

Ecological Adaptation Patterns to Tropical Climate Change Phenomena in Climate-Resilient Potato Crop Engineering

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ABSTRACT

Climate change has a significant impact on tropical agricultural systems, particularly in potato cultivation, which is highly sensitive to environmental fluctuations. This study aims to analyze ecological adaptation patterns in potato crop engineering to enhance resilience against the impacts of tropical climate change. A mixed-methods approach was employed, combining field observations, climate data analysis, and controlled environment experiments to evaluate plant responses to varying climatic conditions. The results indicate that fluctuations in temperature, irregular rainfall, and increased humidity have a significant impact on potato growth, yield, and disease susceptibility. Adaptation strategies, such as selecting climate-resilient potato varieties, optimizing irrigation management, and implementing soil conservation techniques, were found to mitigate the negative effects. Based on these findings, this study suggests incorporating climate-resilient crop engineering into sustainable agricultural policies to ensure long-term food security in tropical regions.

Keywords-climate change; ecological adaptation; potato crop engineering; sustainable agriculture; tropical agriculture

I. INTRODUCTION

According to the 2023 IPCC report, global surface temperatures from 2011 to 2020 were approximately 1.1°C higher than those observed between 1850 and 1990, primarily due to increasing Greenhouse Gas (GHG) emissions. This rise in temperature has had significant effects, disrupting ecosystem structures that, in turn, affect food supply and water resources. These ecosystem changes are primarily driven by changing

climate conditions, which have traditionally been recognized as crucial factors in development activities, including agriculture.

Climate change significantly increases the likelihood of severe droughts or prolonged dry seasons [1, 2]. Extended droughts and shifts in rainfall patterns have a significant impact on agricultural sustainability [3]. These conditions have raised global concern about food security and the future of the food supply. Additionally, the negative impacts of climate change

tend to disproportionately affect lower socio-economic communities, especially small-scale rural farmers [4, 5]. In the Indonesian context, as a tropical country, Indonesia has unique climate conditions compared to non-tropical regions. Climate anomalies caused by the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) have a significant influence on Indonesia's climate patterns. These anomalies have led to significant setbacks in Indonesia's development efforts, particularly in the agricultural sector. Positive phases of ENSO and IOD typically bring severe droughts, while negative phases can impact the Madden-Julian Oscillation (MJO), leading to extreme weather events such as tropical storms and cyclones. Overall, the characteristics of ENSO and IOD, including variability, frequency, dynamics, teleconnections, impacts, and predictability, are expected to change due to climate change [6]. As a result, Indonesia faces a higher risk of climate-related disasters, which are likely to worsen as the climate crisis deepens.

South Sulawesi Province, a crucial food-producing area in Indonesia, is among the most vulnerable regions in eastern Indonesia to climate-related hazards. The National Disaster Risk Assessment 2022–2026 for South Sulawesi shows that floods could damage 4,677 hectares of land, leading to economic losses of IDR 23.533 trillion. In comparison, droughts may impact 661,732 hectares and cause losses of IDR 37.394 trillion [7]. Climate change poses significant risks to agricultural production, particularly in Gowa Regency, the primary potato-growing region in South Sulawesi. According to Statistics Indonesia (BPS), potato yields reached 407,017 tons in 2020.

Climate change has significantly impacted agricultural productivity, including potato farming, and has substantially harmed farmers' livelihoods, making them among the most vulnerable groups [8, 9]. Climate anomalies, such as rising temperatures and shifts in rainfall patterns, have degraded soil quality and its functionality [10]. These conditions directly influence potato crop yields, which are further impacted by the increased presence of pathogens, such as late blight disease. These pathogens thrive in environments with higher rainfall, temperatures, and humidity, resulting in decreased productivity and, in severe cases, complete crop failure [11]. For farmers, climate change poses a new and significant challenge, yet many lack the capacity to effectively mitigate its impacts. This limitation mainly results from a lack of awareness about climate change, insufficient financial resources, and limited access to agricultural technology [12, 13]. Additionally, factors such as age, gender, farm size, formal education, access to extension services, and participation in farmer organizations affect farmers' ability to adapt to climate change [14].

However, each farming community develops unique institutional arrangements influenced by ongoing interactions between society and the environment. As a result, institutional capacity is essential for shaping adaptation strategies [15]. Furthermore, smallholder farmers' ability to cope with climate vulnerabilities largely depends on their understanding of current climate conditions [16]. Understanding climate is crucial for assessing the urgency of adaptation strategies and reflects farmers' capacity to adapt [17].

II. LITERATURE REVIEW

Numerous studies have examined farmers' adaptation strategies in response to the impacts of climate change. Authors in [18] found that many farmers have limited knowledge about climate change and rely solely on their farming experience to understand its effects. Those who were aware of climate change adjusted their planting schedules based on water availability, used generator-powered irrigation systems, and enhanced pest control methods by applying pesticides, insecticides, and fungicides. Authors in [19] discovered that most farmers identified three major climate events caused by climate change: irregular rainfall patterns, rising temperatures from intense sunlight, prolonged droughts, and an earlier start to the rainy season. These climate changes pose significant risks, including crop failures, challenges to farm sustainability, and increased infestations of pests and diseases. Authors in [20] found that extreme weather events have altered lodging resistance in rice crops, highlighting the importance of cultivating lodging-resistant rice varieties in regions prone to such conditions. The author in [21] revealed that, although government initiatives have been implemented to adapt farming systems, there is still a need for future climate projections to better anticipate the impacts of climate change on tropical fruit and vegetable crops. Meanwhile, authors in [22] emphasized that Indonesia's national action plan for climate change adaptation requires active involvement from business communities, academia, civil society organizations, development partners, and all segments of society to effectively address climate change and improve national food security.

Overall, these studies examine the impact of global climate change on agriculture and local adaptation strategies; however, they do not fully consider the unique aspects of tropical climate change at global, regional, and local levels. Additionally, many recommended adaptation strategies tend to be broad and focus on macro-level solutions, often overlooking the specific adaptation methods used by farmers, which could differ across regions affected by climate change.

III. METHODOLOGY

This study utilizes human ecology theory, which classifies ecological adaptation patterns into three main categories [23]:

1. Environmental Determinism describes how adaptation patterns are entirely influenced by the environment. Human societies across various regions often exhibit similar cultural responses and behaviors when confronted with environmental changes.
2. Environmental Possibilism describes how different cultures adapt in various ways even when faced with similar environmental conditions. When environmental changes happen, different cultures may develop their own unique responses.
3. Environmental Culture involves adaptation patterns that depend entirely on innovation and technology to address environmental challenges. This approach, often referred to as cultural ecology, encompasses practices such as building irrigation dams, modifying weather patterns to

produce artificial rain, and other technological solutions. It challenges the first two adaptation theories.

This research was carried out in the Tinggi Moncong District, a key hub for horticultural production in South Sulawesi Province. Therefore, this study employs a constructivist interpretive framework, drawing on the case study approach. This method is chosen to examine tropical climate change in South Sulawesi, its effects on horticultural crops, and the ecological strategies farmers implement to cope with these climate shifts.

Data collection methods encompass field observations, in-depth interviews, documentation, and triangulation, which aim to ensure the validity of the data related to the research context. For instance, when farmers report high rainfall, we cross-check their reports with weather station data to validate the information they provide. In line with case study traditions, the analytical process follows a holistic analysis approach divided into four stages [24]: 1. Data collection – gathering both primary and secondary data. 2. Data reduction – filtering and organizing relevant information. 3. Data display – arranging data into patterns for analysis. 4. Drawing conclusions – analysing findings to identify key insights.

IV. RESULTS AND DISCUSSION

Farmers play a vital role in agriculture and are among the first affected by climate change. However, they are also leaders in implementing climate adaptation strategies. The local knowledge gained from experience is a crucial resource for developing and applying these adaptive methods, which are essential for maintaining household livelihoods.

A. Climate Change Phenomenon

The agricultural sector, which is crucial for providing food at local, national, and global levels, is facing increasing challenges in meeting the food needs of a growing population. These challenges are expected to worsen as climate change persists, especially without efforts to reduce and adapt to its effects. In this context, the Pattapang Subdistrict, a key area for horticultural crop production in South Sulawesi Province, is not immune to the impacts of climate change on agriculture, particularly on potato farming. The following sections will describe the specific climate change phenomena observed in the study area and their impact on agricultural production.

1) Unpredictable Weather

Climate change has led to weather anomalies reaching unprecedented levels. Farmers, who have traditionally depended on local knowledge gained from years of interacting with their environment, can no longer rely on weather patterns to determine the best time to plant. This unpredictability directly affects their agricultural practices, which are vital for their livelihoods. This challenge is evident in the responses from participants in this study:

"With this kind of weather, potato crops are less fertile, and their growth is not normal, especially in the past 2–3 months. The unpredictable weather, with rain at night, has been damaging. Up until now, the harvested potatoes have resulted

in crop failure. Most farmers have suffered crop losses starting this season." (HUN, 59 years old)

Another farmer expressed a similar concern, describing the rapid fluctuations between rain and heat as a major factor affecting potato growth.

"Sometimes it rains, and sometimes it's hot. The unpredictable weather, shifting between rain and sun, has the greatest impact on potatoes. That's what causes them to wilt." (JSR, 27 years old)

To handle these conditions, some farmers delay planting until the weather stabilizes. However, this decision significantly impacts their household finances, as their income is entirely dependent on the agricultural yield.

"There was a year when the western winds never came. We anticipated it and decided not to plant, but in the end, there was nothing. When it comes to wind and rain, we can't predict or control them. The only thing we can do is pray. Last year, the western winds arrived at the end of January, while in 2024, it came much later. In previous years, by mid-December, we already had rain and western winds, sometimes even causing flooding on the roads." (TTG, 50 years old)

This increasing unpredictability in climate conditions continues to pose significant risks to farmers, making it more challenging for them to sustain agricultural production and protect their livelihoods.

2) Rainy Season Shift

Data from BMKG from 2014 to 2023 reveals notable shifts in rainfall patterns in Tinggi Moncong District (see Figure 1). Traditionally, local communities believed the rainy season began and ended at specific times each year based on local knowledge. However, these patterns have altered, with rainfall now occurring outside traditional seasons, including mid-year. This change in typical weather patterns complicates farmers' reliance on their established climate knowledge for farming decisions and planning.

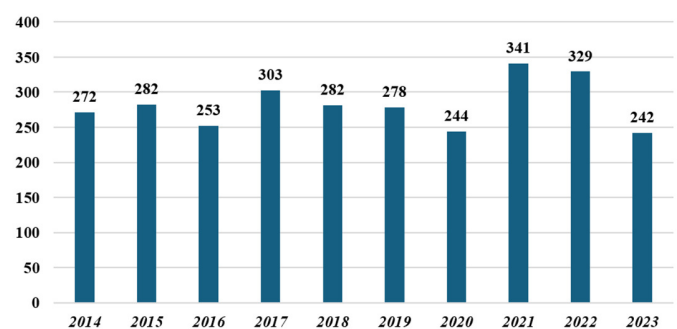


Fig. 1. Average rainfall (in mm) in Tinggi Moncong District in the last 10 years.

The data above indicate that the years with high rainfall were 2017, 2021, and 2022, while the other years experienced moderate rainfall. Over the past decade, rainfall has occurred throughout the year, although some months in 2014, 2015, 2018, and 2023 received little to no significant precipitation

(Figure 1). This data highlights the frequency of weather anomalies in the study area, particularly regarding rainfall patterns that have significantly impacted horticultural farming, including potato cultivation, which is highly vulnerable to heavy rainfall. These findings match the experiences shared by farmers in the region.

"We rely on experience, and over the years, rainfall patterns have changed significantly. In the past, rain usually occurred in the afternoon, but now it frequently rains at night, continuing until dawn and sometimes even into the morning. There may be a brief period of sunshine, but then it rains again." (HUN, 59 years old)

Additionally, there has been an increase in rainy days, with farmers observing rain even during the dry season. Traditionally, based on their own experiences and lessons passed down through generations, they did not expect rainfall at this time.

"Now, even during the dry season, we still get rain. It's not like before. In the past, once the rainy season began, it would rain continuously, and during the dry season, there would be no rain at all. Now, it's unpredictable..." (JSR, 27 years old)

Farmers have only recently recognized this changing weather pattern, which makes it harder for them to determine the best time to start planting on their land.

"If I'm not mistaken, this has been happening for about three years now. It has become difficult to predict the weather. Sometimes it rains, sometimes it's hot. This unpredictability affects potatoes the most. It causes them to wilt." (JSR, 27 years old)

Some farmers have faced losses due to decreased yields caused by unexpected early rainfall. In the study area, potato planting usually occurs in March-April and July-August to avoid heavy rain during the critical growth stages. Since potatoes mature in less than 70 days, heavy rain or strong winds during this period can cause crop failure.

"Last year, it started raining in November, but we expected it to rain in December or January. The rain came earlier than we anticipated, which significantly reduced our potato harvest. Usually, heavy rains start in December or January, but last year, they arrived in November." (UN, 43 years old)

Unexpected changes in seasonal rainfall have disrupted traditional farming schedules, increasing financial risks for farmers who depend on accurate weather forecasts for successful potato cultivation.

3) Strong Winds

Potatoes are particularly vulnerable to strong winds, especially during the first 70 days of growth, when tubers are developing. External stressors, such as high winds, can break stems and lead to crop failure. Climate anomalies influence not just rainfall but also wind patterns. Traditionally, strong winds have mostly occurred during the rainy season, but recently, they have also been observed in July, September, and from December to January.

"Weather patterns have always changed over time, but the biggest difference now is in timing. Sometimes the strong winds appear in July, sometimes in September. The west winds, accompanied by heavy rain, usually start at the beginning of December. That has been my experience over the years." (TTG, 50 years old)

There have been instances when heavy rain and strong winds persisted for 1.5 months, significantly hindering farmers' ability to manage their farmland.

"Yes, this usually happens at the end of the year. I even recorded a time when, for 1.5 months, we had continuous rain and strong winds, and the sun was completely obscured. It was always cloudy, raining, and windy." (HUN, 59 years old)

These prolonged extreme weather events pose significant challenges for potato farmers, affecting both crop growth and overall farm productivity.

B. The Phenomenon of Climate Change Impacts

Climate change has led to significant shifts in agricultural systems. Farmers have faced various impacts, including reduced crop yields and total harvest failures, which are directly attributed to climate variability. This has disrupted household livelihoods, as most farmers rely entirely on their agricultural output for survival. Weather anomalies caused by climate change have had various effects on agriculture, including an increase in pests. Climate change has altered the distribution and population patterns of insect pests, affecting pest levels and status in specific regions [25]. Consequently, areas experiencing climate anomalies due to climate change are likely to undergo notable changes in their agricultural systems, including shifts in pest populations. Within the study area, farmers' experiences confirm that these changes have already been observed.

"There is a noticeable difference between the 1990s and now. Back in the 1990s, we only used fungicides and pesticides sparingly because the weather was good, and pests and diseases were rare... Yes, now there are far more pests than in the 1990s. But we are still grateful that Malino is different from other areas." (TTG, 50 years old)

Another farmer also observed an increase in pest infestations affecting potato crops.

"It's different now. There are more pests. Many farmers complain about plant diseases." (JSR, 27 years old)

High rainfall levels have also led to increased fungal growth, affecting potato leaves and causing leaf rot disease. If left untreated, this disease could potentially destroy the entire potato crop.

"Potatoes cannot withstand too much rain. Fungal diseases are very common during the rainy season..." (HUN, 59 years old)

Young potato plants, especially those in the early growth stage (1 to 2 months old), are highly vulnerable because of their thin and fragile leaves, which increase their susceptibility to fungal infections.

"Yes, the early growth phase. From 1 to 2 months old, potatoes are very vulnerable. During this period, the leaves are still thin and highly susceptible to disease." (HUN, 59 years old)

Additionally, pests do not only appear during the rainy season; they also occur during the dry season, especially under extreme heat conditions.

"Soil pests and leaf damage—when the leaves turn black, they won't produce potatoes. We prioritize keeping the potato leaves healthy. If the leaves start turning black, the plant won't bear fruit. There are many problems with potatoes... because it rains almost every day, even at night." (UN, 43 years old)

In addition to rainfall anomalies, temperature fluctuations have a significant impact on pest development. Data from BMKG over the past five years reveal varying temperature patterns. Notably, over the last three years, the Tinggimoncong District has experienced a marked increase in temperatures compared to 2019 and 2020 (Figure 3). This sharp rise, coupled with inconsistent rainfall and strong winds, has intensified agricultural challenges, further complicating potato farming for local farmers.

The sharp increase in temperature has had a negative impact on farmers.

"Yes, the temperature is higher during the rainy season. But during the dry season, insecticide use increases significantly because different pests emerge. During the rainy season, soil caterpillars are common, but in the dry season, we deal with thrips, aphids, and nerumisa." (TTG, 50 years old)

Thrips pests reproduce quickly at humidity around 70% and temperatures between 27 and 32°C. Based on BMKG temperature data, the chances of thrips proliferation are significant. Infested potato plants exhibit symptoms like leaf curling and stunted growth. In severe cases, the plants may wither and die, posing a serious threat to potato yields and increasing farmers' difficulties amidst climate irregularities.



Fig. 2. Potato leaves starting to be attacked by fungus.

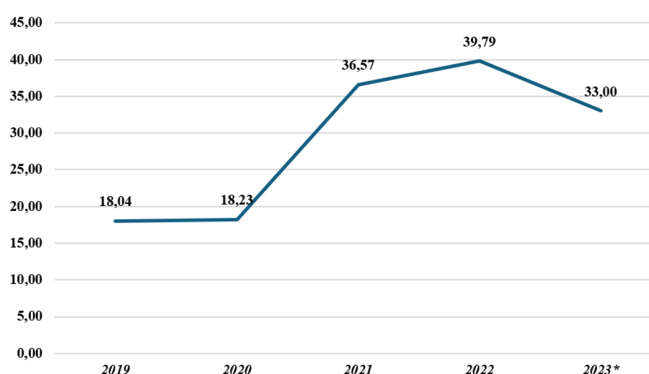


Fig. 3. Average temperature of Tinggimoncong sub-district.

Along with thrips infestations, bacterial wilt disease presents other major challenges for potato farmers. This disease is primarily caused by *Ralstonia solanacearum*, a pathogen that significantly impacts plant health and yield. Potato plants infected by this bacterium typically exhibit wilting symptoms, starting with the young leaves; the disease primarily affects plants younger than six weeks. Besides damaging the leaves, the disease also harms the tubers, causing blackened or rotting spots. If left untreated, bacterial wilt can result in substantial yield losses, exacerbating the challenges posed by climate change and unpredictable weather.

In recent years, bacterial wilt disease has remained a persistent problem for farmers, with the past two years being the worst in terms of outbreaks. Although the occurrence of wilt disease has decreased compared to two years ago, symptoms are still frequently seen in potato crops.

"It has happened several times, about 3–4 times. Almost every year now. Two years ago, there were many cases of wilting due to heavy rain. Currently, the plants are not completely wilting, but their growth is not normal either." (HUN, 59 years old).



Fig. 4. Average temperature of Tinggimoncong sub-district.



Fig. 5. Condition of plants experiencing wilt disease.

Some farmers still do not understand the exact cause of wilt disease. Many believe that plant wilting is only caused by weather conditions. This attitude limits their response options, as they think that preventing climate-related problems is almost impossible.

"The plants wilt, but we don't really know whether it's the seed or something else. But most farmers say it's because of the weather. Sometimes it rains, sometimes it's hot." (JSR, 27 years old)

"The plant stems develop holes, and after the wind stops, they immediately wilt. That's why they don't produce tubers—because the roots, which are supposed to form potatoes, have already been damaged." (UN, 43 years old)

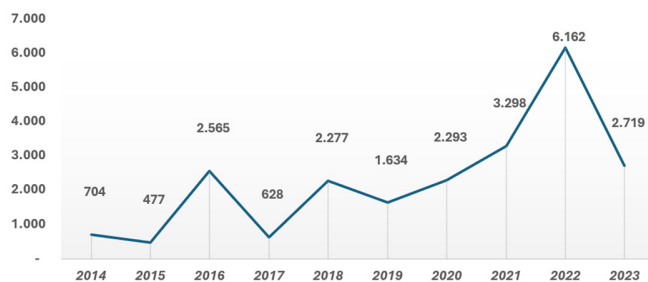


Fig. 6. The amount of potato production in Tinggimoncong District in the last 10 years.

These adverse conditions led to a sharp decline in production, with some farmers experiencing complete crop failures. Data from the Gowa Regency Agricultural Office shows that 2022 had the highest potato yield in the past decade (2014–2023). However, in 2023, production dropped by 44.13% from the previous year, underscoring the serious impact of climate anomalies on potato cultivation. Comparing this with BMKG rainfall and temperature data reveals that climate change has profoundly influenced potato yields. Farmers interviewed for this study also expressed this concern.

"In the past, average production per hectare was around 20–30 tons. Now, it's about 20 tons on average, and if there's crop failure, it drops to around 10 tons. Even when prices are high, we don't feel the benefits because production is low. The main factor is the weather. This season, most farmers have experienced crop failure. In the past, when the seasons were predictable, production was good. But now, things have changed. Especially during the last season, those who planted

in February and March couldn't even harvest." (HUN, 59 years old)

"This land is about 500 hectares, and we usually plant around 200 kg of seed potatoes. Normally, we harvest about 3–4 tons per cycle. Before, it used to be over 5 tons." (JSR, 27 years old).

"During the rainy season, production drops drastically. For example, last time on one hectare of land, the yield was not even 3 tons. Normally, it should be around 15–20 tons." (TTG, 50 years old)

Climate change affects crops by increasing pest infestations and causing significant economic costs for farmers. As pest outbreaks worsen, farmers must spend more on inputs such as pesticides and fungicides to protect their harvests. Typically, spraying occurs once a week; however, during periods of heavy rain and high pest activity, it is increased to two or three times a week. More rainfall increases the amount of pesticides used per session.

"During the rainy season, our production costs double or triple because we have to spray pesticides up to three times a week." (JSR, 27 years old)

"It costs multiple times more than during the dry season. For example, in the dry season, we can mix 1 kg of pesticide into three drums of water. But in the rainy season, we need 500 grams per drum, so the concentration is much higher." (TTG, 50 years old)

Since Gowa Regency plays a key role in providing food for South Sulawesi and other regions, it is essential to focus on increasing production capacity. The increasing challenges posed by climate change and extreme weather require immediate adaptation strategies to support potato farming and ensure food security in the region.

C. Adaptation Strategy

Adapting to climate change in agriculture involves maintaining production capacity despite changing environmental conditions. The author in [23] emphasizes an adaptation model that relies entirely on innovation and technology for managing the environment, suggesting that farmers must adopt new agricultural practices to adapt to these changes. The decline in production and frequent crop failures clearly show that traditional farming methods are no longer suitable for current climate conditions.

In this study, farmers have adopted various adaptation strategies to sustain agricultural production in response to climate anomalies. These strategies aim to reduce risks and adapt farming practices to unpredictable weather, rising pest infestations, and changing rainfall patterns. The following sections will discuss how farmers are tackling climate-related challenges to protect their crops and incomes.

1) Shifting the Planting Season

Farmers' experiences with unpredictable and ever-changing weather conditions have increased their awareness of the need to adjust planting schedules. This approach aims to minimize

losses caused by heavy rainfall, which greatly impacts potato crops.

"Our way of anticipating this... we simply adjust the planting schedule. We have to delay planting, especially during the dry season. If suddenly there is heavy rain and we have already planted in low-lying or wet areas, then we have no choice but to postpone the planting schedule." (TTG, 50 years old)

When rainfall lasts longer than expected, farmers choose to delay planting until the rainy season ends, even if the seed potatoes they prepared have already sprouted in storage.

"Some farmers here even hold off planting their seed potatoes. For example, if the planting season is supposed to start this month, they delay it until the next month. Some even store the seed potatoes until the sprouts grow longer because the weather is still unfavorable." (JSR, 27 years old)

Farmers, drawing on their past experiences, schedule their planting based on known rainfall patterns. Their goal is to ensure that potatoes reach a specific maturity stage before heavy rain and strong winds occur.

"Yes, it's dangerous if the plants are still under 50 days old because they are still in the fruiting phase. But if heavy rain comes when the plants are 90 days old, it's safe because they have already produced tubers." (JSR, 27 years old)

This adaptation strategy illustrates how farmers adjust their planting schedules to better manage climate risks, aiming to enhance crop survival and yields amid climate variability.

2) Reducing Wind Speed

As previously explained, along with rainfall, strong winds also present a significant concern for farmers. To minimize damage to potato crops, farmers have constructed wind barriers that reduce wind speed and protect their plants.

"There is a way—we use shade nets (paranet) to reduce the intensity of the wind." (TTG, 50 years old)

Besides shade nets, farmers often plant tall vegetation, such as elephant grass, corn, or other plants, around their fields. While corn is cultivated as a crop, these other tall plants are primarily used as natural windbreaks, rather than for harvest.

"Indirectly, these plants help block the wind. The key is to have them along the edges of the fields. We let the grass grow naturally without clearing it. Elephant grass, in particular, grows very fast, spreading quickly because its flowers produce seeds rapidly." (HUN, 59 years old)

These strategies highlight how farmers adapt to climate variability, demonstrating their efforts to protect crops and sustain agricultural productivity despite increasing climate uncertainties. Several other farmers also mentioned this approach.

"We already use various methods, such as planting elephant grass or corn along the edges of the fields. We use corn stalks as wind barriers. But the wind is unpredictable—it doesn't appear every month. Four days ago, for example, the

wind was three times stronger than it is now." (TTG, 50 years old)

This statement underscores the difficulties caused by unpredictable wind patterns, even with farmers' protective measures. Although natural windbreaks decrease wind strength, abrupt and powerful gusts continue to threaten potato crops and farm productivity.



Fig. 7. Paranet as a strategy to reduce wind speed.



Fig. 8. Garden border plants that can reduce wind speed.

This approach effectively shields potato plants within a 4–5-meter radius from the field edges. However, plants beyond five meters or those in the center of the field are still at risk from strong winds.

"But only the plants within a few meters are protected—about 4–5 meters. If the edge plants grow too tall, they block sunlight from reaching the potatoes. And plants need sunlight." (HUN, 59 years old)

To reduce the risk of yield loss due to strong winds, farmers plant border vegetation as a natural barrier against severe weather. Although this method might not entirely shield all crops, it offers notable advantages in maintaining plant health and supporting farm productivity.

3) Using Superior Seeds

Using high-quality seeds is crucial for ensuring both the yield and quality of farm produce. Farmers choose superior seeds to reduce the risks of crop failure and financial loss in the future.

"Every year, we bring in new G0 seeds. In terms of pest resistance, G0 is stronger because it is new and still sterile. The yield is also better. ... During the dry season, as long as irrigation is sufficient, we can harvest up to 25 tons per

hectare. If we use G3 seeds, the yield is lower, around 18–20 tons per hectare." (HUN, 59 years old)

According to [26], G0 seeds deliver substantially higher production quality than other seed classes, such as G1, G2, or G3. Their research showed that G0 seeds boosted production by 34.33 times, increasing from 0.9 kg to 30.63 kg, making them the most productive option. Despite this, some farmers still use G1, G2, G3, or even G4 seeds due to economic considerations. Many prefer growing their own seeds to maintain quality and manage farming expenses.

"Most people here buy G0 seeds first, then cultivate them to produce more seeds, continuing up to G3 or G4. That way, they know the lineage of the seeds they are using." (JSR, 27 years old)

Other farmers also adopt this practice:

"At first, we buy the seeds, then we propagate them. After each harvest, we keep the smaller potatoes until they sprout, and then we plant them again. We don't sell them until they reach G3. Since these are still G1, we store them for two planting seasons. By the time they reach G3, the yield starts to decline, so we sell all of them at that stage." (UN, 43 years old)

Although G3 seeds are widely used, farmers recognize that certain batches may contain viruses, which could present risks.

"Many people sell G3 seeds, and we have samples, but there is always a chance that they carry viruses." (JSR, 27 years old)

The Ministry of Agriculture of Indonesia explains that seeds classified as G1 to G4 are derived from seeds classified as G0. Using different seed classes is considered a practical approach by farmers to improve household financial management and lower input expenses in farming.

"G0 seeds are small and quite expensive. The price here reaches 500,000 IDR per kilogram." (HUN, 59 years old)

This choice also serves as a risk management strategy to mitigate potential losses from crop failures or unknown seed sources. Although G0 seeds provide the highest yield, using lower-quality seeds remains a practical option for farmers to balance costs and production levels.

4) Crop Rotation and Resting the Land

Crop rotation on the same plot is a common strategy used by farmers. According to their experience, potatoes cannot be replanted immediately in the same plot after harvesting. This practice helps reduce the risk of bacterial wilt and prevents plant death.

"It's not possible. If we harvest potatoes this year, we can't plant potatoes again in the same plot. We have to alternate with other crops. If we plant potatoes back-to-back, the plants will immediately wilt—sometimes more than 50% of them." (JSR, 27 years old)

This practice, based on experience, aligns with scientific guidelines. Literature indicates that crop rotation is a proven method for managing bacterial wilt in potatoes. This approach helps remove or lower the pathogen inoculum remaining in the

soil from previous potato crops. Farmers generally rotate crops three times a year, planting three different crops on each plot over the course of a year, with each crop cultivated for approximately four months.

"Yes, we first plant carrots, then cabbage, and then potatoes again—if there's enough time within a year. Each crop cycle lasts four months: four months for potatoes, four months for carrots, and four months for cabbage." (BNG, 72 years old)

During crop rotation, farmers aim to improve soil fertility and maintain a balanced soil pH by using organic manure, primarily chicken manure. To neutralize soil acidity, they spread lime over the fields.

"Here, we use manure before planting. When the soil is plowed, we mix it with manure. Later, we just apply pesticide spraying to control pests." (JSR, 27 years old)

"Oh, it's very different. Back in the 1990s, the soil pH was still good. Now, without liming, production will be much lower. We have to restore the soil's pH balance." (TTG, 50 years old)

When farm labor is scarce, the land must often be left fallow. This practice improves soil health by allowing the land to recover its nutrients.

"Some farmers plant carrots, but if they don't have time, they just leave the land idle. If the soil is continuously planted, its nutrients will be depleted. Resting the soil improves its productivity compared to continuously planting. Plus, pests also die off when the land is left fallow." (HUN, 59 years old)

However, leaving land fallow is rarely practiced. This choice is usually made when the harvest seasons for horticultural crops and rice overlap, making it difficult for farmers to find labor to tend to their fields.

V. CONCLUSION

Climate change has significantly changed weather patterns, disrupted seasonal cycles, and made rainfall forecasts more difficult for farmers. It has also led to increased rainfall, which affects the growth and distribution of pests. These shifts have greatly impacted both the quality and quantity of potato yields. Farmers often experience lower yields when rainfall occurs while their crops are still in the early stages of growth (less than two months old), as young plants are particularly vulnerable to excess rain and pest infestations, which can lead to crop failure. To address these issues, farmers have adopted various strategies to adapt, aiming to mitigate the effects of climate change. These include adjusting planting schedules, selecting high-quality seeds, implementing crop rotation, and planting border plants to shield crops from wind. These strategies originate directly from farmers' experiences in managing crops, demonstrating their efforts to mitigate losses caused by climate change and maintain sustainable productivity in agriculture.

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