Chapter

Challenges and Opportunities for Indonesian Cocoa Development in the Era of Climate Change

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Abstract

In recent years, the area of cocoa plantations in Indonesia has tended to decline, one of which is attributed to climate change that threatens the sustainability of production; even though cocoa production and consumption have become popular globally, the consumer demand for cocoa products has also increased. Climate change causes increased air temperature, erratic rainfall patterns, increased sea level and surface temperature, and extreme weather. Cocoa requires an ideal rainfall of 1500–2500 mm/year and dry months (rainfall <60 mm) for about 1–3 month a year. Climate change can be a challenge for Indonesian cocoa development. Several efforts should be made to turn existing challenges into opportunities through appropriate technological inputs, such as the use of improved cocoa genetic resources (recommended clones) as well as improving nursery and field management practices, including shading and watering the seedlings, modification of growing media, mycorrhizal application, rainwater harvesting, and managing shade plants and intercropping.

Keywords: cacao clone, growing media, harvesting rainwater, intercropping, mycorrhiza, shading, watering

1. Introduction

Indonesia is one of the world's largest cocoa producers. Most of Indonesia's cocoa (about 80%) is cultivated on smallholder plantations (SP), while a small portion is owned by the state (government plantations (GP)) and private plantations (PP). Over the past 5 years, Indonesia's cocoa bean production has decreased from 270,000 tons in 2017 to 170,000 tons in 2021. This has resulted in Indonesia's ranking as the world's fourth largest cocoa producer dropping to seventh after Côte d'Ivoire, Ghana, Ecuador, Cameroon, Nigeria, and Brazil. One of the main causes is the global climate change [1].

Based on data [2], in the last 10 years (2013–2022), Indonesian cocoa has faced the problem of decreasing planting area. The average rate of decline in the area of Indonesian cocoa plantations has reached 1.80%, and based on the plantation conditions, immature young plants have decreased drastically, around 6.62% per year. Even though the reduction in the area does not have much impact on national cocoa production, this trend will pose a significant threat to the development of Indonesian cocoa in the future. However, during 2013–2022 there was a slight increase in production (0.96% per year) due to an increase in harvested area, although the productivity remained below 1 ton/hectare/year (**Figure 1**).

Many factors affect the decline in the area and productivity of Indonesian cocoa, one of which is due to the impact of climate change. The effect of climate change on cocoa growth and production is very significant because cocoa cultivation is highly dependent on climatic conditions. This impact affects not only Indonesian cocoa but almost all cocoa plantations in the world. Previous studies in Ghana and Côte d'Ivoire showed that due to the impact of climate change, there would be a significant reduction in the extent or size of suitable lands for cocoa for estimates until 2050 [4]. The impact of the 2015–2016 El Niño on cocoa in Brazil caused high plant mortality and a severe decline in production [5]. Therefore, the impact of climate change on cocoa has become a global concern; on the one hand, world cocoa production tends to decrease, while on the other hand, consumer demand continues to increase.

Climate change causes an increase in air temperature, erratic rainfall patterns, an increase in sea surface temperature and sea levels, and extreme weather. These changes affect not only environmental factors related to plant physiological aspects [6] but also the aspects of the diversity and spread of pests and diseases. Climate change is an important factor affecting the quality of cocoa beans. A long dry season leads to a smaller size of cocoa beans, and the flowers easily wilt or fall off [7], and an increase in temperature in the cocoa planting area accelerates the fruit ripening process, resulting in imperfect flavors [8]. In addition, climate change affects pests' life

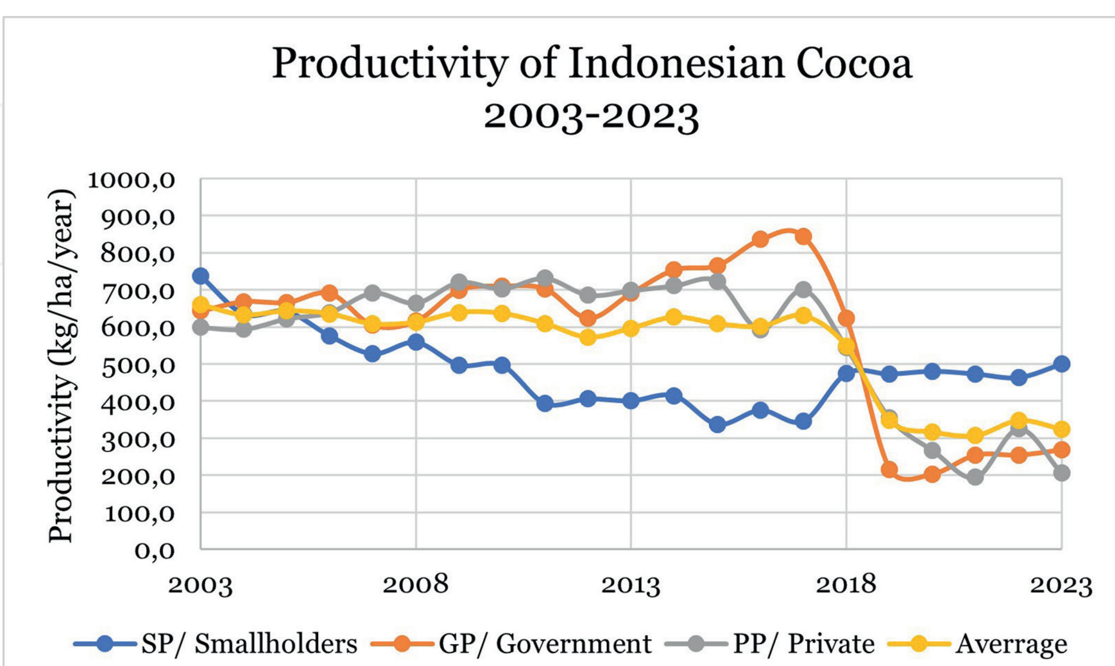

Figure 1.
Productivity of Indonesian cocoa, 2003–2023. Source: [3].

cycles, which indirectly affect the growth and production of cocoa. The intensity of cocoa pod disease attacks increases due to climate change [9]. In Brazil, the spread of the fungus *Phytophthora palmivora*, which causes black pod disease in cocoa, increases during the more intense rainy season and higher temperatures [10]. Moreover, the biological agents controlling cocoa pests are also affected, so the pests become resistant and attack cocoa plants easily [11]. High rainfall will also influence production due to low solar radiation, thereby reducing the number of flowers and delaying fruit ripening [12]. Therefore, in addition to the need for adaptation through good plant management practices, breeding programs for resistance to biotic and abiotic factors also play an important role [6, 11].

In Indonesian cocoa plantations, the adaptation process to climate changes can be carried out in various ways, including the extensification and intensification programs. However, the options for area extensification programs are rather limited, considering the increasing competition for land use with other sectors. The experience in Ghana and Côte d'Ivoire showed that the optimal altitude for cocoa cultivation is estimated to increase toward the hilly areas. However, this area is included in the protected forest zone. Thus, it will be an obstacle if used for cocoa expansion [13].

This chapter identified the strategy for adaptation of cocoa plantations to climate change and emphasized intensification by improving plant genetic resources and managing plants from the nursery to the field level. In addition, fixing the limitations and deficiencies of land suitability needs to be carried out through appropriate technological inputs.

2. Challenges facing Indonesian cocoa in the era of climate change

2.1 Impact of climate change on the ecosystems of cocoa plantation

Climate change has brought about changes in several climatic elements, including increasing air temperature, changing rainfall patterns, increasing sea surface temperature and sea levels, and extreme weather. Climate changes affect the agricultural ecosystem, including the cocoa ecosystem. Climate changes also impact the degradation of soil quality (physical, chemical, and biological), so it could disturb plant growth, and even many cocoa plants have died. Such conditions contribute to a decline in the number (population) of cocoa plants in Indonesia. Hence, efforts are needed to reduce the negative impacts of climate change through appropriate technological innovations.

2.1.1 Increasing air temperature

Based on the studies, the temperature of the earth's surface was predicted to increase by 2.1–3.9°C due to global climate change [14]. The measurements over 95 years (1901–1995), in the low latitudes of Asia, Africa, and Central America, air temperature increased with variations of less than 1.5°C, while at the higher latitude, their increase was relatively greater [15]. In various regions of Indonesia, there is also an increase in air temperature, which varies from one region to another. Over the past 30 years (1991–2020), temperatures in the Indonesian regions have increased by an average of around 0.9°C [16].

The increase in air temperature is related to the changes in relative humidity and the evapotranspiration rate in agricultural areas, including cocoa plantations. If the air temperature increases, evapotranspiration increases while the relative humidity decreases. In the dry season, the changes are more significant because an increase in solar radiation triggers them. On the other hand, there is a substantial difference between the temperature of the day and the night. Previous research on cocoa plantations in East Java showed that the increase in temperature within 2–4 months before harvest time had a negative impact on production [17]. Similarly, in Gunungkidul, Yogyakarta, the changes in air temperature are one of the factors affecting fluctuations in cocoa yields [18].

2.1.2 Extreme weather events: Changes in rainfall, increasing temperatures, and rise in sea levels

One of the effects of climate change is that rainfall patterns become irregular, making the wet and dry seasons more erratic. At the same time, one area may experience drought, while another area will experience flooding and landslides. Prolonged drought will cause forest fires and trigger soil degradation, reducing soil fertility and killing various soil microorganisms. The final impact of these problems will result in reduced agricultural land that is considered suitable for certain commodities, including areas for cocoa cultivation.

Cocoa plants only require dry months (rainfall <600 mm/month) for 1–3 months. Therefore, the occurrence of prolonged dry months due to the impact of climate change will reduce cocoa production and quality. Dry months for 1–6 months before harvest reduce the cocoa pod quality in Sukabumi, West Java [19]. Meanwhile, decreased rainfall 2–4 months before harvest has negatively impacted cocoa production in East Java [17]. In 2019, a prolonged drought in Lampung reduced the number of cocoa pods, even causing crop failure [20]. Drought stress reduces vegetative growth, plant biomass, relative water content, leaf chlorophyll content, and nitrate reductase activity, while leaf phenol and proline content increased [21]. Drought stress also reduces mesophyll thickness, leaves, and abaxial epidermis, affecting the stomata's density and closure [22]. Other studies have shown that the number of dry months was correlated positively with the severity of vascular streak dieback (VSD) disease [23].

On the other hand, excessive rainfall causes soil erosion, flooding, and landslides. Soil erosion causes a decrease in soil fertility, which reduces the productivity of cocoa plants. Floods will damage cocoa plantations at low and medium altitudes. In addition, the landslide risk can occur because cocoa is generally intensively cultivated in low to medium altitudes (0–700 m above sea level (asl)). In addition to heavy rainfall, flooding will damage cocoa plantations in the coastal areas due to rising sea levels caused by climate change. During excessive rainfall, the spread of cocoa disease caused by *Phytophthora palmivora* and *Ceratobasidium theobromae* is relatively faster. The rainfall factor causes fluctuations in cocoa yields in Gunungkidul, Yogyakarta [18].

Another impact of climate change is extreme weather, which causes heavy rains, strong winds, and high waves in water areas. The indirect effect of extreme weather is reduced biodiversity, such as pollinators, birds as seed dispersers, and populations of natural enemies for pests and diseases [23]. The effect of La Niña in 2016 reduced the number of cocoa pods in Bali, and the vegetative growth of plants appears to be more dominant than the generative growth [24].

2.2 Development of Indonesia's cocoa area and production, 2013-2022

The total area of Indonesian cocoa during the last 10 years (2013–2022) has decreased by 1.80% per year. The sharp decline occurred in government plantations

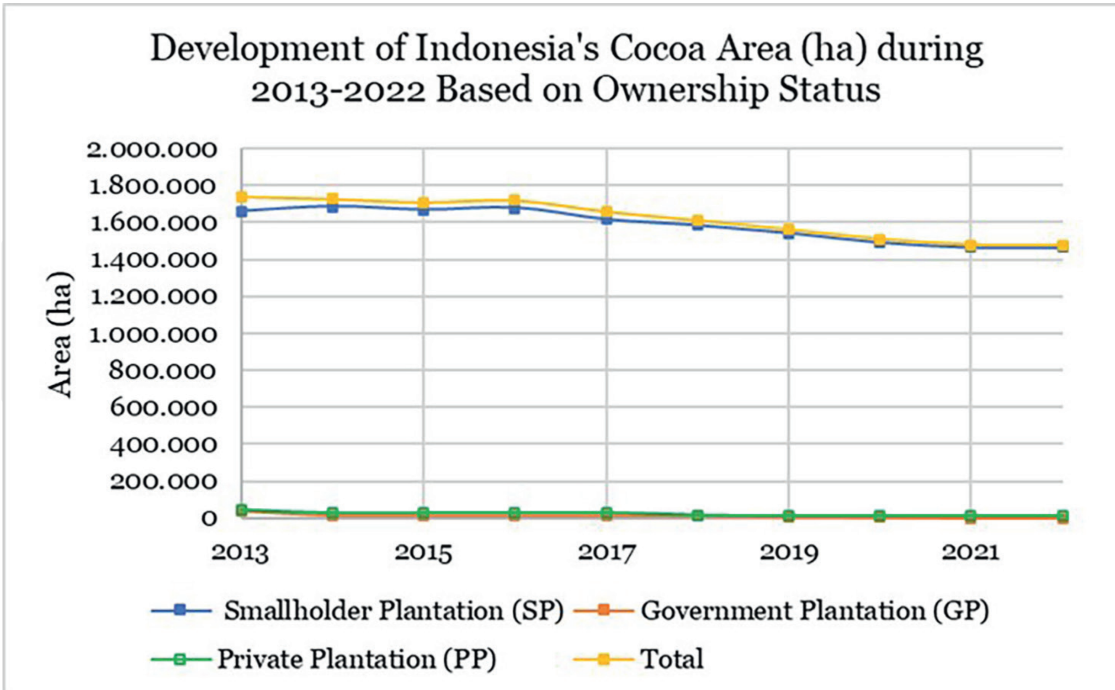

Figure 2.
Development of Indonesia's cocoa area (ha) during 2013–2022 based on ownership status. Source: [2].

(GP) and private plantation (PP) by 28.33 and 11.33% per year, respectively. Smallholder plantation (SP), which dominates Indonesia's cocoa population, has experienced a decrease in land area but is relatively smaller than those of GP and PP, which is around 1.37% per year (**Figure 2**).

Figure 3 shows that the area of mature plants (MP) increased by 1.99% per year. In line with the increasing plant age, many plants changed their status. Initially they

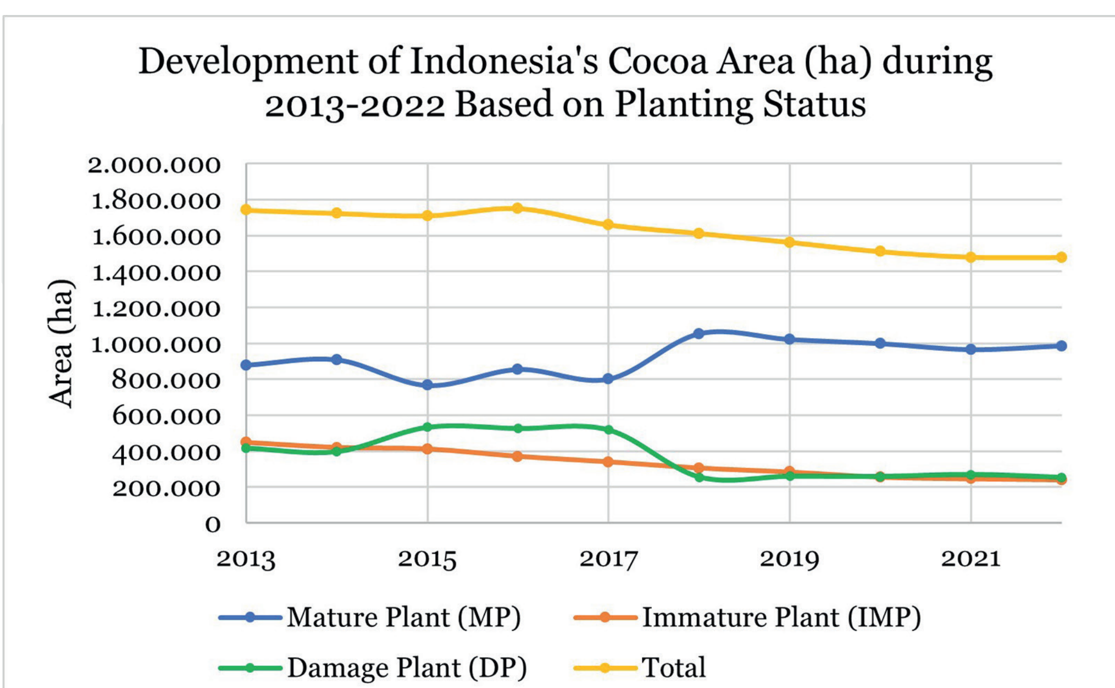

Figure 3.
Development of Indonesia's cocoa area (ha) during 2013–2022 based on planting status. Source: [2].

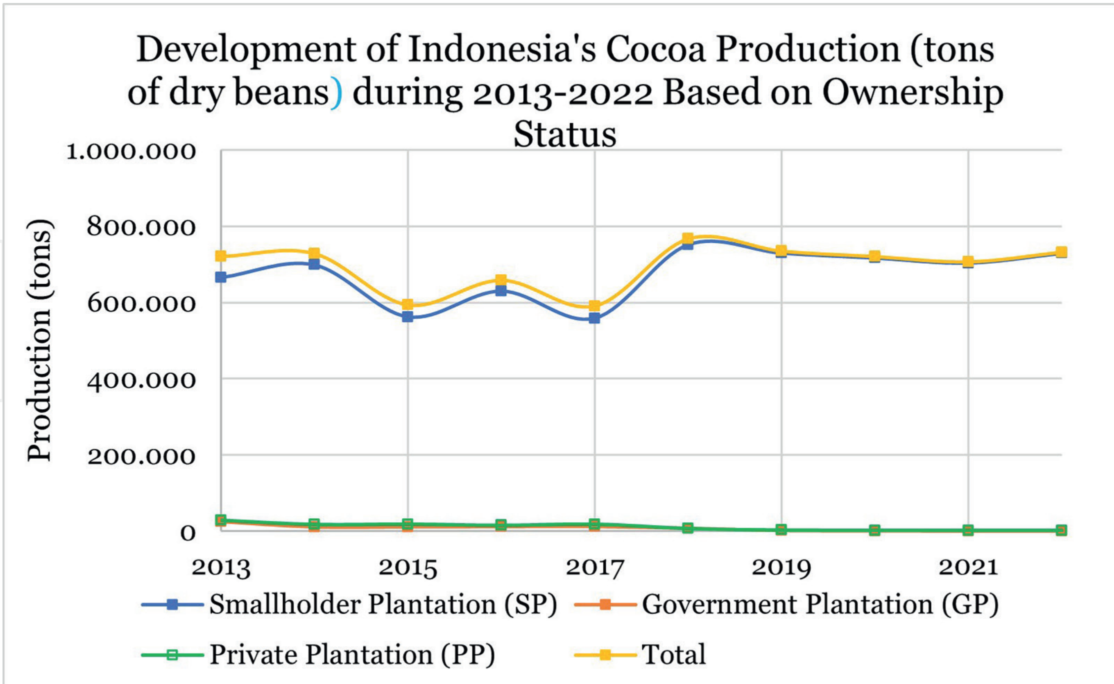

Figure 4.
Development of Indonesia's cocoa production (tons of dry beans)) during 2013–2022 based on ownership status. Source: [2].

were categorized as immature plantations (IMP), then changed to MP. However, the increase in MP number was not proportional to the decrease in IMP (about 6.62% per year), even though the damaged plant (DP) decreased by 2.71% per year. It indicates that during the last 10 years (2013–2022), many young cocoa plants have died before entering their production period. The declined area of DP is caused by the death of many plants, causing a decrease in the total area. This phenomenon will threaten national cocoa production in the next few years.

Many factors contribute to the high rate of decline in IMP, such as stress on the biophysical environment due to changes in climatic conditions. Cocoa plants that are stressed by the biophysical environment will be very vulnerable to pests and disease attacks, even though control has been carried out. Therefore, it is necessary to take action to suppress and reduce the impact of climate change by manipulating growing environmental conditions and implementing good agricultural practices.

Indonesia's total cocoa production during 2013–2022 increased, although relatively small, by about 0.96% per year (**Figure 4**). The main driver of this increase in production was the increase of MP area, as shown in Table 2. Over the past 10 years, the cocoa production of SP has increased by 1.98% per year. Meanwhile, GP and PP cocoa production experienced a sharp decline of 30.49 and 17.6% per year, respectively. The extent of the SP planting area has contributed significantly to the increase in national cocoa production.

3. The technological innovation of adaptation to climate change through good agricultural practices

Cocoa crop management in the era of climate change requires several adaptation strategies, including the use of drought-tolerant clones, followed by improvements in cultivation management from the nursery to the field level.

3.1 Drought-tolerant clones

The use of drought-tolerant clones is the leading strategy in dealing with the phenomenon of climate change. Cocoa clones known to be drought-resistant are Sca 6, Amelonado, TSH 919 [25], KW 163, KW 165, KW 215 [19], KW 641 [23, 26], KW 514, KW 535, KW 619, KW 516 ([26], and KW 562 [27].

3.2 Management at nursery level

3.2.1 Shading and watering of cocoa seedlings

Several methods can be used in water-saving irrigation systems in nurseries, such as sprinkler irrigation, drip irrigation, and capillary wick system. Shading of cocoa seedlings using "paranet" made from nylon materials and watering using sprinkler irrigation method at the Pakuwon Agroscience Park, Indonesian Agricultural Research and Development Agency, has been proven to improve seedling growth and save water use (**Figure 5**). Dealing with water shortages for nurseries, especially during the dry season, can be assisted by micro and semipermanent rainwater harvesting ponds (**Figure 6**).

3.2.2 Modification of growing media

Modifying the growing media has been shown to increase the resistance of cocoa seedlings under water-stress conditions. Several ameliorants can be used as growing media for cocoa seedlings, including manure, compost, biochar, sawdust, and hydrogel [28–30]. Using up to 9 g of cocoa pod husk (CPH) biochar per kg of soil and 12 g

Figure 5.
Shading and sprinkler irrigation for cocoa and coffee seedling at Pakuwon Agroscience Park, in Sukabumi, West Java.

Figure 6.
Micro and semipermanent rainwater harvesting ponds at Pakuwon Agroscience Park, in Sukabumi, West Java.

of CPH biochar per kg of soil with every 6 days of water frequency increases water use efficiency by 208.8 and 262.22%, respectively, compared to control (without biochar) [28]. In addition, adding compost to growing media increases the height, stem diameter, number of leaves, and root weight of cocoa seedlings [31]. Growing media mixed with sawdust, rice husk biochar, and compost in ratios of 60:20:20 and 60:10:30 recovered cocoa seedlings after water stress [30].

3.2.3 Mycorrhizal applications

Mycorrhizal inoculation in nurseries is crucial because it overcomes the problems of limited nutrition, various abiotic stresses (salinity, drought, extreme temperatures, and acidity), and biotic stresses. Therefore, it is necessary for seedlings to be resistant to environmental stress and soil-borne pathogens [32]. Application of mycorrhiza increases water use efficiency [33, 34], nutrient uptakes [34], and seedling growth of cocoa [34–39]. Mycorrhizal inoculation at the nursery stage is expected to have a positive impact on the growth of cocoa plants in the field.

Research progress (1):

An experiment entitled "The Application of Mycorrhiza and Ameliorants to Improve the Growth of Cocoa Plants in Acid Soil" was conducted in a greenhouse at the Pakuwon Agroscience Park, Sukabumi, West Java, starting in 2022/2023. Cocoa seedlings were planted in the polybags on acidic soil media. A completely randomized factorial design consisting of two factors with three replications was used in this study. The first factor consisted of mycorrhizal and without mycorrhizal applications, while the second factor was the application of ameliorant (dolomite and cow manure) and control. Preliminary results showed that mycorrhizal application in acid soil increases cocoa seedlings' root volume and fresh weight. In addition, cow manure had a better effect than dolomite and control (with or without mycorrhizal application) (**Figures 7** and **8**).

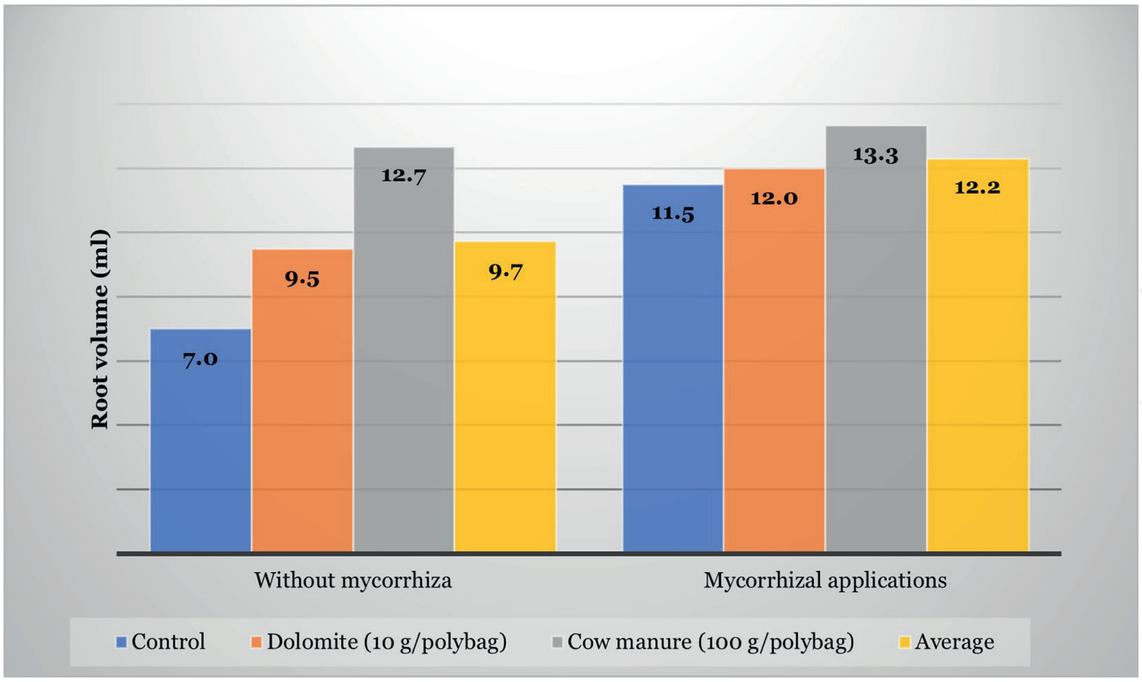

Figure 7.
The effect of mycorrhizal, dolomite, and cow manure on the root volume of cocoa seedlings at 3 months after application in acid soil.

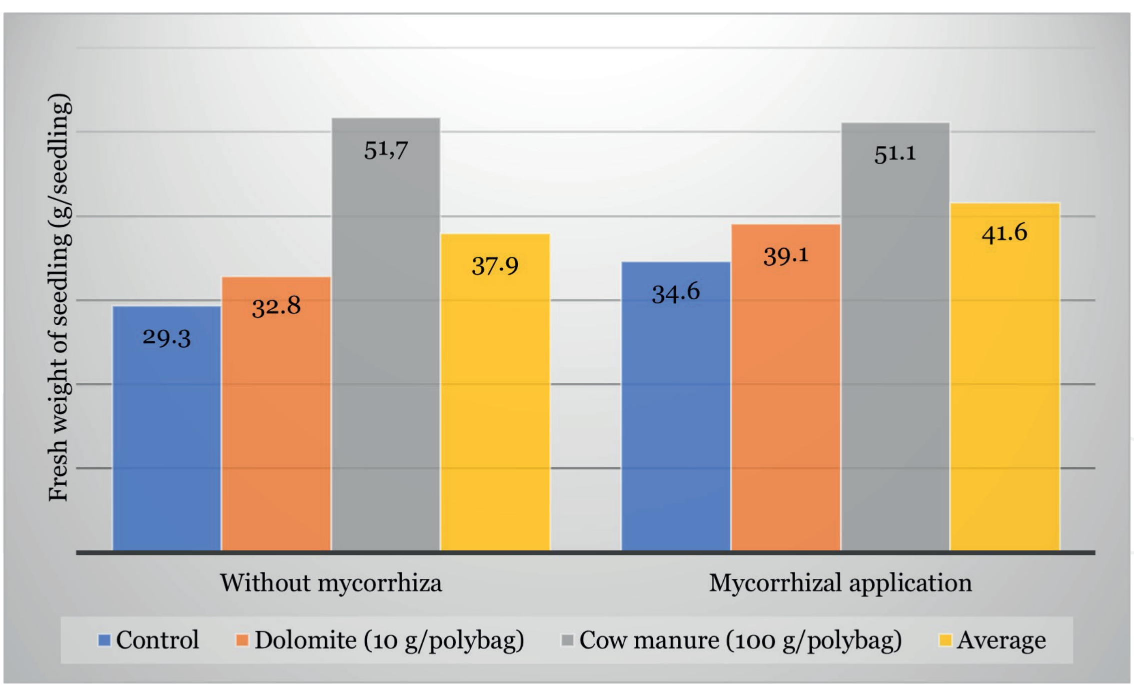

Figure 8.
The effect of mycorrhizal, dolomite, and cow manure on the fresh weight of cocoa seedlings at 3 months after application in acid soil.

Research progress (2):

The experiment entitled "The Application of Mycorrhiza and Ameliorants to Improve the Growth of Cocoa Plants in Drought Conditions" was conducted in a greenhouse at the Pakuwon Agroscience Park, Sukabumi, West Java, starting in 2022/2023. Cocoa seedlings were planted in the polybags. A split plot design with four replications was used in this study. The main plot consisted of two watering treatments, 123 and

61 ml/polybag every 3 days (applied 2.5 months after planting), while the split plot was subjected to the application of mycorrhizal, hydrogel, biochar, cow manure, and control mycorrhizal applied 1,5 months after planting. Preliminary results showed that the watering of cocoa seedlings significantly affects the root volume and fresh weight of cocoa seedlings. In conditions of limited water (watering of 61 ml/polybag), using mycorrhiza added with hydrogel, biochar, or cow manure increased root volume and fresh weight of seedlings compared to the control (**Figures 9** and **10**).

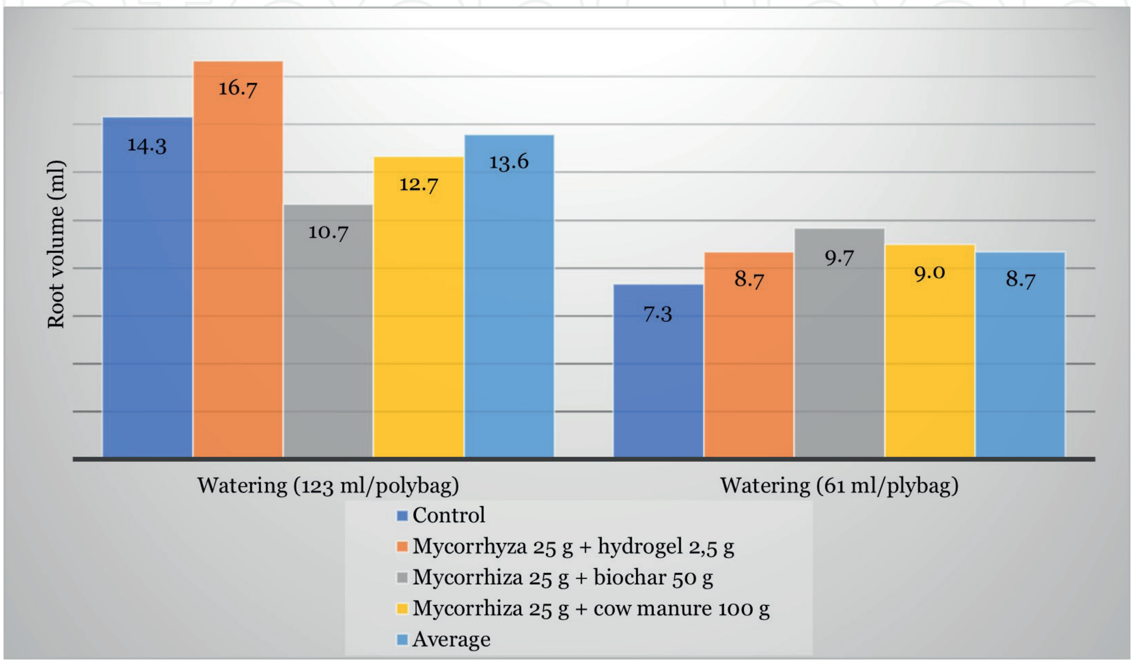

Figure 9.
The effect of mycorrhizal, biochar, cow manure, and two watering treatments on the root volume of cocoa seedlings at 5 months after planting.

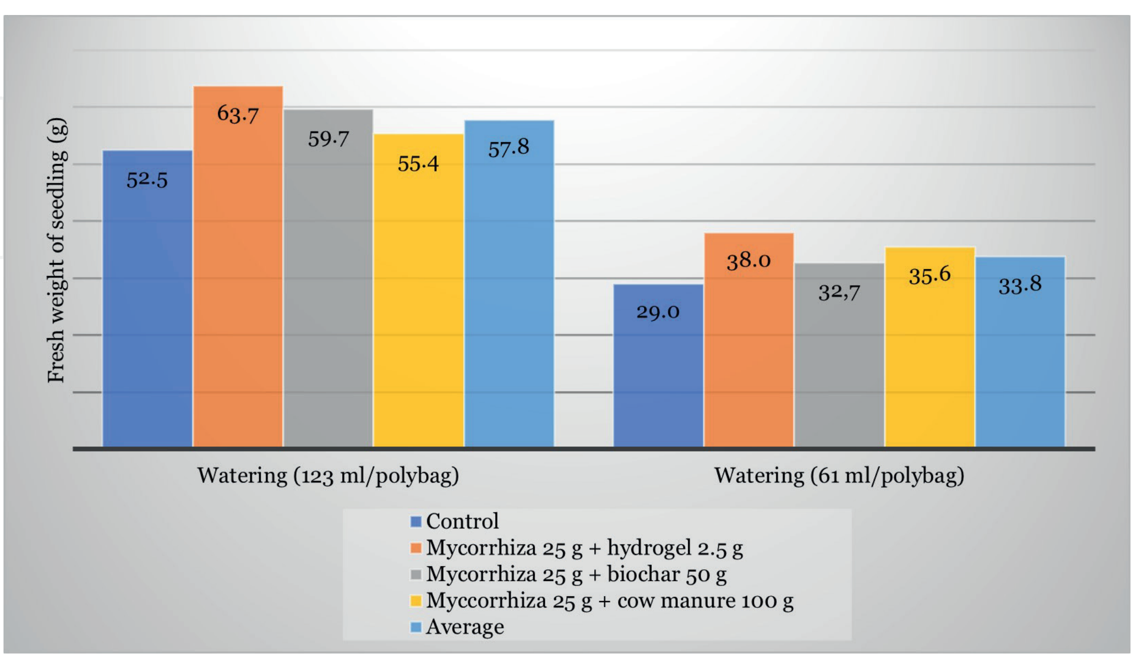

Figure 10.
The effect of mycorrhizal, biochar, cow manure, and two watering treatments on the fresh weight of cocoa seedlings at 5 months after planting.

3.3 Crop management at the field level

Crop management at the field level is focused on three main activities, such as: (i) harvesting rainwater by constructing water storage ponds, (ii) shading cocoa to reduce the effect of solar radiation and high temperatures, and (iii) reducing the evapotranspiration rates by planting intercrops or cover crops.

3.3.1 Harvesting rainwater

The technology for rainwater harvesting is through making ponds, channel reservoirs, and "rorak" systems (sediment pits). Making ponds for cocoa planting is more directed to meet water needs at the start of planting when cocoa's sensitivity to water is limited. The ponds are simple in their construction and size, so it applies to the farmer's level (**Figure 11**). In large cocoa planting areas, permanent ponds of a larger size are needed so that they can serve the existing cocoa population. In this case, the role of the government is very much needed considering the cost of building such a reservoir is very high. Meanwhile, during the dry season when the water starts to decrease, the rorak can function to accommodate organic matter sourced from the pruning of cocoa plants, shading plants, or cover crops. Mowidu and Endang Sri Dewi [40] stated that using rorak in cocoa cultivation increases the total nitrogen (N) and phosphorus (P) available in the soil.

3.3.2 Shading cocoa

Cocoa is a shade-demanding crop that requires shade crops, with only about 60–80% of the solar radiation necessary for growth. Without shade crops, cocoa yields can be increased in the short term, but in the long term, the sustainability of

Figure 11.
The simple ponds for harvesting rainwater at smallholder cocoa plantation, Soppeng, South Sulawesi.

production is threatened. Physiologically, the function of shade on cocoa plants is related to the improvement of microclimate and site conditions (reduction of air and soil temperature extremes, reduction of wind speed, maintenance of soil moisture and water availability, improvement and maintenance of soil fertility including reduction of erosion) and the reduction of solar radiation penetration in both quantity and quality to avoid flushing in cocoa [41]. Therefore, in the current era of climate change, the discussion on the function and role of shade trees for cocoa crops has become a matter of great urgency. Improper management of shade trees will not provide optimal benefits. In fact, it will have a negative impact on cocoa plants. Proper management of shade trees can support growth and increase yields. However, too much shade creates a microclimate that favors the incidence of diseases. Therefore, the selected shade trees should have an architecture capable of transmitting optimal solar radiation for cocoa, their roots should not compete with cocoa for water and nutrients, they should not become host for cocoa pests and diseases, they should be relatively easy to plant and maintain, and they should have a high economic value.

The critical period for cocoa is the young plant stage or initial planting period. Therefore, shade plants should be planted before cocoa, so they can provide shade when cocoa begins to enter production period. In the early stages of cocoa growth, temporary shade plants can use annual or biennial crops such as bananas (**Figure 12**). Bananas have wide canopies that could shade young cocoa plants and maintain adequate soil moisture levels. And for permanent shade perennial crops, such as coconut, areca nut, rubber, *Gliricidia, Albizia*, *Leucaena, Cassia,* or *Erythrina*, can be used. The

Figure 12.
Bananas as temporary shade plants for young cacao at smallholder cocoa plantation, Soppeng, South Sulawesi.

Figure 13.
Mulch from cocoa pruning at cocoa plantations of Pakuwon Agroscience Park, in Sukabumi, West Java.

research results at cocoa plantations in Sulawesi with *Gliricidia* shade plants showed their tolerance to drought [42, 43].

The increase in air temperature due to climate change requires shade trees to be planted at closer distance. Pruning of shade trees is carried out according to seasonal conditions, where pruning should not be carried out in the dry season to allow the tree to withstand too much sunlight. Pruning of shade trees should be done before the rainy season. The leaves from cocoa pruning can be utilized as mulch to minimize evapotranspiration and as a source of organic matter (**Figure 13**).

3.3.3 Intercropping

Cocoa planted under shade plants is an intercropping pattern. Cocoa is planted between two rows of shade crops, and the distance between the cocoa and shade crops is quite large. This cropping pattern still leaves space between the two crops, so there is still an opportunity to plant other crops as intercrops. Intercropping between cocoa and shade trees suppresses weed growth, reduces evapotranspiration, and can withstand runoff, erosion, and landslides on sloping topography. In addition, planting intercrops will produce various agricultural products, so if properly and correctly managed, it will sustainably increase farmers' income. By planting intercrops on an annual or a biennial basis, results will be obtained quickly, the frequency of tillage will be more intensive, so that the soil's physical, chemical, and biological conditions will always be maintained, and as a source of easy and cheap organic material.

The integration of cacao, shade plants, and intercrops is similar to the cacao agroforestry model that has been widely discussed in the era of climate change. A dynamic cocoa agroforestry system can develop various crops with different life cycles. It resembles multistoreyed cropping systems [44] and high-density cropping systems in coconut [45].

The selection of intercrops to be planted between cacao is based on the microclimatic conditions between the canopies and market opportunities. Some intercrops identified as tolerant and able to adapt well to highly shaded conditions are colocasia, amorphophallus, banana, ginger, turmeric, arrowroot, and kacholam [46]. In addition, the selection of intercrops should also consider the habitus of the trees lower than cacao, the rooting structure of the intercrops should be different from that of cacao, and intercrops should not be hosts to cacao pests and diseases. On the other hand, legume cover crops as intercrops may not provide direct economic returns, but these crops can help fertilize the soil, suppress weed growth, and retain runoff to prevent sloping topography from erosion and landslides. In livestock areas, planting fodder crops as intercrops can easily and sustainably provide fodder, allowing for mixed farming. Research shows that sequential planting of rice and soybean as intercrops under cocoa could improve productivity in the long term [47], as can intercropping with patchouli; even the nutrients given to patchouli plants can be absorbed by cocoa plants, allowing them to grow better than cocoa monoculture [48]. In addition to choosing the right type of intercrops and spacing them appropriately, providing adequate intakes for each combined crop (cocoa, shade plants, and intercrops) will avoid the effects of water and nutrient competition that may occur.

4. Conclusion

The impact of climate change on cocoa production in Indonesia has been highlighted. The rate of decline in Indonesia's cocoa area during 2003–2022 is 1.80% per year, with young cocoa plants declining the most at 6.62% per year. During the same period, the slight increase in production (0.96% per year) is not due to increased productivity but rather to an increase in harvested area. As a result, Indonesia has fallen from fourth to seventh place as the world's largest cocoa producer. To minimize further impacts of climate change on Indonesian cocoa, adaptation strategies through improved crop management are needed. Strategies through extensification programs are still open to opportunities, but these strategies face obstacles because they will compete with other sector development. The intensification strategy that needs to be implemented starts from selecting cocoa clones that are considered drought tolerant, followed by good nursery management through watering and shading, modification of growth media, and application of mycorrhiza to produce planting material with good vigor. Furthermore, at the field level, practices, such as rainwater harvesting technology, optimal management of shade crops, and planting appropriate intercrops, should be promoted for adoption by farmers for sustainable cocoa production. The advantage of yields of intercrops can meet farmers' short-term food and income needs.

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