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ISSN 2959-6157

The impact of extreme weather events in Guangdong on soil health and its mitigation strategies

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Abstract:

Guangdong Province, due to its own climatic conditions and geographic location, has resulted in a high incidence of extreme weather in the region.In recent years, with global climate change, the frequency and intensity of extreme weather events such as typhoons and heavy rains, droughts, heat waves and cold snaps have increased significantly and have had negative impacts on the natural environment and soil health in Guangdong Province, such as destruction of soil structure, soil salinization, soil erosion, loss of soil nutrients, and reduction of biodiversity.In this paper, we conducted a systematic study on the impacts of extreme weather on soil health in Guangdong, and proposed measures to strengthen agricultural management, soil improvement, soil and water conservation, and monitoring and early warning systems.The results of the study show that integrated and systematic management measures can effectively mitigate the damage to soil caused by extreme weather and can promote sustainable agricultural development in Guangdong Province.This study provides theoretical support and practical reference for soil conservation and adaptation to future climate change in Guangdong.

Keywords: Guangdong; extreme; weather; soil health; agricultural management; mitigation strategies

1. Introduction

As an economic center in southern China, the agricultural production and ecosystems of Guangdong Province are chronically affected by extreme weather events. Guangdong Province has a subtropical monsoon climate, which is warm and humid all year round. With the rapid changes in global climate, it has been vulnerable to extreme weather events such as heavy rainfall, drought, heat waves, and cold waves in recent years [1,2]. Extreme weather not only threatens social life and agricultural production in Guangdong but also poses a serious threat to the soil health condition [3].

Soil health conditions include indicators of soil support for biodiversity, promotion of carbon cycling,

maintenance of agricultural production, and water regulation. Healthy soils have good physical and chemical properties, regulate carbon and nitrogen cycling within ecosystems, provide sufficient water and nutrients for a wide range of organisms, and filter a variety of pollutants [4]. However, extreme weather exacerbates soil erosion, soil nutrient loss, soil structure disruption, and reduction in soil fertility, affecting the long-term sustainability of soils [5].In recent years, there has been extensive academic discussion on the impact of extreme weather on soil health, which is multifaceted. Flooding caused by heavy rainfall can lead to soil erosion and nutrient loss, which is particularly evident during the typhoon season in Guangdong [6]. Runoff from heavy rainfall can wash away the topsoil and the organic matter contained in it, leading to a decrease in soil fertility [7]. Drought can lead to a severe shortage of soil moisture, which can affect the water absorption capacity of plants [8]. Prolonged drought can lead to a decrease in the rate of decomposition of organic matter in the soil, which can lead to a decrease in soil fertility [9]. Heat waves increase the temperature of the soil and reduce the activity of microorganisms in the soil, thus affecting the decomposition of organic matter and nutrient cycling in the soil [10]. Cold waves, on the other hand, damage soil structure through freeze-thaw cycles, especially in mountainous areas, which can lead to the disintegration of soil aggregates and increase the risk of soil erosion [11].

Although a great deal of academic research has been done on the effects of extreme weather on soil, the existing literature lacks an analysis of the combined effects of multiple extremes in response to the variable climate of the Guangdong region. How to develop effective soil protection measures by combining the climate conditions and the current situation of agricultural development in Guangdong. It is still an urgent problem to be solved [12].

Guangdong Province is an important agricultural production province in China, and extreme weather not only affects soil health conditions but also threatens food security and ecological safety [13]. Therefore, it is of great importance to analyze the effects of extreme weather on soil health conditions and agricultural production in Guangdong and develop protective measures. The objective of this study was to analyze the impacts of extreme weather such as heavy rainfall, drought, heat waves, and cold waves on soil health status in Guangdong Province and to discuss ways to reduce the negative impacts of extreme weather by strengthening agricultural management, soil improvement techniques, soil and water conservation measures and monitoring and early warning systems [14]. The results of the study will provide a theoretical basis and practical experience for Guangdong Province to cope with extreme weather and promote the sustainable development of ecosystems and agriculture. This paper aims to analyze the impacts of extreme weather events on soil health in Guangdong Province and to explore existing mitigation strategies, to provide a scientific basis and practical guidance for future soil management and climate change adaptation policies.

2. Impacts of extreme weather events on soil health

2.1 Impact of heavy rainfall and flooding

2.1.1 Soil erosion

The large amount of runoff generated by heavy rainfall has an extremely strong scouring effect on the topsoil, especially in the agricultural areas located in the sloping areas of Guangdong, where the topsoil and the organic matter and nutrients it contains are lost with the water, leading to a decrease in soil fertility [15]. Soil erosion is most serious in the mountainous and hilly areas of Guangdong, where the scouring force of heavy rainfall on the soil is more pronounced due to the greater slope gradient. Studies have shown that the greater the slope, the greater the amount of soil loss caused by heavy rainfall, and the rate of nutrient loss from the soil increases linearly [16]. Especially if the soil structure has already been damaged, flood deposits may further hinder soil recovery and lead to long-term soil degradation. Therefore, the frequent occurrence of heavy rainfall and flooding poses a serious threat to agricultural production and ecosystems in Guangdong Province.

2.1.2 Soil structure damage

Heavy rainfall and flooding not only trigger soil erosion but also lead to serious damage to soil structure. The impact of heavy rainfall destroys the soil's aggregate structure, which leads to a decrease in soil permeability and aeration. When the soil structure is destroyed, it leads to increased runoff from the soil surface, making it difficult for water to penetrate downward into the deeper layers of the soil, which ultimately causes the soil to become more infertile and exacerbates soil degradation. It will lead to hardening of the soil, weakening the soil's support for the plant root system, and ultimately affecting the normal growth of plants [17]. Therefore, soil structure destruction is a major challenge to soil health from extreme weather, and effective soil remediation and management measures are needed to mitigate its adverse effects.

2.1.3 Nutrient loss

Due to runoff from heavy rainfall, important nutrients

ISSN 2959-6157

such as nitrogen and phosphorus are also washed away from the soil, greatly weakening soil fertility [18]. Fertility loss due to heavy rainfall has a significant impact on the local agricultural economy, with huge nutrient losses during flooding leading to suppressed crop growth and reduced productivity of farmland. In the Pearl River Delta (PRD) region of Guangdong, the loss of agrochemicals triggered by heavy rainfall has led to an increasingly serious problem of water pollution, which has had a serious impact on the regional ecosystem [19].In the long term, nutrient loss not only reduces the productivity of the land but also may lead to more fertilizer inputs, which in turn aggravates water pollution and ecosystem deterioration. Therefore, preventing nutrient loss is key to ensuring soil health and needs to be addressed through sustainable soil management and soil and water conservation measures.

2.2 Impact of drought

2.2.1 Soil moisture deficit

Despite the large amount of water brought in by heavy rains and floods, the soil may instead experience a moisture deficit after the flood waters recede. This is due to the disruption of the soil structure after heavy rainfall, resulting in a reduction in its water retention capacity. The reduced porosity in the soil allows for rapid water loss, which cannot be effectively retained in the rhizosphere. Prolonged drought leads to a serious lack of water in the soil, and the plant root system is unable to absorb enough water from the soil, leading to shrinkage or even death of plants and affecting their growth [20]. Especially in the coastal areas of Guangdong, drought exacerbates the evaporation of water, and the water content of the soil continues to decline. Long-term water deprivation not only affects the growth of plants but also makes the soil more fragile and susceptible to wind erosion and other external erosive forces.

2.2.2 Decreased decomposition of soil organic matter

Drought inhibits the activity of soil microorganisms, leading to a significant reduction in the rate of organic matter decomposition [21]. Over time, soil fertility declines, and the reduction of organic matter in the soil means disruption of nutrient cycling and supply and deterioration of soil structure to support high-intensity agricultural activities. In agricultural areas of high soil fertility in Guangdong, the long-term effects of drought may pose a lasting threat to soil health.

2.2.3 Soil salinization

Under drought conditions, water evaporates from the soil surface, leaving behind higher concentrations of salts and gradual salinization of the soil [22]. Salinized soil not only affects plant growth but also changes the physical structure of the soil, increases soil hardening, and reduces soil productivity. This phenomenon is particularly significant in the coastal areas of Guangdong, where the dual effects of drought and salinization greatly limit crop growth.

2.3 The Impact of Heat Waves

2.3.1 Increase in soil temperature

Heat waves can cause soil temperatures to rise significantly, which affects microbial activity in the soil. Under high-temperature conditions, the activity of microorganisms is inhibited, which leads to the reduction of the decomposition rate of organic matter and the weakening of the carbon cycle in soil. This effect can persist for some time after the heat wave ends, hampering the soil's recovery rate. Especially in Guangdong, the heat wave will affect the organic carbon content in the soil, and the long-term high temperature will accelerate the loss of carbon in the soil and further aggravate soil degradation. High temperature leads to a significant increase in soil temperature, which affects the activity of microorganisms in soil and inhibits the activity of microorganisms, resulting in a decrease in the decomposition rate of organic matter and a weakening of carbon cycling in soil. More importantly, this effect may persist even after the end of the heat wave, affecting the rate of soil recovery [23]. The heat wave will affect the organic carbon content in the soil in Guangdong, and the continuous high temperature will accelerate the carbon loss in the soil.

2.3.2 Increased evaporation of water

Under high-temperature conditions, the evaporation rate of water in the soil is accelerated, especially in the dry season in central and southern Guangdong, where the soil is easy to become abnormally dry. The rapid loss of water will not only reduce the water-holding capacity of the soil but also make the plant unable to obtain sufficient water, seriously affecting the growth and yield of the plant. Continued high temperatures and soil dryness pose serious challenges to agriculture and ecosystems. High temperatures increase the evaporation of water from the soil, and the soil becomes particularly dry during the dry season in the central and southern parts of Guangdong. The rapid loss of water in the soil will reduce the water-holding capacity of the soil so that plants can not get enough water, and eventually affect the normal growth of plants. [24]

2.3.3 Reduction of soil biodiversity

High temperatures hurt the microbial, invertebrate, and other biological communities in the soil, resulting in a significant reduction in the number of these groups of organisms, thereby affecting soil biodiversity. The loss of

biodiversity not only weakens nutrient cycling in the soil but also negatively impacts soil stability and overall ecological functioning, further threatening agricultural production and the balance of ecosystems. High temperature hurts the microbial and invertebrate and other biological communities in the soil, resulting in a significant reduction in the number, and thus affecting the biological diversity in the soil [25]. The reduction of biodiversity in the soil harms the ecological function of the soil, weakening nutrient cycling in the soil and soil stability.

2.4 The impact of the cold wave

2.4.1 Freeze-thaw cycle

The low temperatures brought on by cold waves cause water in the soil to freeze and melt when temperatures rise, creating a freeze-thaw cycle. This frequent freeze-thaw process breaks down the aggregate structure of the soil, making soil particles more loose and increasing the risk of soil erosion. The low temperature brought by the cold wave will cause the water in the soil to freeze, and then melt when the temperature rises. The frequent freeze-thaw cycle destroys the soil aggregate structure, making the particles in the soil looser and easy to erode. In addition, soil permeability is negatively affected, resulting in increased soil compactness, which affects the normal development of plant roots [26].

2.4.2 Plant root damage

The low temperatures brought on by cold waves can cause serious damage to plant roots, making them unable to effectively absorb water and nutrients from the soil. This will not only cause plant growth to stall or atrophy, but also may continue to affect plant recovery for a period of time after the cold wave, extending the growth cycle of the plant. The low temperature of cold waves will cause damage to plant roots, making plant roots unable to absorb enough water and nutrients from the soil, affecting the normal growth of plants, resulting in growth stagnation and atrophy. Even sometime after the end of the cold wave, plants with damaged roots still need a longer recovery period, during which nutrient and water cycling in the soil is affected.

2.4.3 The decrease of soil biological activity

The low temperature of cold waves can significantly reduce the activity of microorganisms in soil, thus inhibiting the decomposition of organic matter and nutrient cycling. The decrease in microbial activity directly affects the ecological function of the soil, especially after the end of the cold wave, the soil temperature has not yet returned to the appropriate level, and this inhibition can last for weeks or even months. During this time, nutrient cycling in the soil becomes less efficient, with long-term effects on the functioning of plants and other ecosystems. The low temperature brought by the cold wave will significantly reduce the microbial activities in the soil, thus inhibiting the decomposition of organic matter and nutrient cycling, and hindering the nutrient cycling [28]. This inhibition may last for weeks or even months until soil temperatures return to suitable microbial activity.

3. Mitigation strategy

3.1 Agricultural management practice

3.1.1 Conservation tillage

Conservation tillage techniques such as no-tillage and low-tillage are important means to reduce soil disturbance, which can effectively reduce soil erosion and maintain the stability of soil structure [29]. By reducing the mechanical disturbance, the soil organic matter content can be kept unchanged, the soil permeability and water retention can be improved, and the erosion effect of heavy rain on soil can be reduced. In sloping farming areas in Guangdong, no-till technology can significantly reduce soil erosion and runoff and retain water.

3.1.2 Crop rotation and intercropping

By planting different kinds of crops to improve soil structure, increase soil biodiversity, and reduce pests and diseases, crop rotation and intercropping can increase the content of organic matter in the soil, improve soil biodiversity, reduce soil erosion and diseases and pests, and make full use of nutrients in the soil. Through the rotation of different crops, the nutrient cycle in the soil is more balanced, and the root structure and growth cycle of different crops can avoid the excessive consumption of a certain or a certain type of nutrient in the soil by a single crop [30]. In Guangdong, crop rotation can also effectively reduce soil nutrient loss and water evaporation.

3.1.3 Cover crop

By planting cover crops, a natural plant barrier can be formed to protect exposed soil from wind and rain [31]. Cover crops can protect the surface of the soil from wind and water erosion during the non-growing period, and can also enhance the water retention of the soil and reduce the hardening of the soil. In addition, cover crops are able to increase the organic matter content in the soil, improve soil structure, and increase the water retention capacity of the soil by reducing water evaporation.

ISSN 2959-6157

3.2 Soil improvement technique

3.2.1 Organic fertilizer application

Organic fertilizer can significantly improve soil fertility and structure and enhance soil water retention capacity by increasing the organic matter in soil [32]. Compared with chemical fertilizers, the advantage of organic fertilizers is their long-term stable utility, which can promote microbial activity in the soil, increase the soil organic matter content, and improve the physical and chemical properties of the soil. In Guangdong's farmlands, the application of organic fertilizers can effectively combat soil erosion and nutrient loss. Compared to chemical fertilizers, organic fertilizers have a longer and more stable effect and do not cause soil compaction or nutrient loss problems. In the farmlands of Guangdong Province, the application of organic fertilizer can effectively alleviate soil erosion, reduce nutrient loss, and increase the content of organic matter in the soil to further improve the overall health level of the soil. In addition, the use of organic fertilizers also improves soil permeability and structural stability, enabling the soil to better store and supply water, helping plants cope with the challenges posed by extreme weather. Therefore, the promotion of organic fertilizer application in areas such as Guangdong is not only important to improve soil health, but also to improve the sustainability of agricultural production.

3.2.2 Biochar application

Biochar is a highly effective soil amendment that improves soil water retention, nutrient retention, and soil structure. Biochar has high water retention and fertility retention capacity, which can reduce water evaporation and nutrient loss [33]. The porous structure of biochar can effectively adsorb water and nutrients in the soil, reduce water loss, and provide an ideal habitat for microorganisms, promoting the restoration of soil ecosystems. Biochar applications are particularly effective in arid and heavily salinized areas of Guangdong, where they can significantly improve soil health. Therefore, biochar, as an environmentally friendly soil amendment, not only plays an important role in improving soil's ability to retain water and fertilizer, but also plays a key role in addressing soil health challenges brought about by climate change.

3.2.3 Soil conditioner

The application of conditioning agents such as gypsum or lime can effectively improve the physical and chemical structure of soil and alleviate the soil degradation caused by salt accumulation [34]. The conditioner can effectively reduce the sodium content in the soil, improve the soil structure, increase the soil pH value, and make the soil more suitable for the growth of crops. The application of soil conditioners can not only effectively alleviate these problems, but also improve soil fertility and stability, providing a healthier growing environment for crops. Therefore, the wide application of soil conditioners in Guangdong and other regions will provide important support for sustainable agricultural development and ecosystem restoration.

3.3 Soil and water conservation measures

3.3.1 Vegetation restoration

Vegetation restoration is an effective means to reduce soil and water loss in hilly and mountainous areas of Guangdong Province. Natural vegetation fixes the soil through its roots, reduces soil erosion, and regulates water in the soil through the transpiration of vegetation. In slope and mountain areas, vegetation restoration can reduce surface runoff, fix soil, and effectively reduce soil erosion [35].

3.3.2 Engineering measure

Such as building terraces, slope protection, and other engineering measures, through these engineering means, can effectively reduce surface runoff, stabilize soil structure, and reduce soil erosion. The terraces, through their ladder-like design, slow the flow of water and increase the chance of precipitation seeping into the soil, thereby reducing the amount of soil loss. Especially in the hilly and mountainous areas of Guangdong, these engineering measures have helped to stabilize the soil and reduce erosion [36].

3.4 Monitoring and early warning system

3.4.1 Soil health monitoring

Soil health monitoring is a key link to ensure sustainable agricultural development and ecosystem balance. By monitoring soil regularly, soil degradation, nutrient loss, and structural damage caused by extreme weather events can be detected in time. Modern soil monitoring systems use sensors, satellite remote sensing technology, drones, and geographic information systems (GIS) to obtain a variety of soil indicators, including soil temperature, moisture content, nutrient levels, pH, and organic matter content. By establishing a soil health monitoring system, real-time tracking of soil moisture, organic matter content, and nutrient status can be carried out to help decision-makers and farmers take timely measures to reduce the damage of extreme weather to soil [37]. The collection and analysis of these data can not only help assess the current state of soil health but also identify long-term trends in soil health by comparing historical data.

3.4.2 Meteorological early warning system

Meteorological early warning systems are a key tool for responding to extreme weather events and reducing their impact on soil health and agricultural production. By monitoring atmospheric conditions, rainfall, temperature, wind speed, and other meteorological parameters in real-time, the meteorological early warning system can predict possible extreme weather events such as rainstorms, floods, droughts, heat waves, and cold waves in advance, and send early warning signals to help farmers and relevant departments take preventive measures. Modern weather early warning systems rely on satellite remote sensing, ground-based weather stations, radar, and high-precision calculation models to quickly analyze weather trends and provide accurate forecasts for specific areas. These warnings not only help farmers adjust planting plans and soil management strategies in a timely manner but also inform decisions by local governments to reduce the damage to soil health and ecosystems caused by natural disasters. By integrating with soil health monitoring systems, meteorological early warning systems can provide complete data support before and after extreme weather events, ensuring more effective pre-disaster prevention and post-disaster recovery.

Meteorological early warning systems can predict extreme weather events such as heavy rainfall, drought, and heat waves in advance, and help agricultural producers take preventive measures to reduce the negative impact on soil health [38]. The province has already used its weather warning system to forecast typhoons and heavy rains and will step up warnings for drought and heat waves.

4. Conclusion

In this paper, the effects of extreme weather events on soil health in Guangdong Province were systematically studied and effective mitigation strategies were discussed. Studies have shown that extreme weather such as typhoons, rainstorms, droughts, heat waves, and cold waves is frequent in Guangdong, causing significant negative effects on soil structure, fertility, and biodiversity. These impacts include soil erosion, salinization, nutrient loss, and loss of biodiversity, severely affecting agricultural production and ecosystem health.

To address these challenges, the study proposes a series of integrated management measures, such as enhanced agricultural management, soil improvement techniques, soil and water conservation, and monitoring and early warning systems. The implementation of these measures can not only effectively reduce the damage of extreme weather to soil, but also promote the sustainable development of agriculture. For example, conservation tillage and crop rotation can improve soil structure and increase biodiversity, while the application of organic fertilizers and biochar can help improve soil water retention and nutrient retention. In addition, vegetation restoration and engineering measures such as terracing can also effectively reduce soil erosion.

The significance of this study is to provide a set of scientific and practical soil protection and management strategies for Guangdong Province and other regions with similar climatic conditions. In the context of global climate change, these strategies not only help to improve soil health and ensure food security but also have important significance for maintaining ecological balance and promoting regional sustainable development. By implementing these measures, agricultural systems can be made more resilient and better able to adapt to future extreme weather events that are likely to intensify.

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