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Article

Soil Quality Testing and Counseling Coastal Agricultural Communities in Taiwan

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Abstract: The Mailiao Town is a traditional agricultural community, located in the south-central region of Taiwan. In this region, the northeast monsoon is entrained with salt for seven months a year. Soil fertility test results between 2011 and 2021 showed that the tillage soil was alkaline and salinized. The content of total nitrogen, phosphorus, calcium, magnesium, potassium, and sodium in the soil were mostly excessive. In the region, open-air continuous farming with heavy fertilizer has been performed. Based on the 10 years of data from the test of soil fertility, we counseled farmers to understand the significance of the values in the reports and the impact on crop growth. We promoted rational fertilization with a series of agricultural counseling actions. The results of the continuous counseling showed that the dependence on nitrogenous fertilizer gradually decreased with the continuous increase of the application of organic fertilizers. The total nitrogen and exchangeable sodium content in soil decreased significantly, and the carbon-nitrogen ratio (C/N) increased every year. The soil environment became close to equilibrium gradually. As a result, the yield and quality of local crops have gradually improved.

Keywords: Soil fertility, Total nitrogen, Carbon-nitrogen ratio

1. Introduction

In the early days, a significant amount of fertilizers were used in agriculture to grow and harvest vegetables and fruits rapidly, ignoring soil deterioration. This has made agriculture difficult. Nowadays, soil quality has been regarded as important in conservation agriculture (CA) to alleviate soil nutrient loss, save water, and reduce land degradation and soil erosion, and agricultural production technology has been developing.

Soil fertility is affected by a variety of factors such as pH, organic matter content, and soil texture [1]. When pH is low, the soil is less likely to store nutrients, resulting in a lack of nutrients. Soil organic matter is maintained for the time being, and water retention and permeability in soil are reduced by soil erosion, in which a stable source of plant nutrients is lost [2]. Nutrients in soil include essential elements such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S), and micro-elements such as boron (B), chloride (Cl^-), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni) and (Zn) [3]. Excessive or deficient nutrients hinder crop growth and impact the yields and quality of crops. To make crops grow normally, it is needed to increase soil fertility by adding fertilizer, but often, the presence of salt and subsequent salinization in the soil is ignored.

To monitor, manage, and improve soil quality, we organized a cultivation counseling team to guide farmers to carry on a fertilization plan according to soil test results in 2011. The agricultural cultivation area of Mailiao district in Yunlin County is located in the south-central region of Taiwan. The region is the major agricultural area in Taiwan. The area for farming is about 2,602 ha with an agricultural population of 14,781. The crops include peanuts, garlic, and rice, of which peanuts and garlic are planted after harvesting rice as their unit price is higher than that of rice. Mailiao Township is located in the northwest of Yunlin County with an area of about 106 km^2. The soil is composed of clay, silt, and sand, and mixed with alluvial soil. The region has a subtropical climate with an average annual temperature of about 22 °C. From October to February, the strong and salty northeast monsoon comes, damaging crops planted in winter considerably. With the Taiwanese government's subsidies for greenhouse and mushroom production facilities in the Mailiao Township from 2011 to 2022, farmers developed facilities to reduce environmental impacts. At present, the main crops in the region include tomatoes, cucumbers, cantaloupes, and other fruits. In this article, the result of agricultural counseling is presented on soil quality and fertilization.

2. Materials and Methods

2.1. Soil Monitoring

According to the soil sampling method (NIEA S102) of the Environmental Inspection Institute, five topsoil samples at 0−15 cm were collected using a mud drill. The samples were air-dried and crushed and then screened with 2 mm (10 mesh) and 0.15 mm (100 mesh) mesh for the experiment. pH, conductivity (ECs), total organic carbon (TOC), total nitrogen (TN), available phosphorus, exchangeable calcium, magnesium, potassium, and sodium in the soil were analyzed to judge the quality of soil for cultivation. Based on the result, we offered suggestions for farmers to adjust the control of fertilizer components.

2.2. Outdoor and Facility Cultivation

Traditional agriculture is conducted outdoors, and farmers in the Mailiao area experimented with facility cultivation. The two cultivation methods differ in soil management, mainly in the control of rainwater, temperature, and light. In facility cultivation, greenhouse and net chamber cultivation are used. The greenhouse covers a farming area with a transparent cloth so that the rainwater cannot be absorbed by the soil, resulting in the accumulation of fertilizer not absorbed by the crops in the soil. Therefore, it is necessary to change the irrigation and fertilization methods such as drip irrigation. The temperature difference between the greenhouse and the open air can be set as high as 9°C to guarantee the movement of water-soluble ions in the soil from bottom to top by capillary effect. In the greenhouse, soluble salts are also evaporated from the soil surface, resulting in the salinization of the soil surface due to irrigation water and the application of soluble chemical fertilizers. The most important advantage of facility cultivation is the shading from sunshine and the avoidance of rain erosion and insect invasion, which reduces the impact of abnormal climate on crops [4]. However, the maintenance of soil quality is more important than in the open air. In 2021, there were 146 areas for open-air cultivation, and in 40 cultivation areas, there were greenhouses or net chambers in Mialiao township, which participated in the agricultural counseling project.

2.3. Soil Quality Analysis

Soil fertility is judged based on the soil nutrient grading table in the "Collection of Grading Standards for Soil Fertility Factors" compiled by the Agricultural Committee of the Executive Yuan of R.O.C. (Table 1). The analysis items and methods for the soil are as follows. pH is analyzed based on the National Environmental Analysis (NIEA S410). Conductivity (EC) was tested using the method of Rhoades. TOC and TN were analyzed following NIEA M403. Exchangeable Ca, Mg, K, and Na were analyzed based on the metho of Thomas [5] and the available phosphorus content was analyzed according to Olsen and Sommers. The criteria for the available phosphorus was adjusted to the range of 14−27 mg/kg. The organic material (OM) was calculated from the TOC value with a conversion factor range from 0.58 to 1.76%.

Table 1. Soil nutrient grading table.

Project	**Unit**	**Suitable Soil**	**Fertility Grading**		
			Degeneration (D)	**Proper (P)**	**Excess (E)**
pH	-	all soils	＜5.5	5.5-7.0	＞7.0
Organic Matter (OM)	%	all soils	＜1	1-3	＞3
Cation Exchange Capacity (CEC)	cmol/kg	all soils	＜6	6-12	＞12
Available Phosphorus	mg/kg	paddy field soil	＜20	20	＞20
Exchangeable Calcium	mg/kg	all soils	＜800	800-1600	＞1600
Exchangeable Magnesium	mg/kg	all soils	＜30	30-60	＞60
Exchangeable Potassium	mg/kg	all soils	＜67	67-125	＞125
Iron (Fe)	mg/kg	all soils	＜50	50-300	＞300
Manganese (Mn)	mg/kg	all soils	＜20	20-140	＞140

3. Results and Discussion

3.1. Soil pH and Saturated EC

pH and conductivity are important indicators of soil quality as they show the degree of the natural weathering of soil materials. They affect the physicochemical properties and microbial ecosystem in the soil and are closely related to the effectiveness of absorbing nutrients in the soil [6,7]. The appropriate pH range in the soil is 5.5−7.0. EC is used as an index to monitor the concentration of soluble salts. The concentration of soluble inorganic salts including Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} are used to assess the fertilization of the soil.

The monitoring results of soil pH and ECs in the Mailiao area for open-air and facility cultivations from 2011 to 2021 are shown in Fig. 1. Because it is located in a coastal area, the soil is affected by the original terrain and water quality environment, and the pH value was in the range of 6.2−8.0. Compared with open-air cultivation, facility cultivation has little effect on soil pH value. The pH of the regions was suitable for crop growth and nutrients. Soil ECs were higher than general values [8]. The ECs of the soil of open-air cultivation are smaller than those of greenhouse cultivation. The local irrigation water quality (groundwater) was 1408 µS/cm on average, which was higher than the Taiwan irrigation water quality standard of 750 µS/cm. The ECs of the soil of the open-air cultivation are lower than those of the greenhouse cultivation as the greenhouse prevents rainwater. After applying fertilizer and irrigation water in each planting period, the crops absorb the remaining fertilizer. Salt was washed insufficiently, causing crop growth disorders and affecting subsequent crop yields [9]. In recent years, microorganisms such as *Bacillus megaterium* has been introduced in soil digging to provide microbial diversity, decrease excessive fertility, and maintain the ecological environment [10].

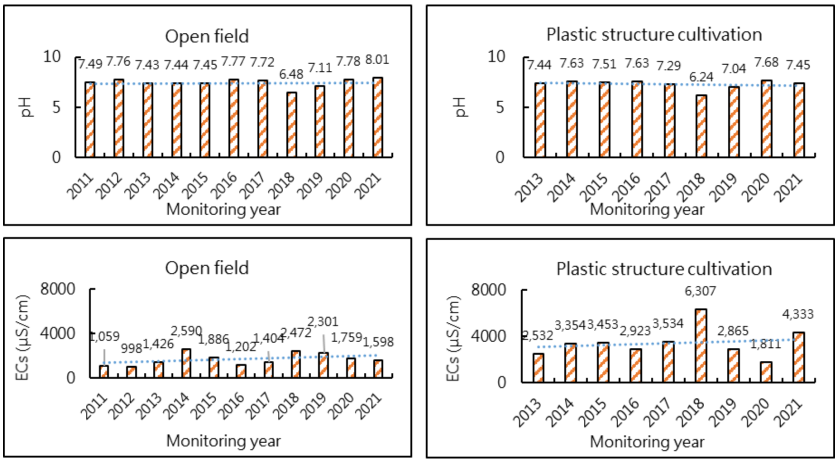

Fig. 1. Ten-year trend chart of soil pH and EC.

3.2. TOC and TN

Soil organic matter is one of the indexes of soil fertility. The content of organic matter is estimated by multiplying the total organic carbon value by the fixed value [11]. Fertilizers increase the activation of many microorganisms such as Actinobacteria and Ascomycota. However, they reduce the oxidation of TOC at the same time. Increased activity of hydrolase stabilizes the value of TOC too avoid excessive biodegradation of organic matter [12]. The amount of nitrogen in the soil limits the efficiency of nutrient absorption and utilization. This affects crop yield and soil salinization [13]. Therefore, TOC and TN in soil are important indicators of soil health and are necessary to keep the C/N ratio stable in the nutrient cycle of soil and crops. The C/N ratio affects the microbial activity in soil and nitrogen fixation that forms biological soil crusts (BSCs) [14]. Figure 2 shows that the TOC value continued to increase with an average of 0.58 to 1.76% which is appropriate according to the standard value regardless of open-air and greenhouse cultivations. TN gradually decreased, affecting the increase of the C/N ratio. The C/N ratio was 4.52 in early 2010 and 12.3 in 2022 for open-air cultivation, while 13.5 in 2013 and 3.54 in 2022 for greenhouse cultivation. The C/N ratio of local soil was lower than 25, maintained between 8−15, indicating a reasonable level [15]. The normal decomposition of soil fertilizers and the absorption rate of crops were observed. However, farmers needed to properly apply nitrogen fertilizer to decompose organic matters to effectively improve the application of crop fertilizer.

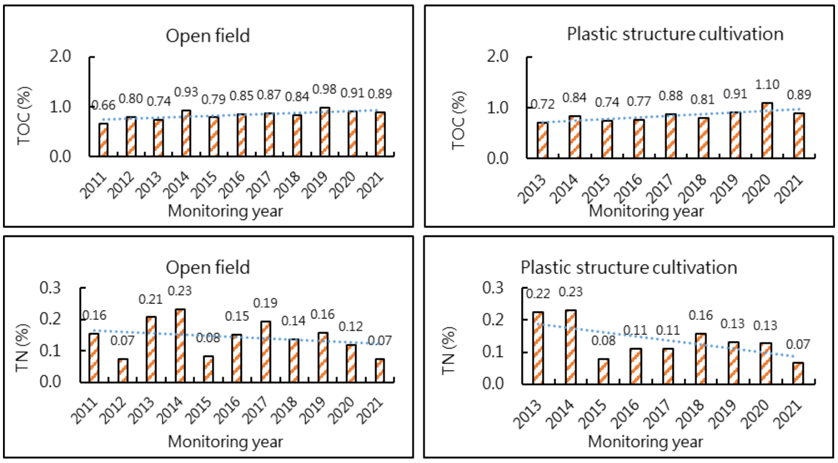

Fig. 2. Ten-year trend chart of soil TOC and TN.

3.3. P, Ca, Mg, K, and Na

P is important in early root development and late fruit sweetness. Figure 3 shows that the fertility values were 14−27 mg/kg over the years, which were in the excess range. However, P in the greenhouse showed a gradual decrease. The use of phosphate fertilizer was adjusted according to the needs of planting crops. The low mobility of P in soil and the local alkaline soil helps reduce its adsorption in the soil [16]. Figure 3 shows that the annual fertility values of exchangeable calcium were in the range of 800−1600 mg/kg. The exchangeable Ca in the greenhouse was excessive but was stable in the open air. This was due to the influence of plants. The crops cultivated in the open air were peanuts, garlic, and rice, which need more nitrogen fertilizer. Cucumbers, tomatoes, and cantaloupes were cultivated in the greenhouse, all of which need Ca to stabilize physiology. Therefore, it is necessary to adjust the concentration of Ca according to crop types [17,18]. The application of NPK fertilizer promotes the preferential combination of calcium ions and organic carbon into Ca-OC, but the long-term application reduces the storage of Ca-OC in the process of soil acidification. Therefore, farmers were instructed to effectively use Ca, maintain the soil pH higher than 6.5, increase soil TOC, and add NPK fertilizer appropriately [19].

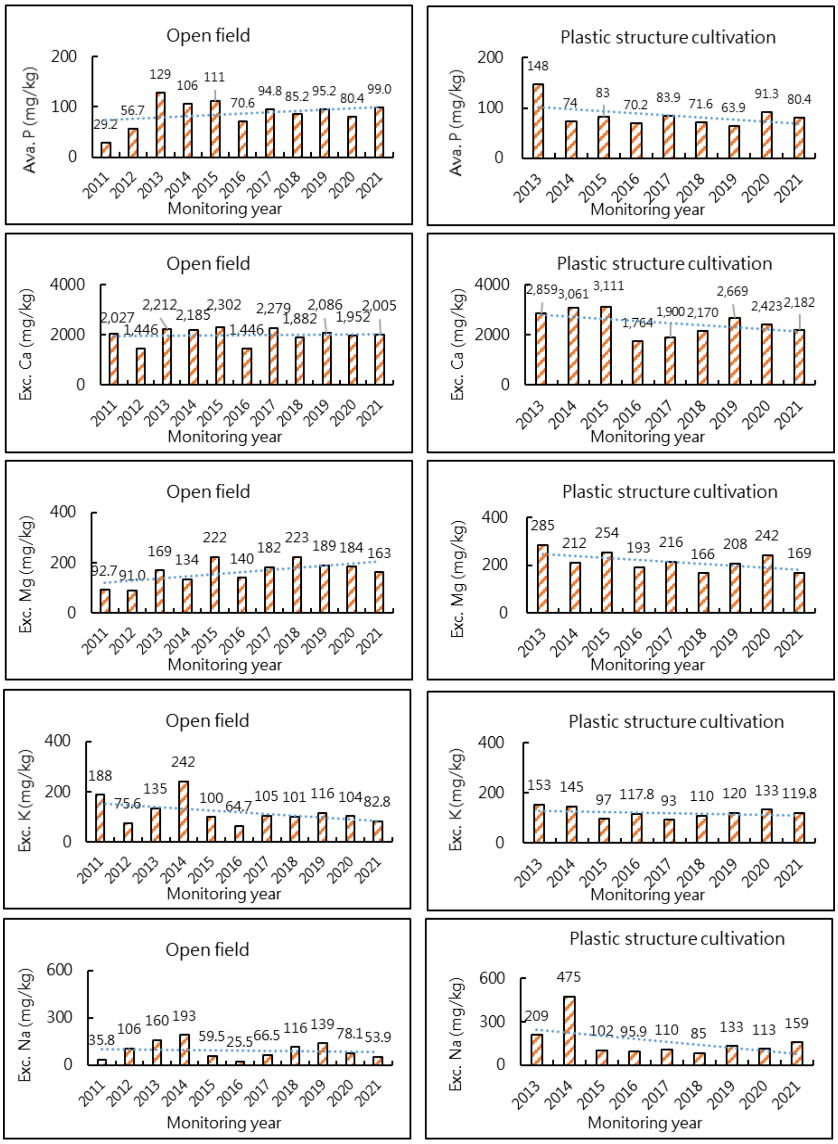

Fig. 3. Ten-year trend graph of soil available P and exchangeable Ca, exchangeable Mg, exchangeable K, and exchangeable Na.

Figure 3 also shows that the fertility of exchangeable Mg over the years was 30−60 mg/kg, which showed an excessive range. The exchangeable Mg value for the open-air cultivated soil increased, which was lower than the average value of the greenhouse. As one of the important elements, Mg participates in plant metabolism and functions and is helpful for the late fruiting of peanuts and garlic [18]. Excessive magnesium is toxic to the environment, though. When the ratio of Ca to Mg in irrigation water is greater than 1 and the percentage of exchangeable magnesium in the soil is greater than 25%, the quality of irrigation water must be changed [20]. The values of exchangeable potassium were in the range of 67−125 mg/kg. K in the soil was excessive. K ion concentration in the greenhouse was relatively stable. In greenhouse cultivation, most crops are fruits. K increases the sweetness. The excess decreases the absorption of Ca and Mg. The lack of K ion makes leaves older and tissues of crops dry up, which reduces the resistance and changes fruits and grains in size. Therefore, it is necessary to adjust its quantity according to crop types to keep the nutritional balance between K and Mg [18,21]. Exchangeable Na decreased year by year, especially in the greenhouse soil. Na ions lead to soil salinization and increase its electrical conductivity. The absorption of Na ions to plants stabilizes the cell balance. while excessive Na ions stunt and blacken leaves, and destroy the cohesive structure of soil. In a dry season, skin crusting occurs. In the rainy season, the soil becomes muddy with insufficient drainage. Thus, fertilizer with higher organic matter must be applied instead of chemical fertilizer to reduce soil salinization [22,23].

4. Conclusions

From 2011 to 2021, the soil monitoring and cultivation counseling results showed that the management methods with much fertilizer were changed in the Mailiao area. Farmers began to evaluate crop growth to supply appropriate amounts of nutritional elements. Counseling on fertilization based on soil analysis guided farmers to improve their fertilization strategy. Farmers of facility cultivation were more willing to learn soil analysis results than those of open-air cultivation. The concentration of TN, exchangeable Ca, Mg, K, Na, and available P decreased significantly, while TOC contents remained stable. Due to the lack of natural rain in the greenhouse, the EC values of the soil of facility cultivation were not stable. Such information helped farmers pay attention to and establish a helpful strategy to improve their productivity.

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