

Soil Mineral Element Characteristics under Different Tillage Practices in Dragon Fruit Fields of Dry-Hot Valley Rocky Desertification Areas: Postprint

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Abstract

This study investigates the variation characteristics of soil mineral element content under different tillage methods, aiming to promote dragon fruit growth, development, and quality improvement. The study area employed five tillage methods: intercropping with alfalfa (*Medicago sativa*), organic fertilizer application, chemical fertilizer and pesticide application, plastic film mulching, and no measures. Using 22 mineral elements in the soil of each method as evaluation indicators, we compared the differences in mineral element content among different tillage methods and elucidated the correlation relationships among soil mineral elements. The results showed that, compared with no measures, the content of elements such as Ca, Si, and Mn in other tillage methods exhibited increasing trends, while the content of Fe, Mg, Al and other elements decreased, with no significant difference in Na content. The mineral element content was most abundant under organic fertilizer application, followed by plastic film mulching, and lowest under intercropping with alfalfa. Correlation analysis revealed that significant correlations mostly existed among mineral elements in dragon fruit orchard soils, with Al, Si, S, and Ni being more closely correlated with other elements, followed by Fe, Mg, Na, Mn, Cu, and Co, all reaching significant or extremely significant levels. Ca, Fe, Mg, Mn, Cu, Zn, and B were mostly negatively correlated among each other, demonstrating antagonistic effects. In dry-hot valley rocky desertification areas, organic fertilizer should be prioritized as the nutrient addition method for dragon fruit cultivation, and soil mineral nutrient deficits caused by different tillage methods should be promptly supplemented, especially for elements such as Fe, Mg, Al, Na, Cu, and Zn.

Full Text

Characteristics of Soil Mineral Elements Under Different Tillage Methods in Pitaya Plantations of Dry-Hot Valley Rocky Desertification Regions

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Abstract

This study investigated the characteristic variations of soil mineral elements under different tillage methods to promote pitaya growth, development, and quality improvement. Five tillage methods were evaluated in the study area: intercropping with alfalfa (*Medicago sativa*), organic fertilizer application, chemical fertilizer and pesticide application, plastic film mulching, and no measures. Using 22 mineral elements in soil under each method as evaluation indicators, we compared differences in mineral element contents among tillage methods and elucidated correlations between soil mineral elements. Results showed that compared with no measures, other tillage methods increased the contents of Ca, Si, Mn, and other elements, while decreasing Fe, Mg, Al, and other elements; Na content showed no significant difference. Organic fertilizer application yielded the most abundant mineral element content, followed by plastic film mulching, with alfalfa intercropping showing the lowest levels. Correlation analysis revealed significant relationships among most mineral elements in pitaya soils, with Al, Si, S, and Ni showing relatively strong correlations with other elements, followed by Fe, Mg, Na, Mn, Cu, and Co, all reaching significant or extremely significant levels. Ca, Fe, Mg, Mn, Cu, Zn, and B showed predominantly negative correlations, indicating antagonistic effects. When cultivating pitaya in dry-hot valley rocky desertification regions, organic fertilizer should be the preferred nutrient supplementation method, and deficiencies in soil mineral nutrients caused by different tillage methods should be promptly addressed, particularly for Fe, Mg, Al, Na, Cu, and Zn.

Keywords: tillage methods, soil mineral elements, pitaya, dry-hot valley rocky desertification region

Introduction

Pitaya (*Hylocereus* spp.) offers various health benefits including anti-cancer properties, antioxidant activity, and immune system enhancement (Tenore et al., 2012). The crop exhibits strong adaptability to high temperatures, drought, and poor soils (Lyman, 1982), while showing distinct demands for mineral elements such as nitrogen (N), phosphorus (P), and potassium (K) during growth and

development (Wang et al., 2015). Mineral elements affect fruit growth and development (Pan et al., 2011), and their content levels determine fruit flavor and quality formation (Cao et al., 2015). Imbalances in mineral element supply—including N, P, K, calcium (Ca), magnesium (Mg), and trace elements—can impact plant growth (Mao et al., 2015).

Song et al. (2016) investigated mineral elements and quality indicators in non-astringent persimmon fruits, demonstrating that appropriate mineral element contents and ratios can significantly improve fruit quality and yield. Yang et al. (2012) measured and analyzed dynamic changes in mineral elements during white-fleshed pitaya fruit development, revealing varying demands for mineral elements at different growth stages. Huang et al. (2018) studied correlations between ‘Baiyu’ loquat fruit quality and mineral element content, showing that mineral element contents significantly affect fruit quality.

Different tillage methods alter mineral element contents to varying degrees. Liu et al. (2015) studied the effects of selenium foliar spraying on mineral elements in pear fruits, finding that exogenous selenium application significantly increased fruit selenium (Se), iron (Fe), and copper (Cu) contents, though increased Cu can inhibit plant growth (Xiong et al., 2006). Qin et al. (2007) and Li et al. (2015) investigated how tillage methods affect soil physicochemical properties, showing that cattle manure mulching and no-tillage increased root zone soil nutrient contents, with mulching treatments facilitating nutrient decomposition and transformation (Brennan et al., 2011). Sun et al. (2017) examined soil micro-ecological effects of ground mulching, demonstrating that cattle manure mulching in walnut orchards significantly increased soil mineral element contents, while alfalfa mulching showed poorer effects. In summary, mineral elements affect crop quality and yield, and studying the influence of tillage methods on soil mineral elements benefits crop growth, development, and quality formation.

Current research on mineral elements in dry-hot valley rocky desertification regions has primarily focused on soil nutrients (Yue et al., 2016; Yan et al., 2016) and plant leaf element contents (Li et al., 2016), with limited reports on medium and trace soil mineral elements (Yu et al., 2018). Therefore, this study, set in a dry-hot valley rocky desertification region, determined soil mineral element contents under different tillage methods in pitaya plantations to elucidate how soil mineral element contents vary with tillage methods, providing a scientific basis for improving soil mineral element contents and enhancing pitaya yield and quality in this region.

Materials and Methods

1.1 Study Area Overview

The study area is located in Huajiang Town, Guanling County, Xiage Village (105°38 48.48 E, 25°39 35.64 N), featuring distinct habitat uniqueness. The climate is primarily mid-subtropical monsoon humid, with abundant light and

heat resources, warm and dry winters and springs, and hot and humid summers and autumns. The average annual temperature is 18.4 °C, with average annual extreme maximum and minimum temperatures of 32.4 °C and 6.6 °C, respectively. Annual precipitation averages 1,100 mm, concentrated from May to October. The region features deeply incised river valleys with deeply buried groundwater, with elevations ranging from 370 m (at Sancha River) to 1,473 m (at Hujiawan hilltop). Forest coverage is low, bedrock outcrop rates range from 50% to 80%, carbonate rocks account for 78.45% of bedrock, and soils are primarily limestone-derived lime soils. The surface is fragmented, with most areas classified as moderate to severe rocky desertification.

1.2 Sample Collection and Processing

Prior to the study, the area was primarily planted with corn. In 2007, ‘Dahong 1’ pitaya was introduced from Taiwan. Pitaya can be harvested 5–7 times annually with high fertilizer demand. Due to reduced local livestock breeding, rural labor outmigration, and high cultivation costs in rocky mountainous areas, organic fertilizer application has decreased yearly. Along with soil mineralization processes, pitaya plantation soil nutrients show a declining trend, and chemical fertilizer and pesticide use has reduced pitaya yield and quality. In response, our research team established water and fertilizer control experiments in May 2015, including alfalfa intercropping (AF), organic fertilizer application (OF), and plastic film mulching for moisture conservation (FM). Samples were collected and measured in November 2017 after pitaya harvest. Alfalfa intercropping involved sowing in four holes 40–50 cm from the pitaya mother plant at 2–3 cm depth, harvesting when plants reached 40–50 cm height with approximately 5 cm stubble remaining, over a 2.5-year period. Organic fertilizer, composed of fermented pig manure and oilseed residue, was applied at 2–3 kg per plant within 0–60 cm of the mother plant over 2.5 years. Plastic film mulching covered the entire ground surface to prevent soil water evaporation and suppress weeds over 2.5 years. Chemical fertilizer and pesticide application (CFP) represented a relatively extensive management approach practiced for approximately 10 years, with farmers supplementing compound fertilizer and spraying pesticides based on pitaya growth and pest conditions. No measures (NM) represented approximately 10 years without intervention, resulting in poor pitaya growth and low yield and nutrient absorption efficiency.

Sample plots had similar geographic coordinates, elevation, slope, and aspect, reducing spatial heterogeneity of mineral elements. Each plot measured 10 m × 10 m, with three replicates per method. During sampling, surface litter was removed, soil profiles were excavated with a spade, and surface soil samples (0–20 cm) were collected using an “S” shaped five-point mixing method. Approximately 1 kg of soil was extracted via quartering, debris was removed, and samples were sealed in plastic bags, transported to the laboratory, air-dried, ground, and sieved for analysis.

1.3 Measurement Methods

Boron (B), arsenic (As), and selenium (Se) were determined according to *Specifications for Regional Geochemistry Exploration* (DZ/T0167-2006) (Ren et al., 2006). Silicon (Si), Ca, Mg, sodium (Na), aluminum (Al), Fe, Cu, Zn, lead (Pb), chromium (Cr), cadmium (Cd), titanium (Ti), nickel (Ni), cobalt (Co), strontium (Sr), molybdenum (Mo), chlorine (Cl), and sulfur (S) were determined according to *Specifications for Multi-Purpose Regional Geochemical Survey (1:250,000)* (DZ/T0258-2014) (Xi et al., 2014).

1.4 Data Processing

Microsoft Excel 2010 was used for preliminary data analysis and organization, Origin 8.6 for graphing, and SPSS 20.0 for statistical analysis. One-way ANOVA was used for significance testing of soil mineral element contents, least significant difference (LSD) method for multiple comparisons, and Pearson correlation analysis to examine relationships among soil mineral elements under different tillage methods.

Results

2.1 Effects of Different Tillage Methods on Fe, Ca, Mg, Na, Al, and Si Contents

As shown in Table 1, compared with NM, Si content under different tillage methods increased by 2.7%–17.5% with significant differences ($P < 0.05$). Fe, Mg, and Al contents decreased significantly by 12.9%–25.9%, 17.2%–42.8%, and 6.0%–25.8%, respectively. Except for FM treatment, which decreased Ca content by 47.1% compared with NM, all other tillage methods significantly increased Ca content, with AF increasing Ca content by 100.9%. For Na, different tillage methods showed no significant effect. These results indicate that fertilization and mulching treatments promoted Si and Ca accumulation while inhibiting Fe, Mg, and Al accumulation.

Table 1 Fe, Ca, Mg, Na, Al, and Si contents in different tillage methods ($\text{g} \cdot \text{kg}^{-1}$)

Tillage method	Fe	Ca	Mg	Na	Al	Si
NM	60.62 ± 0.149a	149.08 ± 0.1015b	101.59 ± 0.0256a	52.56 ± 0.3093b	30.93 ± 0.0350a	93.50 ± 0.111c
AF	44.86 ± 0.2184f	218.47 ± 0.10143g	101.43 ± 0.02478a	52.478 ± 0.22976a	22.976 ± 0.0007	100.7 ± 0.114d
OF	48.87 ± 0.3197e	175.2 ± 0.07522f	110.58 ± 0.284906	110.58 ± 0.103203	28.4906 ± 0.103203	103.203 ± 0.798b
CFP	251.80 ± 0.84127	112.7 ± 0.2972e	77 ± 0.08665	98.665 ± 0.252c	25.46 ± 0.08065	80.665 ± 0.692d
FM	287.93 ± 0.84305	43.5 ± 0.087093	93 ± 0.08305	93.05 ± 0.252c	25.46 ± 0.08065	80.665 ± 0.692d

Note: NM = No measures; AF = Alfalfa intercropping; OF = Organic fertilizer; CFP = Chemical fertilizer and pesticides; FM = Film mulching. Different lowercase letters indicate significant differences ($P < 0.05$). The same below.

2.2 Effects of Different Tillage Methods on Mn, Cu, Zn, Cd, Cr, and Pb Contents

As shown in Table 2, compared with NM, AF decreased Mn and Pb by 10% and 7.3%, respectively, reaching significant levels, while the other three methods increased Mn and Pb contents, with Mn showing significant differences. All tillage methods decreased soil Cu, Zn, and Cr contents to varying degrees. Except for CFP treatment, which significantly increased Cd content by 7.7% compared with NM, the other three methods decreased Cd content by 28.6%, 5%, and 41.8%, respectively. These results indicate that fertilization and mulching treatments promoted Mn and Pb accumulation while inhibiting Cu, Zn, and Cr, and CFP increased the heavy metal Cd content.

Table 2 Mn, Cu, Zn, Cd, Cr, and Pb contents in different tillage methods (g · g⁻¹)

Tillage method	Mn	Cu	Zn	Cd	Cr	Pb
NM	3.03±0.054c	0.03±0.0081a	1.0±0.1790a	0.06±0.0130a	0.40±0.0376a	0.028a
AF	2.66±0.040d	0.14±0.023c	1.2±0.71350b	0.01±0.0143b	0.25±0.0378b	0.594b
OF	3.64±0.035a	0.05±0.0081b	0.62±0.91482a	0.09±0.01123a	4.45±0.23±0.594a	
CFP	3.57±0.032a	0.76±0.481b	0.92±0.92210a	0.07±0.0070a	0.90±1.43720	1.237a
FM	3.38±0.048b	0.32±0.0690b	0.1±0.7.2554c	0.07±0.0094b	3.20±3.2030	2.008a

2.3 Effects of Different Tillage Methods on S, Cl, As, Se, and B Contents

As shown in Figure 1 [Figure 1: see original paper], compared with NM, S and B contents under different tillage methods showed significant differences, with OF showing the highest S and B contents, increasing by 2.16% and 72.7%, respectively. Cl and Se contents under FM and OF differed significantly from NM, with FM decreasing Cl content while the other three methods increased it, with OF showing the highest Cl content. The trend for Se content was opposite to that of Cl. As content showed no significant difference among tillage methods compared with NM. These results indicate that OF input significantly increased S, Cl, and B contents but inhibited Se accumulation.

2.4 Effects of Different Tillage Methods on Ti, Mo, Ni, Co, and Sr Contents

As shown in Figure 2 [Figure 2: see original paper], compared with NM, Ti content increased under OF but decreased under the other three methods, all reaching significant differences. Mo and Sr showed similar trends: except for OF, which showed no significant difference from NM, the other three methods showed significant differences in Mo and Sr contents. Ni content decreased significantly under all tillage methods compared with NM. Co content showed no significant differences. These results indicate that Co content was not significantly affected

by different tillage methods, while Ti, Mo, Ni, and Sr contents were all affected to varying degrees.

2.5 Correlations Among Soil Mineral Elements

As shown in Table 3, correlations among mineral elements varied. Al, Si, S, and Ni showed relatively strong correlations with other elements, followed by Fe, Mg, Na, Mn, Cu, and Co. Fe showed extremely significant positive correlations with Al, Ni, and Cr ($P < 0.01$), and significant positive correlation with As, demonstrating synergistic effects, while showing significant negative correlations with Si and B, indicating inhibitory effects. Si showed extremely significant positive correlation with Mo, significant positive correlation with Co, and extremely significant negative correlations with Al, Ni, and Cr, and significant negative correlations with Cu and Mg. Al showed extremely significant positive correlations with Ni, Cr, and Fe, significant positive correlation with As, extremely significant negative correlations with Si and B, and significant negative correlations with Mn, S, and Co. Mg showed extremely significant positive correlations with Na, Cu, Zn, and Ni, and significant positive correlation with Cd. Na showed extremely significant positive correlation with Ti, significant positive correlations with S, Cu, and Zn, and significant negative correlation with Se. Mn showed extremely significant positive correlations with Co and Pb, with a correlation coefficient of 0.914 for Pb, and significant positive correlations with S and B. S showed extremely significant positive correlation with B, significant positive correlations with Ti and Cl, and extremely significant negative correlation with Se. Cu showed extremely significant positive correlations with Zn and Cd, and significant positive correlation with Ni. Additionally, Zn and Cd, Ni and Cr, and Co and Pb showed good synergistic effects, while B showed strong inhibitory effects on Cr and Se.

Table 3 Correlation among mineral element contents in pitaya land

*Note: ** indicates significant correlation at the 0.01 level; * indicates significant correlation at the 0.05 level.*

Discussion

3.1 Characteristics of Mineral Element Changes Under Different Tillage Methods

Mineral elements, as essential nutrients for crop growth and development, are closely related to biological molecules including proteins, vitamins, nucleic acids, and physiological metabolic activities. Their contents are influenced by numerous factors including altitude (Yu et al., 2018), soil parent material (Yang et al., 2017), and rocky desertification development degree (Li et al., 2016). Additionally, soil mineral element contents are affected by anthropogenic inputs (Zhou et al., 2010), with tillage methods directly acting on soil and influencing soil structure and nutrient transformation, transport, and cycling (Camara et al.,

2003). In this study, most soil mineral element contents changed with tillage methods, with Ca, Si, and Mn increasing and Fe, Mg, Al, Cu, and Zn decreasing compared with no measures. We speculate that pitaya has high demand for Fe, Mg, Al, Cu, and Zn during late maturity, and these elements should be supplemented promptly during cultivation.

Rational fertilization methods also affect crop yield and quality (Wei et al., 2015). Organic fertilizer application promotes soil biochemical reactions and enhances crop absorption, transport, and accumulation of soil trace elements by affecting bioavailability (Gao et al., 2000). Long-term organic fertilizer application can increase soil nutrient supply capacity, accelerate humic acid activation of soil nutrients, thereby increasing soil nutrient content and maintaining supply balance (Huang et al., 2010). Liu et al. (2009) reported that organic fertilizer application increased soil Cu, Zn, Pb, and Cd contents, which partially differs from our results. While Pb content increased, the difference was not significant, and Cu, Zn, and Cd contents all decreased, with Cu showing significant differences. This may be due to different crop absorption patterns of soil mineral elements or selective absorption by different plants. Fu et al. (2017) studied fertilization effects on wheat yield, showing that N-P fertilizer application increased soil nutrient content. Wang et al. (2012) found that chemical fertilizer alone decreased soil available B, Fe, Zn, and Cu contents, which partially differs from our results where B content increased significantly, possibly due to reduced B content in pitaya flesh transferring to soil (Wang et al., 2015). However, Song et al. (2010) demonstrated that organic fertilizer inputs far exceed chemical fertilizers in trace element quantity, indicating organic fertilizer superiority in agricultural production with lower soil pollution. In this study, combined chemical fertilizer and pesticide application affected soil ecological benefits while constraining pitaya quality improvement. Therefore, organic fertilizer application is more beneficial for crop growth and quality formation in agricultural activities, providing theoretical basis and scientific support for soil mineral element management.

The dry-hot valley rocky desertification region features high temperatures, drought, and poor soil nutrients. Plastic film mulching reduces surface exposure, decreases soil evaporation, and improves water use efficiency (Fu et al., 2017; Deng et al., 2014), while promoting soil fauna and microbial activity and facilitating organic matter mineralization and decomposition (Mao et al., 2010). Mulching can regulate tillage layer soil temperature (Awe et al., 2015), with plastic film mulching generally showing warming effects (Chang et al., 2018). Jiang et al. (2016) reported that warming affects soil Al, Fe, Mn, and Zn contents. In this study, plastic film mulching decreased soil Al, Fe, and Zn contents while increasing Mn content, possibly due to different warming effects and treatment methods leading to variations in soil moisture and temperature conditions, regional microbial populations, and organic matter mineralization and loss rates.

Green manure itself contains trace elements. After decomposition through plowing, nutrient elements return to the soil, increasing mineral nutrient content in

the surface layer. Its root system releases large amounts of organic acids and enzymes that activate rhizosphere microbial activity, with microorganisms continuously absorbing and utilizing P, K, Mg, and other minerals from minerals, facilitating mineral nutrient release and availability (Mclaren, 1984). Huo et al. (2011) reported that long-term green manure planting in pear orchards increased soil Ca, Mg, Fe, Mn, Zn, and Cu contents. In this study area, alfalfa intercropping decreased Mg, Fe, Mn, Zn, and Cu contents except for Ca, due to nutrient competition between alfalfa and pitaya, or possibly because of different green manure types and shorter planting duration leading to differences in decomposition rates and nutrient accumulation effects.

3.2 Correlations Among Soil Mineral Elements

Investigating correlations among soil mineral elements can prevent misjudgment from using single elements as nutritional indicators. Xu et al. (2014) found that various mineral elements affect fruit growth, development, and quality formation through synergistic regulation. Chen et al. (1992) studied Fe-Mn interactions and their effects on plant physiology and biochemistry, reporting antagonistic effects between Fe and Mn, consistent with our results. In this study area, Fe showed extremely significant positive correlations with Al, Ni, and Cr, with correlation coefficients all above 0.907, indicating that soil Fe can effectively activate other elements. Zn, Mg, and Cu showed extremely significant positive correlations pairwise, with correlation coefficients greater than 0.875, demonstrating strong synergistic effects and mutual enhancement. Soil Ca showed negative correlations with Fe and Mn, Mn showed negative correlations with Fe, Mg, Cu, and Zn, and B showed negative correlations with Fe, Mg, and Cu, indicating that mineral elements exhibit characteristic trade-off relationships.

Conclusion

- (1) Among the five tillage methods, organic fertilizer application provided the most abundant mineral element supplementation, followed by chemical fertilizer and pesticide application, with plastic film mulching in the middle and alfalfa intercropping the least effective.
- (2) Compared with no measures, other tillage methods increased Ca, Si, Mn, and other contents to varying degrees, while decreasing Fe, Mg, Al, and other contents, with no significant difference in Na content. When cultivating pitaya, mineral elements including Fe, Mg, Al, and Na should be added to soil to promote growth, development, and yield and quality improvement.
- (3) Mineral elements showed certain correlations with synergistic or inhibitory effects, particularly for Al, Si, S, and Ni, which showed relatively strong relationships with other elements.

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