthesis [19].

II. LITERATURE REVIEW

A) Climate

Climate refers to the characteristic long-term weather patterns of a specific region or geographic area, typically spanning several decades [20]. The weather data encompasses a range of meteorological factors, including ambient temperature, humidity, wind speed, precipitation (rain, snow, etc.), and other observable and measurable weather phenomena that can be recorded for extended durations.

B) Coffee

Worldwide consumption of coffee makes it one of the most significant commodities in international trade [21]–[23]. To establish, nurture, and produce high-quality coffee beans, coffee cultivation entails a succession of procedures. This cultivation method necessitates knowledge of plant care, coffee bean processing, and favorable environmental conditions (including climate, temperature, humidity, and altitude) [24].

C) Productivity

Productivity, in a broad sense, refers to the measure of efficiency with which an organization, corporation, or individual converts resources (inputs) into desired outcomes or outputs [25]–[27]. Coffee productivity pertains to the level of efficiency and efficacy in the cultivation and production of coffee, as well as the quantity of coffee that may be generated per unit of land or labor. The productivity of coffee is contingent upon multiple aspects, and a comprehensive comprehension of these factors can assist farmers in augmenting both the quantity and caliber of their coffee crop [28].

D) Agroforestry

Agroforestry is a method of managing land that involves the simultaneous or alternating cultivation of trees, annual plants, and/or perennial plants (such as shrubs, herbs, or tubers) inside a single agricultural or forestry production unit [29], [30]. Agroforestry integrates agricultural and forestry practices to effectively promote productivity, conserve natural resources, and ensure long-term sustainability [29], [31].

III. METHODS

The research was conducted in Pujon Malang, East Java, Indonesia. The research method for collecting primary data [32] was obtained from field observations in the form of coffee production data and microclimate data (temperature, humidity and sunLuminous intensity) for each plot measuring 20×20 meters under the shade of trees containing coffee plants. Observations of Luminous intensity were carried out 3 (three) times a day (morning: 07.00-08.00 WIB; afternoon 12.00-13.00 WIB and evening: 17.00-18.00 WIB). Secondary data obtained from BMKG Malang includes rainfall data and average wind speed data. Daily sunLuminous intensity is calculated using the formula:

$$IC_{Daily} = \frac{IC_{Morning} - IC_{Afternoon} - IC_{Evening}}{3}$$

Note:
IC = Daily Luminous intensity;
ICmorning, ICafternoon, ICevening = Luminous intensity measurements in the morning, afternoon and evening.

$$T_{Daily} = \frac{2T_{Morning} - T_{Afternoon} - T_{Evening}}{4}$$

Note:
T = Daily Air Temperature;
Tmorning, Tafternoon, Tevening = air temperature measurements in the morning, afternoon and evening.

$$RH_{Daily} = \frac{2RH_{Morning} - RH_{Afternoon} - RH_{Evening}}{4}$$

Note:
RH = Daily Air Humidity;
RHmorning, RHafternoon, RHevening = air temperature measurements in the morning, afternoon and evening.

Respondents were taken with a minimum of 10% representation of the total number of coffee farmers, using the Slovin (1960) formula:

$$n = \frac{N}{1 + N(e^2)}$$

Note:
n = number of respondents;
N=population size;
e = percentage of leeway in accuracy of sampling errors that can still be corrected.

The total population to be studied is 1118 farmers, so the calculation of the number of respondents is as follows:

$$n = \frac{1118}{1 + 1118(0.01)}$$
$$n = 91{,}78$$

Note:
n = 91.78 adjusted by the researcher to 92 respondents

Data analysis was carried out using multiple regression analysis to examine the influence of microclimate results on each shade.

IV. RESULTS AND DISCUSSION

General Conditions of Research Locations The Pujon¸ Malang District area, East Java, is one of the sub-districts in Malang Regency with a distance of + 30 km west of the capital of Malang Regency. The physical geographical conditions of Pujon District are as follows: Flat to wavy: 40%, wavy to hilly: 30%, hilly to mountainous: 30%. In the form of production forest covering an area of 3,157.80 Ha and protected forest covering an area of 6,423.60 Ha. The number of coffee farmers is around 1118 people, located at an altitude of 1000 - 2,500 meters above sea level, the air temperature is between 14 - 220C. Average rainfall is 1,724 mm/year.

A) Analysis Results

This research shows that tree shade can reduce air temperature, stabilize relative humidity, and reduce direct exposure to solar radiation; two analyses were carried out, namely, ANOVA analysis, which was then continued using multiple regression analysis presented in Table 1.

Table 1: ANOVA and regression analysis

Variable	Shade	Analysis Anova	Analysis Multiple Regression
Luminous intensity	Pine us	0,000	0,000
Temperature	Lamtoro	0,143	0,043

Based on the results of the analysis of variance, Luminous intensity, temperature, and humidity on coffee productivity have a significant influence of 0.000 < 0.005. The results of the ANOVA variance analysis of flowers, stalks, coffee plant height, canopy width, and coffee stem diameter showed > 0.05, which means it is not significant and to determine the differences in Luminous intensity, temperature and humidity on coffee yield, flowers, stalks, coffee plant height, canopy width, coffee diameter were further tested by multiple regression, only Luminous intensity was significant at 0.000 < 0.05 on production, and temperature in the lamtoro shade showed results of 0.043 < 0.05. means significant to coffee production.

The microclimate is better at retaining soil moisture and reducing the intensity of sunlight [33]. The results of observations of coffee production under pine shade/stands are that the shade is the best compared to other shades; pine shade is capable of producing 9-10 kg of coffee/stem. Luminous intensity in coffee = 347.75 candela, durian shade = 191.21 candela and lamtoro = 197.69 candela. The average height of the tree is 25-30 meters, so the coffee plant gets good Luminous intensity; the average diameter of the pine is 40 cm, and it has needle-shaped leaves (acerocus); in Figure 1 below, a graph of the average microclimate from various shades is presented.

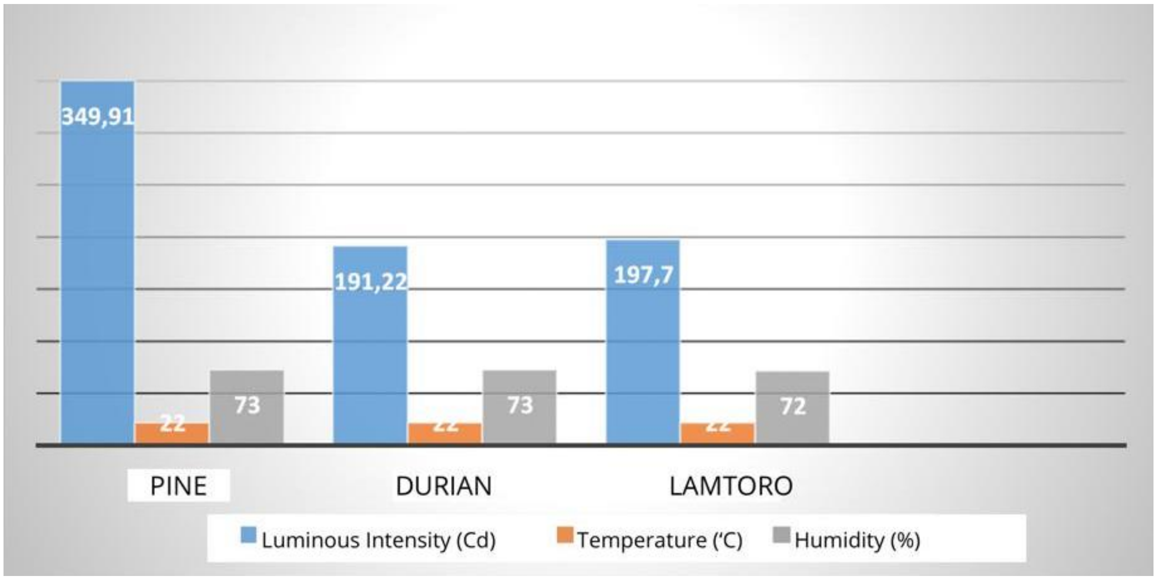

Fig. 1. Average Microclimate Graph

Based on graphic image 2, the higher you go, the smaller the cone shape becomes. The shape of the stem is rounded with a shape that resembles a pyramid, so that the intensity of light entering the coffee plant can be optimal, which will produce flowers that become coffee fruit/beans. Consecutively, pine shade coffee production is 9-10 kg/stem, durian shade 6-7/stem, and lamtoro shade 8-10 kg/stem. Humidity at the research location is 92% in accordance with the humidity requirements for growing coffee. The lamtoro plant (Leucaena sp.) is an ideal shade tree for coffee plants [34]. Shade trees are productive, have a canopy structure that is easy to regulate, and their litter is a source of organic material. Lamtoro has compound leaves with a double pinnate shape.

There are 3-10 pairs of fins and 5-20 pairs of leaflets per fin; the leaves are not too dense, and the width of the crown is large so that the intensity of incoming light is very optimal, resulting in a heavier weight of coffee beans. Rainfall greatly influences coffee-growing areas. In wet areas, it is often cloudy, so photosynthesis is lacking, and as a result, seed growth is hampered [35]. The drier it is, the thinner and less juicy the fruit flesh is, so the seeds become heavier. Explained that there are differences in seed size based on the planting climate conditions [18]. The size of the coffee beans shows a positive correlation with the altitude because the higher the temperature, the lower the temperature. According to the statement of [36], air humidity plays a role in regulating water loss from evaporation; when air humidity is high, water loss decreases and vice versa. The humidity under pine stands is very high, or you could say it produces the most seeds per tree compared to coffee plants under durian, lamtoro stands and without stands. The main effect of shade on coffee plants is to reduce air temperature fluctuations by 2-3°C, reduce wind speed, and increase the relative humidity of dry air [37], [38]. According to [39], it is thought that the amount of sunlight received by coffee plants does not support the efficiency of photosynthesis, so photosynthesis is produced in small quantities. Light is really needed by plants, especially plants that have green leaf substances (chlorophyll) because without light, the photosynthesis process will not occur in the leaves, which produces energy for plant growth [40], [41]. The following figure 2 shows the productivity of coffee under shade.

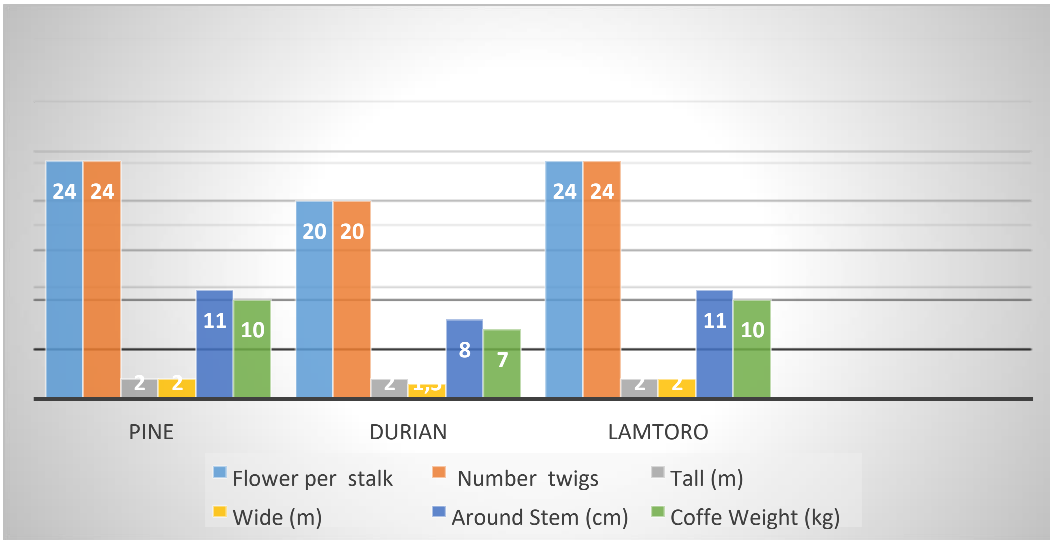

Fig. 2. Average Coffee Productivity Diagram

In Figure 2, several factors influence coffee productivity, apart from the microclimate, which is also influenced by differences in growth and physiological characteristics in the productivity of coffee treated with different levels of shade due to differences in the intensity of sunlight received by the plants [37], [42]. The shade of coffee-based agroforestry can vary significantly, depending on the type of shade tree, tree density, canopy structure, and other environmental factors.

B) Agroforestry Forms and Patterns

Agroforestry practices must be adapted to environmental sustainability [29], [43]. The establishment of an agroforestry system on empty land must be considered [13]. Land management that combines production, environmental services and social benefits has created interest in agroforestry systems [44]. Coffee-based agroforestry plants are generally planted under plantation forest stands, which also reduce soil loss and improve soil fertility and climate change for environmental sustainability [11], [18]. The planting pattern used by coffee agroforestry farmers is a random planting pattern (Random Mixture). This random mixture pattern can be seen in Figure 3.

Fig. 3. Flowers and fruit of a coffee plant

The agroforestry pattern implemented is influenced by various considerations of farmers as resource managers who hope for optimal (coffee) production and product diversification, in addition to maintaining the forest ecosystem [7]. The decline in environmental quality and quantity causes the environment to be less or no longer able to function to support environmental conservation efforts [45]. Appropriate planting patterns are needed to prevent land degradation and as an effort for global food security against current and future risks of climate change [46]. The impact of coffee agroforestry is really felt by farmers as a source of household income. because they believe that the selling price of coffee is relatively stable [47]. This increase in productivity then has implications for increasing people's real income, so that it plays a role in increasing the productivity of every business activity and national income [48], [49]. The complexity of the interaction between agroforestry and shade in microclimate regulation and its relevance to productivity and sustainability of coffee-based agroforestry [50]–[52]. Decent farming income by using forest land for plantations of non-timber crops, which provides a significant contribution [53], [54]. Intercrop crops, which are generally planted under plantation forest stands with intensification, have ecological impacts and alternative residues that must be known [55], [56].

V. CONCLUSION

Based on the results of the multiple regression analysis, which was significant, namely for coffee under the shade of pine with a Luminous intensity of $0.000 < 0.05$ and in the shade of lamtoro, the temperature was also significant, which produced a figure of $0.043 < 0.05$ and the results from the field obtained the best shade were pine trees and Lamtoro produces 8-10 kg of coffee per tree, while in the shade of durian, the amount is 6-7 kg per tree. The thing that influences coffee productivity is the intensity of light that enters to illuminate the coffee plants.

Coffee farmers really need to be given insight into shade plants to develop and maintain the sustainability of coffee-based agroforestry, including in climate change.

VI. REFERENCES

[1] J. Triwanto, A. Syarifuddin, and T. Mutaqin, “Aplikasi Agroforestry di Desa Mentaraman Kecamatan Donomulyo Kabupaten Malang,” *J. Dedik.*, vol. 9, no. 1998, pp. 13–21, 2012, doi: 10.22219/dedikasi.v9i0.1380.

[2] P. Vázquez-Delfin, A. Casas, and M. Vallejo, "Adaptation and biocultural conservation of traditional agroforestry systems in the Tehuacán Valley: access to resources and livelihoods strategies," *Heliyon*, vol. 8, no. 7, p. e09805, Jul. 2022, doi: 10.1016/j.heliyon.2022.e09805.

[3] R. Evizal and F. E. Prasmatiwi, "Coffee plantation characteristics of migrant farmers: a case study in Tanggamus, Lampung, Indonesia," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1018, no. 1, p. 012035, Apr. 2022, doi: 10.1088/1755-1315/1018/1/012035.

[4] C. Wulandari, S. P. Harianto, and D. Novasari, *Pengembangan Agroforestri yang Berkelanjutan dalam Menghadapi Perubahan Iklim*, Oktober 20. Bandarlampung: Pusaka Media, 2020.

[5] I. Saroh and Krisdianto, "Manfaat Ekologis Kanopi Pohon Terhadap Iklim Mikro Di Ruang Terbuka Hijau Kawasan Perkotaan," *J. Hutan dan Masy.*, vol. 12, no. 2, pp. 136–145, 2020, doi: 10.24259/jhm.v12i2.10040.

[6] F. Tesfay, Y. Moges, and Z. Asfaw, "Woody Species Composition, Structure, and Carbon Stock of Coffee-Based Agroforestry System along an Elevation Gradient in the Moist Mid-Highlands of Southern Ethiopia," *Int. J. For. Res.*, vol. 2022, pp. 1–12, Jun. 2022, doi: 10.1155/2022/4729336.

[7] Y. Berhanu *et al.*, "Nitrous oxide and methane emissions from coffee agroforestry systems with different intensities of canopy closure," *Sci. Total Environ.*, vol. 876, p. 162821, Jun. 2023, doi: 10.1016/j.scitotenv.2023.162821.

[8] J. Triwanto, "Institutional Analysis of Agroforestry Farmers to Achieve Forest Preservation in Bendosari and Ngabab Villages of Pujon, Malang, Indonesia," *RJOAS*, vol. 5, no. 125, pp. 217–221, 2022, doi: 10.18551/rjoas.2022-05.25.

[9] Triwanto dan Mutaqqin, “Kajian Agroforestri Di Bawah Tegakan Pinus Untuk Meningkatkan Produktivitas Lahan Dan Kesejahteraan Petani Studi Kasus : Di Desa Pujonkidul Kecamatan Pujon Kabupaten Malang,” *Sylva J. Penelit. Ilmu-Ilmu Kehutan.*, vol. 7, no. 2, pp. 40–48, 2018, doi: 10.32502/sylva.v7i2.1539.

[10] J. Andrews and M. Borgerhoff Mulder, "Forest income and livelihoods on Pemba: A quantitative ethnography," *World Dev.*, vol. 153, p. 105817, May 2022, doi: 10.1016/j.worlddev.2022.105817.

[11] D. Suprayogo *et al.*, "Litter layer and earthworms as an indicator of coffee production in the coffee and pine based agroforestry system," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 950, no. 1, p. 012036, Jan. 2022, doi: 10.1088/1755-1315/950/1/012036.

[12] S. P. Wuthaningsih and R. F. Alham, "Diversity of bird species in the coffee agroforestry landscape: Case study in the Pangalengan Sub-district, Bandung District, West Java, Indonesia," *Biodiversitas J. Biol. Divers.*, vol. 21, no. 6, May 2020, doi: 10.13057/biodiv/d210619.

[13] F. Fitriani, B. Arifin, W. A. Zakaria, and R. H. Ismono, “Kinerja Usahatani Kopi di Hulu DAS Sekampung, Tanggamus, Lampung,” *J. Penelit. Pertan. Terap.*, vol. 18, no. 3, p. 165, Jan. 2020, doi: 10.25181/jppt.v18i3.1503.

[14] B. D. S. Aji, N. Wijayanto, and B. Wasis, "Visual Evaluation of Soil Structure (VESS) Method to Assess Soil Properties of Agroforestry System in Pangalengan, West Java," *J. Manaj. Hutan Trop. (Journal Trop. For. Manag.*, vol. 27, no. 2, pp. 80–88, Aug. 2021, doi: 10.7226/jtfm.27.2.80.

[15] S. Gagliardi, J. Avelino, E. de M. Virginio Filho, and M. E. Isaac, "Shade tree traits and microclimate modifications: Implications for pathogen management in biodiverse coffee agroforests," *Biotropica*, vol. 53, no. 5, pp. 1356–1367, Sep. 2021, doi: 10.1111/btp.12984.

[16] R. A. Villarreyna, J. Avelino, and R. Cerda, “Adaptación basada en ecosistemas: efecto de los árboles de sombra sobre servicios ecosistémicos en cafetales,” *Agron. Mesoam.*, pp. 499–516, May 2020, doi: 10.15517/am.v31i2.37591.

[17] Z. Lopes *et al.*, “Luminosidade na Produção de Plantas : Cultura do Café Luminosity in the Production Plant : Coffee Culture,” pp. 8–11.

[18] Y. Sarvina, T. June, E. Surmaini, R. Nurmalina, and S. S. Hadi, “Strategi Peningkatan Produktivitas Kopi serta Adaptasi terhadap Variabilitas dan Perubahan Iklim melalui Kalender Budidaya,” *J. Sumberd. Lahan*, vol. 14, no. 2, p. 65, Dec. 2020, doi: 10.21082/jsdl.v14n2.2020.65-78.

[19] H. N. de Souza, "Biodiversity and Key Ecosystem Services in Agroforestry Coffee Systems in the Brazilian Atlantic Rainforest Biome," Wageningen University, 2012.

[20] E. Mapfumo, D. S. Chanasyk, and D. Puurveen, "Long-term annual climate trends around the Breton Plots area, Alberta: is there any evidence of local climate change?," *Can. J. Plant Sci.*, vol. 103, no. 3, pp. 285–299, Jun. 2023, doi: 10.1139/cjps-2022-0211.

[21] J. Pancsira, "International Coffee Trade: a literature review," *J. Agric. Informatics*, vol. 13, no. 1, Mar. 2022, doi: 10.17700/jai.2022.13.1.654.

[22] P. S. Kumar and N. T. K. Kishore, "Direction of trade of Indian arabica coffee," *Int. J. Agric. Sci.*, vol. 19, no. 1, pp. 122–125, Jan. 2023, doi: 10.15740/HAS/IJAS/19.1/122-125.

[23] C. L. R. Vegro and L. F. de Almeida, "Global coffee market: Socio-economic and cultural dynamics," in *Coffee Consumption and Industry Strategies in Brazil*, Elsevier, 2020, pp. 3–19.

[24] S. Siyang and T. Kerdcharoen, "Development of Low-cost and Robust IoT Field Station for Coffee Plantation," in *2023 15th International Conference on Knowledge and Smart Technology (KST)*, Feb. 2023, pp. 1–4, doi: 10.1109/KST57286.2023.10086759.

[25] W. T. Fariati, “Pengaruh Pengawasan, Disiplin dan Motivasi Kerja terhadap Produktivitas Kerja Pegawai Toserba Yogya Sukabumi,” *J. BUANA Inform.*

CBI, vol. 5, no. 2, pp. 97–116, Dec. 2022, doi: 10.53918/jbicbi.v5i2.31.
[26] L. Kumar, "Productiveness Vs Productivity," *Manag. Dyn.*, vol. 17, no. 2, pp. 70–79, Apr. 2022, doi: 10.57198/2583-4932.1055.
[27] W. M. Shodiq, "Model CPRV (Cost, Productivity, Risk Dan Value-Added) dalam Upaya Meningkatkan Pendapatan Petani Indonesia: a Review," *J. Hexagro*, vol. 6, no. 2, pp. 115–127, 2022, doi: 10.36423/hexagro.v6i2.657.
[28] J. Kipkorir Cheruiyot, "Farmers' Information-inputs and their Sway on Coffee Productivity in the West of Rift, Kenya," *J. Appl. Life Sci. Int.*, pp. 1–14, Apr. 2022, doi: 10.9734/jalsi/2022/v25i230282.
[29] N. V. Thevathasan, A. M. Gordon, and P. K. R. Nair, "Agroforestry," in *Encyclopedia of Soils in the Environment*, Elsevier, 2023, pp. 68–87.
[30] A. K. Patra, *Introductory Agroforestry*. London: CRC Press, 2022.
[31] Jeyanny Vijayanathan, Darshini Rawichandran, Mohd Zaki Abdullah, Rosdi Koter, Rozita Ahmad, and Mohd Afif Hazmi Anuar, "Agroforestry Practices to Achieve Sustainable and Climate Resilient Forests," *J. Trop. Plant Physiol.*, vol. 14, no. 2, p. 12, Dec. 2022, doi: 10.56999/jtpp.2022.14.2.22.
[32] M. N. Islam and M. S. Islam, "Data Collection and Analysis," in *Islam and Democracy in South Asia*, Cham: Springer International Publishing, 2020, pp. 49–65.
[33] T. Hidayat, Y. Koesmaryono, I. Impron, and M. Ghulamahdi, "Canopy Microclimate Modification with Reflective Mulches Under Oil Palm and Its Role to Soybean Growth," *Agromet*, vol. 34, no. 1, pp. 1–10, Mar. 2020, doi: 10.29244/j.agromet.34.1.1-10.
[34] A. Emire, "Status of Soil Properties Under Canopy of Farmers' Preferred Coffee Shade Tree Species, in Adola Rede District, Guji Zone, Southern Ethiopia," *Am. J. Agric. For.*, vol. 6, no. 5, p. 148, 2018, doi: 10.11648/j.ajaf.20180605.15.
[35] C. N. Campos, G. A. L. Torres, A. R. Lopes, A. P. Pantano, and J. A. S. de Almeida, "Influence of meteorological factors on the relative water content of coffee plants in the field," *Agrometeoros*, vol. 31, Apr. 2023, doi: 10.31062/agrom.v31.e027178.
[36] D. P. Widayani and K. S. Usodri, "Kajian Kesesuaian Lahan Perkebunan Kopi Rakyat Kawasan Lereng Gunung Arjuna Kabupaten Malang," *J. Agrinika J. Agroteknologi dan Agribisnis*, vol. 4, no. 2, p. 108, Sep. 2020, doi: 10.30737/agrinika.v4i2.1036.
[37] F. Yuliasmara, U. Sumirat, K. P. Wicaksono, and E. Widaryanto, "Growth and Plant Architecture of Several Introduced Coffea canephora Clones Under Different Shade Levels," *Pelita Perkeb. (a Coffee Cocoa Res. Journal)*, vol. 38, no. 3, pp. 155–170, Dec. 2022, doi: 10.22302/iccri.jur.pelitaperkebunan.v38i3.517.
[38] A. Koutouleas *et al.*, "Shaded-Coffee: A Nature-Based Strategy for Coffee Production Under Climate Change? A Review," *Front. Sustain. Food Syst.*, vol. 6, Apr. 2022, doi: 10.3389/fsufs.2022.877476.
[39] S. Wilujeng, I. Darliana, R. F. Solihat, and T. Rohmat, "Pertumbuhan Anakan Kopi (Coffea Arabica Lin.) Berbasis Sistem Agroforestri di Hutan Rakyat Cimarias Sumedang," *J. Hutan Trop.*, vol. 9, no. 1, p. 149, Apr. 2021, doi: 10.20527/jht.v9i1.10489.
[40] E. A. Cutolo, Z. Guardini, L. Dall'Osto, and R. Bassi, "A paler shade of green: engineering cellular chlorophyll content to enhance photosynthesis in crowded environments," *New Phytol.*, vol. 239, no. 5, pp. 1567–1583, Sep. 2023, doi: 10.1111/nph.19064.
[41] K. Yang, G. Chen, J. Xian, and H. Chang, "Divergent adaptations of leaf functional traits to light intensity across common urban plant species in Lanzhou, northwestern China," *Front. Plant Sci.*, vol. 14, Jan. 2023, doi: 10.3389/fpls.2023.1000647.
[42] K. Hao *et al.*, "Optimizing Shade Cultivation Method and Irrigation Amount to Improve Photosynthetic Characteristics, Bean Yield, and Quality of Coffee in a Subtropical Monsoon Climate," *Front. Plant Sci.*, vol. 13, Apr. 2022, doi: 10.3389/fpls.2022.848524.
[43] G. A. Bogale and S. E. Bekele, "Sustainability of Agroforestry Practices and their Resilience to Climate Change Adaptation and Mitigation in Sub-Saharan Africa: A Review," *Ekológia (Bratislava)*, vol. 42, no. 2, pp. 179–192, Jul. 2023, doi: 10.2478/eko-2023-0021.
[44] R. Manurung, Y. Nengsih, and R. Marpaung, "PERTUMBUHAN TANAMAN SERAIWANGI (Cymbopogon nardus L) PADA BEBERAPA DOSIS KOMPOS KULIT KOPI," *J. Media Pertan.*, vol. 6, no. 2, p. 68, Oct. 2021, doi: 10.33087/jagro.v6i2.123.
[45] A. Abdurohim, "Environment Conservation in Pressing Climate Change Environmental Fiqih and Islamic Law," *Budapest Int. Res. Critics Inst.*, 2022, doi: 10.33258/birci.v5i1.3804.
[46] E. S. Yusuf *et al.*, "Sustainability of Arabica coffee business in West Java, Indonesia: A multidimensional scaling approach," *Open Agric.*, vol. 7, no. 1, pp. 820–836, Oct. 2022, doi: 10.1515/opag-2022-0144.
[47] L. Istiqomah, S. Laili, and H. Zayadi, "Estimasi Karbon pada Tegakan Varietas Kopi Arabika (Coffea arabica) Di Lahan Agroforestri Precet Wilayah Resort Pemangkuan Hutan Wagir KPH Malang," *J. SAINS ALAMI (Known Nature)*, vol. 5, no. 1, p. 15, Jul. 2022, doi: 10.33474/j.sa.v5i1.12819.
[48] F. Bird, "Increases in Productivity and Their Ambiguous Consequences," 2022, pp. 191–211.
[49] S. S. Nagel, "The New Productivity," in *Promoting Productivity in the Public Sector*, London: Palgrave Macmillan UK, 1988, pp. 231–246.
[50] R. M. Y. A. P. Nugroho, R. Ustiatik, B. Prasetya, and S. Kurniawan, "Response of Different Coffee-Based Agroforestry Management on Microbial Respiration and Density," *J. Ecol. Eng.*, vol. 24, no. 9, pp. 158–170, Sep. 2023, doi: 10.12911/22998993/169179.
[51] Z. D. Wariyo and D. A. Negewo, "Coffee Shade Tree Selection Criteria and Management Techniques in Smallholder Coffee-Based Agroforestry System in Gomma Woreda, Southwest of Ethiopia," *East African J. For. Agrofor.*, vol. 6, no. 1, pp. 84–97, Mar. 2023, doi: 10.37284/eajfa.6.1.1126.
[52] N. Motisi, J. Papaïx, and S. Poggi, "The Dark Side of Shade: How Microclimates Drive the Epidemiological Mechanisms of Coffee Berry Disease," *Phytopathology®*, vol. 112, no. 6, pp. 1235–1243, Jun. 2022, doi: 10.1094/PHYTO-06-21-0247-R.
[53] A. A. Bayesa and D. A. Bushara, "Contribution of Non-Timber Forest Products to Local Communities: The Case of Belete Gera Forest, Southwest Ethiopia," *East African J. For. Agrofor.*, vol. 5, no. 1, pp. 222–240, Oct. 2022, doi: 10.37284/eajfa.5.1.879.
[54] B. Derebe and A. Alemu, "Non-timber forest product types and its income contribution to rural households in the Horn of Africa: a systematic review," *Forest Sci. Technol.*, vol. 19, no. 3, pp. 210–220, Jul. 2023, doi: 10.1080/21580103.2023.2231963.
[55] J. Urgoiti Otazua and A. Paquette, "Mixed Forest Plantations," 2018, pp. 319–341.
[56] J. Shukla, S. Dhyani, P. Pujari, A. Mishra, and P. Verma, "Impact of agriculture intensification on forest degradation and tree carbon stock; promoting multi-criteria optimization for restoration in Central India," *L. Degrad. Dev.*, vol. 33, no. 16, pp. 3103–3117, Oct. 2022, doi: 10.1002/ldr.4375.