Impact of cover crop and mulching on soil physical properties and soil nutrients in a citrus orchard

Tran Van Dung¹, Ngo Phuong Ngoc², Le Van Dang¹ and Ngo Ngoc Hung¹

¹ Soil Science Department, College of Agriculture, Can Tho University, Can Tho, Viet Nam
² Department of Plant Physiology-Biochemistry, College of Agriculture, Can Tho University, Can Tho, Viet Nam

ABSTRACT

Background: Cover crops and mulching can ameliorate soil porosity and nutrient availability, but their effects on the physical characteristics and nutrients in the raised bed soils are unclear.

Methods: The field experiment was conducted in a pomelo orchard from 2019 to 2021, with an area of 1,500 m². The treatments included control (no cover crop), non-legume cover crop (Commelina communis L.), legume cover crop (Arachis pintoi Krabov & W.C. Gregory), and rice straw mulching (Oryza sativa L.). At the end of each year (2019, 2020, and 2021), soil samples were collected at four different layers (0–10, 10–20, 20–30, and 30–40 cm) in each treatment. Soil bulk density, soil porosity, and the concentration of nutrients in the soil were investigated.

Results: The results revealed that soil bulk density at two depths, 0–10 and 10–20 cm, was reduced by 0.07 and 0.08 g cm⁻³ by rice straw mulch and a leguminous cover crop, thus, increasing soil porosity by ~2.74% and ~3.01%, respectively. Soil nutrients (Ca, K, Fe, and Zn) at topsoil (0–10 cm) and subsoil (10–20 cm) layers were not significantly different in the first year, but those nutrients (Ca, K, Fe, and Zn) improved greatly in the second and third years.

Conclusions: Legume cover crops and straw mulch enhanced soil porosity and plant nutrient availability (Ca, K, Fe, and Zn). These conservation practices best benefit fruit orchards cultivated in the raised bed soils.

INTRODUCTION

The loss of nutrients in the soil is considered a key problem for decreasing soil fertility in the fruit orchards grown in raised bed soils (Dang & Hung, 2021). In the Vietnamese Mekong Delta (VMD), soil compaction and degradation are more severe (Dung et al., 2020). Many studies have reported that reduced soil organic matter is a primary cause of increased soil bulk density (Athira, Jagadeeswaran & Kumaraperumal, 2019; Dang, Ngoc & Hung, 2021; Imran, Amanullah & Al-Tawaha, 2022). Citrus needs high soil porosity and available nutrients for optimum growth and development. Pomelo (Citrus grandis Osbeck)
has been cultivated in many places at the VMD, and they are a great source of income for growers (Kieu & Hung, 2019). However, the pomelo productivity cultivated on old raised soils has been reduced due to poor soil fertility and compaction (Dung et al., 2020). Dang, Ngoc & Hung (2022) reported that soil acidity in the citrus orchards increased significantly with chemical fertilizers (ammonium sulfate, superphosphate, and potassium chloride) in the long term. Furthermore, farmers in these areas were not interested in implementing soil conservation measures in their orchards. This may decrease soil moisture, water use efficiency, and biological activity (Cao et al., 2021; Paul et al., 2021).

Soil conservation practices (mulching, cover cropping, crop rotation, etc.) are measures the farmer can apply to mitigate soil degradation and soil erosion (Ogunsola, Adeniyi & Adedokun, 2020; López-Vicente et al., 2020). Soil conservation measures reduce soil loss by keeping a cover over the ground, decreasing soil displacement associated with raindrops and irrigation water affecting soil particles (Vincent-Caboud et al., 2019; Calegari et al., 2020). Additionally, soil conservation measures decrease the pressure and velocity of runoff on the topsoil (Kumawat et al., 2020). According to Page, Dang & Dalal (2020), conservation practices improved the soil’s organic carbon content, soil porosity, water capacity, plant nutrient availability, soil biota activity, and crop productivity.

Cover cropping is a cropping system/method utilized to decrease erosion, ameliorate soil porosity, enhance soil organic matter, weed control, pests, and disease management, and increase biodiversity (Sharma et al., 2018; Das, Kandpal & Devi, 2021). According to Van Sambeek (2017) and Abdalla et al. (2019), cover crops attract pollinators leading to improved fruit set ratio, thus increasing plant productivity. There are two key cover crops: legumes and non-legumes (Abdalla et al., 2019). Leguminous cover crops increase soil nutrients especially total and available nitrogen, because they can fix nitrogen biologically (Kaye et al., 2019; MacMillan et al., 2022; Freidenreich et al., 2022). Meanwhile, the nonlegume cover crops increase crop biomass and decrease soil loss from the surface layer (Romdhane et al., 2019; Amanullah et al., 2021).

Mulches comprising organic materials (straw, litter, etc.) covered the soil surface to control weeds and reduce runoff (Li, Li & Pan, 2021; Khoramizadeh et al., 2021). Mulches help increase soil organic carbon, decreasing soil compaction (Iqbal et al., 2020). The decomposition process of organic mulches releases many nutrients (Khoramizadeh et al., 2021). These nutrients are in a form that is useful to plants and might increase the uptake, improving crop productivity (Singh et al., 2021). Mulching also affects soil microorganism activity and abundance (Rodrigues da Silva et al., 2022).

A previous study indicated that cover cropping with legumes and rice straw mulch significantly increases soil organic carbon, total nitrogen, and phosphorus (Dung et al., 2022). However, the effects of conservation practices on soil compaction and available nutrients (Ca, Mg, K, Cu, Fe, Zn, and Mn) have not been reported. Hence, this study aimed to evaluate soil conservation measures on soil bulk density, porosity, and soil nutrients in a pomelo orchard cultivated on alluvial soil of the Mekong Delta, Vietnam.
MATERIALS AND METHODS

Study site, soil, and climate

A pomelo orchard used for the experiment in this research was the same as described in our previous study (Dung et al., 2022). It was located in Hau Giang province (9°54′30.3″N, 105°51′06.7″E). The soil was classified as Gleyic Anthrosols based on the reference of World Reference Base for Soil Resources (2015).

The average monthly rainfall from 2019 to 2021 at the study site was 175 mm, with September and March usually receiving the highest (470 mm) and lowest (10 mm) rainfalls, respectively. Table 1 shows the physical and chemical properties.

### Table 1 Basic soil physicochemical properties at the study location.

| Depth (cm) | pH<sub>H2O</sub> | SOM (%) | Macronutrients (cmol<sub>c</sub> kg<sup>-1</sup>) | Trace elements (mg kg<sup>-1</sup>) | BD (g cm<sup>-3</sup>) |
|------------|-----------------|---------|----------------------------------|-------------------------------|------------------|
|            |                 |         | Ca<sup>2+</sup> | K<sup>+</sup> | Mg<sup>2+</sup> | Cu | Fe | Zn | Mn |      |
| 0–10       | 5.02            | 1.50    | 3.53               | 0.16              | 2.28     | 22.7 | 8.25 | 55.1 | 28.6 | 1.19   |
| 10–20      | 4.95            | 1.42    | 3.29               | 0.18              | 2.36     | 30.5 | 8.36 | 45.2 | 24.2 | 1.22   |
| 20–30      | 5.25            | 1.35    | 4.10               | 0.21              | 2.32     | 26.9 | 7.45 | 39.5 | 30.1 | 1.25   |
| 30–40      | 5.18            | 1.20    | 3.98               | 0.17              | 2.41     | 27.0 | 6.32 | 40.3 | 25.7 | 1.23   |

Experimental design

The field experiment was arranged in a randomized complete block design, including four treatments. Each treatment had four replications. The treatments were no cover crop (control), nonlegume (*Commelina communis* L.) cover crop (NLC), legume (*Arachis pintoi* Krabov & W.C. Gregory) cover crop (LCC), and rice straw (*Oryza sativa* L.) mulching (RSM). The number of trees per trial plot was three plants. The five-year-old “Da Xanh” pomelo orchard was used in this study, with an average fruit yield of 18 t ha<sup>-1</sup> year<sup>-1</sup>.

The pomelo plants were 3.0–3.4-m tall at the beginning study, and the canopy diameter was 2.8–3.1 m. All treatments accepted the no-till practice. All treatments applied the same amount of NPK fertilizers at rates of 400 kg N, 300 kg P<sub>2</sub>O<sub>5</sub>, and 400 kg K<sub>2</sub>O ha<sup>-1</sup> year<sup>-1</sup> (Dang, Ngoc & Hung, 2022).

Nicotex Co., Ltd. (Thai Binh, Vietnam), a commercial product, was used for weed management in the control plots. The herbicide with commercial name NIPHOSATE 480SL contains 480-g glyphosate IPA salt per liter. The spraying rate was 2.5 liter per ha, per the producer’s recommendation. A hand sprayer (Mitsuyama TL–767) was used for herbicide application. The weeds were regularly controlled when they reached ~8–10-cm tall (~5–6 leaves), and ~3 months of herbicide was applied.

Asiatic dayflower (*Commelina communis* Krabov & W.C. Gregory) was utilized for NLC plots. Asiatic dayflower was cultivated by cuttings that were ~20-cm long. When the Asiatic dayflower was >30-cm high, they cut the tops by ~20 cm using the Honda Grass Cutter GX35. Pinto peanut (*Arachis pintoi*) was used for LCC plots. The pinto peanut was cultivated by clusters of 2–3 cuttings spaced 10–15-cm apart.
The method and timing of rice straw mulch were in accordance with the Southern Horticultural Research Institute (SOFRI) recommendation, Vietnam. The VMD is located in a tropical monsoon area, and the annual highest rainfall was from June to September. Hence, rice straw mulch was regularly carried out twice yearly in the dry season (October and March). When rice straw mulch was conducted in the wet season, it decreased soil drainage capacity, resulting in increased root rot disease of pomelo (Thu et al., 2018).

Under the pomelo tree canopy, the ridges were mulched with a rice straw that was 1.5-m wide and 2–2.5-cm thick. Rice straw used for the experiment was 5.5 t ha\(^{-1}\) year\(^{-1}\), and an average of ~8.8 kg of rice straw tree\(^{-1}\) year\(^{-1}\).

**Soil collection and analysis**

**Soil physical parameters**

In order to determine soil bulk density (BD), soil sample rings Eijkelkamp company were used for soil sampling in 2019, 2020, and 2021. The soil sample ring was 51 mm in height and 53 mm in diameter. Five soil samples were randomly taken from each plot for the BD analysis. After collection, soil cores were dried at 100 °C for 48 h in an oven. BD was calculated from the dry soil mass ratio per unit volume of the soil cores (Mtyobile, Muzangwa & Mnkeni, 2020). The total porosity of the soil was calculated from the soil BD values and the particle density. In this study, particle density is 2.65 g cm\(^{-1}\). The total porosity is shown in the following equation:

\[
\text{Total porosity} \% = 1 - \frac{\text{Soil bulk density}}{2.65} \times 100
\]

**Soil chemical parameters**

In each plot, a soil auger took five soil cores from depths of 0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm, following a zig-zag pattern in 2019, 2020, and 2021. The five samples from the same depth were blended into one composite sample per depth. The soil was then divided into subsamples of ~500 g. All soil samples were air-dried and ground to pass through a 2 mm sieve.

A 0.1 M BaCl\(_2\) extraction was used to analyze the exchangeable base cations (K, Ca, and Mg) (Hendershot & Duquette, 1986). The soil’s iron content was extracted in oxalate–oxalic acid (Novozamsky et al., 1986). Nitric–perchloric acid digestion was performed on Mn, Cu, and Zn, following the procedure recommended by the AOAC (1990). The macroelements (K, Ca, and Mg) and micronutrients (Fe, Mn, Cu, and Zn) were determined using Atomic Absorption Spectrometers (Thermo Scientific™ iCE™ 3000 Series; Thermo Scientific, Waltham, MA, USA).

**Statistics**

The statistical analysis relied on SPSS version 20.0. Analysis of variance was used to compare the differences between means among treatments by the Duncan test at a statistical level of \(P < 0.05\) (*) and \(P < 0.01\) (**).
Effect of soil conservation practices on soil bulk density

Figure 1 shows that using soil conservation practices (LCC and RSM) significantly improved BD at both 0–10- and 10–20-cm after 3 years of experimentation. However, soil conservation measures did not affect BD at two depths (20–30 and 30–40 cm). At the topsoil (0–10 cm), BD in LCC and RSM treatments were lower than in the control and NLC plots. In particular, the mean value of BD in LCC and RSM was ~1.14 and ~1.15 g cm\(^{-3}\), respectively, lower than that in the treatments of control 1.22 g cm\(^{-3}\).

Using of NLC positively affected BD in the topsoil (0–10 cm) in 2020 and 2021 compared with the control treatment (Fig. 1A). Similarly, BD was reduced by covering crops with pinto peanuts and mulching with rice straw in the 10–20 cm soil depth.

**RESULTS**

Effect of soil conservation practices on soil bulk density

Figure 1 shows that using soil conservation practices (LCC and RSM) significantly improved BD at both 0–10- and 10–20-cm after 3 years of experimentation. However, soil conservation measures did not affect BD at two depths (20–30 and 30–40 cm). At the topsoil (0–10 cm), BD in LCC and RSM treatments were lower than in the control and NLC plots. In particular, the mean value of BD in LCC and RSM was ~1.14 and ~1.15 g cm\(^{-3}\), respectively, lower than that in the treatments of control 1.22 g cm\(^{-3}\).

Using of NLC positively affected BD in the topsoil (0–10 cm) in 2020 and 2021 compared with the control treatment (Fig. 1A). Similarly, BD was reduced by covering crops with pinto peanuts and mulching with rice straw in the 10–20 cm soil depth.
Meanwhile, Figs. 1A and 1B showed that BD in the lower layers was not changed after soil conservation measures application. The value of BD in two depths (20–30 cm and 30–40 cm) ranged from 1.23–1.26 g cm$^{-3}$.

**Soil porosity is affected by soil conservation measures**

Soil conservation measures increased soil porosity at two depths, 0–10 cm and 10–20 cm (Fig. 2). Like BD, non-legume or legume cover crops and RSM did not improve soil porosity in deeper soil layers (20–30 cm and 30–40 cm). The use of conservation practices (LCC and RSM) enhanced soil porosity by ~5% and ~3% at 0–10 and 10–20 cm (Figs. 2A, 2B) after 3 years of experiments, respectively. In the depths of 20–30 and 30–40 cm, there was no significant difference in soil porosity between soil conservation measures compared to no conservation (Figs. 2C, 2D).
Influence of soil conservation practices on soil nutrients

Topsoil layer (0–10 cm)

Although the concentrations of macroelements (Ca, K, and Mg) in soil did not improve in the first year of applying conservation practices, they increased significantly in the next two years, except for Mg (Table 2). In particular, the Ca content in the RSM treatments increased by 0.31 and 0.39 cmolₑ kg⁻¹ in 2020 and 2021 compared with the control, respectively. Those in the LCC treatment were 0.29 and 0.38 cmolₑ kg⁻¹. Likewise, the K concentration in RSM and LCC was enhanced by ~0.11 and ~0.12 cmolₑ kg⁻¹ in 3 years of experimentation. Conversely, using the cover crop or mulching did not affect the concentration of Mg in soil. The application of soil conservation measures did not affect the micronutrients (Cu, Fe, Zn, and Mn) contents in 2019 (Table 2). However, the concentrations of Fe and Zn in 2021 were elevated by ~7.0 and ~13.0 mg kg⁻¹ compared to 2019 because the crops were covered with legumes and mulched with rice straw.

The difference in Fe and Zn improvement might be from Fe and Zn contents containing the legume and rice straw, resulting in enhanced soil Fe and Zn concentration. Soil conservation practices did not influence the contents of Cu and Mn.

Subsurface layer (10–20 cm)

Table 3 indicates the effect of cover crops and organic mulching on soil fertility. In 2019, soil nutrients (Ca, K, Mg, Cu, Fe, Zn, and Mn) were not increased by soil conservation practices, except for Zn. LCC significantly increased exchangeable Ca by 0.61 and 0.72 cmolₑ kg⁻¹ compared with control in 2020 and 2021, respectively. Exchangeable Ca
was significantly higher in RSM than in control. The exchangeable K$^+$ was higher by an average of 0.07–0.10 cmol$_c$ kg$^{-1}$ in RSM and LCC than in control in 2020 and 2021. Available Fe concentrations were ~1.5-fold greater in LCC and RSM than in no conservation treatment in 2 years (Table 3). Similarly, RSM and LCC enhanced available Zn by more than 10 mg kg$^{-1}$ compared with control in the experiment of 3 years. In the current research, soil conservation practices did not affect the concentrations of Mg, Cu, and Mn.

The layer of 20–30 cm
In a 3-year study, soil conservation practices did not improve soil quality at a depth of 20–30 cm (Table 4). However, in 2021, the concentration of Cu was the highest in LCC, followed by NLC, RSM, and control. The value of macronutrients (Ca, K, Mg) ranged from 4.00–4.22 cmol$_c$ kg$^{-1}$, 0.18–0.22 cmol$_c$ kg$^{-1}$, and 2.31–2.47 cmol$_c$ kg$^{-1}$, respectively. There was no significant difference in all treatments for micronutrient (Fe, Zn, and Mn) concentrations for micronutrient (Fe, Zn, and Mn) concentrations. Fe, Zn, and Mn concentrations were 8.71–11.3 mg kg$^{-1}$, 38.8–45.9 mg kg$^{-1}$, and 24.3–30.4 mg kg$^{-1}$ from 2019 to 2021.

The layer of 30–40 cm
The results in Table 5 showed no significant differences in all treatments regarding soil chemical properties, except exchangeable K in 2021 was influenced by soil conservation
### Table 4  Influence of soil conservation practices on macro-micronutrients in the soil at a depth of 20–30 cm.

| Years | Treatments | Macronutrients (cmol kg\(^{-1}\)) | Trace elements (mg kg\(^{-1}\)) |
|-------|------------|-----------------------------------|---------------------------------|
|       |            | \(\text{Ca}^{2+}\) | \(\text{K}^+\) | \(\text{Mg}^{2+}\) | \(\text{Cu}\) | \(\text{Fe}\) | \(\text{Zn}\) | \(\text{Mn}\) |
| 2019  | Control    | 4.15  | 0.19  | 2.31  | 24.4  | 8.71  | 39.5  | 26.2  |
|       | NLC        | 4.15  | 0.18  | 2.41  | 26.9  | 8.94  | 39.5  | 25.6  |
|       | RSM        | 4.09  | 0.19  | 2.36  | 23.9  | 8.79  | 43.4  | 27.2  |
|       | LCC        | 4.10  | 0.21  | 2.36  | 23.8  | 8.93  | 44.3  | 25.4  |
| \(P\)-value | ns       | ns    | ns    | ns    | ns    | ns    | ns    | ns    |
| 2020  | Control    | 4.00  | 0.20  | 2.38  | 27.4  | 9.67  | 40.5  | 30.4  |
|       | NLC        | 4.22  | 0.18  | 2.46  | 25.8  | 10.0  | 39.5  | 28.5  |
|       | RSM        | 4.17  | 0.21  | 2.45  | 24.1  | 9.93  | 38.8  | 28.3  |
|       | LCC        | 4.06  | 0.22  | 2.47  | 23.7  | 10.7  | 43.2  | 29.2  |
| \(P\)-value | ns       | ns    | ns    | ns    | ns    | ns    | ns    | ns    |
| 2021  | Control    | 4.05  | 0.19  | 2.33  | 24.2b | 10.3  | 44.7  | 26.2  |
|       | NLC        | 4.11  | 0.19  | 2.45  | 24.3b | 10.9  | 42.0  | 25.8  |
|       | RSM        | 4.07  | 0.19  | 2.31  | 23.9b | 11.3  | 45.9  | 25.5  |
|       | LCC        | 4.03  | 0.18  | 2.42  | 27.8a | 10.0  | 41.8  | 24.3  |
| \(P\)-value | ns       | ns    | ns    | ns    | ns    | ns    | ns    | ns    |

**Note:**
- Control, no conservation practices; NLC, non-legume cover crop; RSM, rice straw mulching; LCC, legume cover crop.
- Different letters in each column indicate significant differences among treatments at \(P < 0.05\) (*); ns, not significant.

### Table 5  Effect of soil conservation measures on availability of plant nutrients at a depth of 30–40 cm.

| Years | Treatments | Macronutrients (cmol kg\(^{-1}\)) | Trace elements (mg kg\(^{-1}\)) |
|-------|------------|-----------------------------------|---------------------------------|
|       |            | \(\text{Ca}^{2+}\) | \(\text{K}^+\) | \(\text{Mg}^{2+}\) | \(\text{Cu}\) | \(\text{Fe}\) | \(\text{Zn}\) | \(\text{Mn}\) |
| 2019  | Control    | 3.98  | 0.17  | 2.33  | 25.3  | 5.72  | 48.9  | 25.7  |
|       | NLC        | 4.02  | 0.17  | 2.33  | 24.2  | 5.79  | 47.0  | 25.7  |
|       | RSM        | 3.88  | 0.18  | 2.39  | 25.5  | 5.94  | 49.2  | 25.4  |
|       | LCC        | 4.09  | 0.18  | 2.34  | 23.7  | 5.61  | 49.5  | 24.7  |
| \(P\)-value | ns       | ns    | ns    | ns    | ns    | ns    | ns    | ns    |
| 2020  | Control    | 4.13  | 0.15  | 2.45  | 25.0  | 6.42  | 52.9  | 25.1  |
|       | NLC        | 4.02  | 0.16  | 2.47  | 25.6  | 6.58  | 54.5  | 25.7  |
|       | RSM        | 4.02  | 0.17  | 2.42  | 24.2  | 6.74  | 54.1  | 25.6  |
|       | LCC        | 3.98  | 0.17  | 2.43  | 24.5  | 6.47  | 53.9  | 26.5  |
| \(P\)-value | ns       | ns    | ns    | ns    | ns    | ns    | ns    | ns    |
| 2021  | Control    | 4.00  | 0.17b | 2.41  | 24.7  | 6.60  | 48.8  | 25.1  |
|       | NLC        | 3.98  | 0.18b | 2.41  | 24.1  | 6.08  | 48.6  | 26.7  |
|       | RSM        | 4.08  | 0.20a | 2.36  | 23.4  | 6.32  | 46.0  | 25.1  |
|       | LCC        | 3.96  | 0.20a | 2.40  | 23.5  | 6.68  | 48.0  | 25.3  |
| \(P\)-value | ns       | **    | ns    | ns    | ns    | ns    | ns    | ns    |

**Note:**
- Control, no conservation practices; NLC, non-legume cover crop; RSM, rice straw mulching; LCC, legume cover crop.
- Different letters in each column indicate significant differences among treatments at \(P < 0.01\) (**); ns, not significant.
practices. The concentration of K\(^+\) was significantly greater by 1.1-fold in RSM and LCC treatments compared with NLC and control.

### Correlation between soil quality parameters

The BD indicated a negative significant relationship with Ca \((r = −0.74^{**})\), K \((r = −0.73^{**})\), Fe \((r = −0.79^{**})\), and Mn \((r = −0.69^{**})\). Table 6 also showed a strong positive correlation between Ca and K \((r = 0.74^{**})\), Ca and Fe \((r = 0.81^{**})\), Ca and Zn \((r = 0.76^{**})\). We found a positive very strong significant relationship between K and Fe and Mn \((r = 0.86^{**}, r = 0.69^{**}\), respectively). The correlation matrix also indicated a significant positive relationship between Fe and Zn \((r = 0.82^{**})\).

### DISCUSSION

Soil BD is a vital indicator of soil degradation because it influences soil porosity, plant nutrient availability, and soil microorganism activity (Recha et al., 2022). According to Shaheb, Venkatesh & Shearer (2021), soil conservation measures decreased soil compaction, resulting in increased root development and length. Shaheb, Venkatesh & Shearer (2021) indicated that soil compaction reduced root biomass significantly. The decreased crop growth and yield due to soil compaction were likely due to poor nutrient availability and uptake, thus limiting/preventing root growth (Gürsoy, 2021).

In this study, cover cropping with pinto peanut and rice straw mulch reduced BD at depths of 0–10 cm and 10–20 cm, −0.10 g cm\(^{-3}\) and −0.08 g cm\(^{-3}\) in a 3-year consecutive trial, respectively (Figs. 1A, 1B). The current research is consistent with Mondal et al. (2019), who reported that conservation agriculture practices contributed significantly reduced soil compaction. Similar results have also been reported by Degu, Melese & Tena (2019), Ceylan (2020), and Belayneh, Yirgu & Tsegaye (2019).

Like BD, soil porosity was increased significantly at two depths, 0–10 cm, and 10–20 cm, when covered with legumes and straw mulch (Fig. 2). Many studies have indicated a strong negative correlation between BD and total porosity (Kakaire et al., 2015; Onwuka et al., 2020). In the present work, cover crops and mulching decreased BD, and this may be due to reduced soil compaction, which improved total porosity. Moreover, our previous study showed that soil organic matter increased remarkably when applying cover with pinto.
peanut and straw mulch (Dung et al., 2022). Improving soil organic carbon is the main reason for the increase in total porosity (Fukumasu et al., 2022).

The first year’s results showed that soil nutrient concentration was not affected by soil conservation practices, except for Zn content in the depth of 10–20 cm (Table 3). However, in the second and third years, Ca, K, Fe, and Mn concentrations in RSM and LCC increased significantly at the topsoil and subsoil layers (Tables 2, 3). Conversely, these nutrients were not elevated at the depths of 20–30 cm (Table 4) and 30–40 cm (Table 5) compared with the control, except for exchangeable K at 30–40 cm in 2021. The cause may be because the root of a plant used for the cover is short, and all treatments followed the no-till practice. The results in legume biomass and straw were unable to move the depths below. Hence, it does not improve the mineral nutrients in the soil. The results did not agree with that of Haruna & Nkongolo (2020) that conservation practices enhanced soil nutrients in 20–40 and 40–60 cm during the second year of study. The difference in soil nutrient concentration between the two studies could be the difference in no-till and till practices. Soil conservation measures can favorably ameliorate soil fertility by enhancing the number of soil biota that decompose organic matter and, in the process, release plant-available nutrients (Veum et al., 2015; Belayneh, 2019). According to Jat et al. (2018), conservation practices are considered a better alternative that recycles plant nutrients in the soil.

Our study showed soil has a high BD, which caused the availability of soil nutrients (Ca, K, Fe, and Zn) to decline. Table 6 showed that there were a strong negative correlation between BD and Ca (r = −0.74**), BD and K (r = −0.73**), BD and Fe (r = −0.79***), and BD and Zn (r = −0.69**). According to Belayneh, Yirgu & Tsegaye (2019), high BD negatively affected soil nutrients due to decreased soil biological and biochemical processes, resulting in reduced soil fertility. A similar result has been reported by Singh et al. (2020). They indicated a negative correlation between BD and soil nutrients. However, the results of the present work in contrast with a report of Duan et al. (2019), who showed that there was a strong positive correlation of BD with exchangeable Ca (r = 0.32), exchangeable Mg (r = 0.45), and available Fe (r = 0.71). The results above show that the relationship between BD and soil nutrient concentration is complex.

CONCLUSIONS

The use of soil conservation practices (LCC and RSM) significantly improved soil BD at the topsoil layer (0–10 cm) and subsoil layer (10–20 cm), enhancing soil porosity compared with applying the herbicide (control). In the first year, LCC and RSM did not affect available macronutrients (Ca, K, and Mg) and micronutrients (Cu, Fe, Zn, and Mn). However, soil nutrients (Ca, K, Fe, and Zn) increased greatly in the second and third years. The current study results suggest that farmers who cultivated fruit orchards in the VMD should use leguminous cover crops or mulch because these practices can mitigate soil compaction and degradation.
ADDITIONAL INFORMATION AND DECLARATIONS

Funding
The authors received no funding for this work.

Competing Interests
The authors declare that they have no competing interests.

Author Contributions
- Tran Van Dung conceived and designed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.
- Ngo Phuong Ngoc performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.
- Le Van Dang performed the experiments, analyzed the data, authored or reviewed drafts of the article, and approved the final draft.
- Ngo Ngoc Hung conceived and designed the experiments, analyzed the data, authored or reviewed drafts of the article, and approved the final draft.

Data Availability
The following information was supplied regarding data availability:

The raw measurements are available as a Supplemental File.

Supplemental Information
Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.14170#supplemental-information.

REFERENCES
Abdalla M, Hastings A, Cheng K, Yue Q, Chadwick D, Espenberg M, Truu K, Rees RM, Smith P. 2019. A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. Global Change Biology 25(8):2530–2543 DOI 10.1111/gcb.14644.
Amanullah S, Khalid S, Khalil F, Elshikh MS, Alwahibi MS, Alkahtani J, Imranuddin, Imran. 2021. Growth and dry matter partitioning response in cereal-legume intercropping under full and limited irrigation regimes. Scientific Reports 11(1):12585 DOI 10.1038/s41598-021-92022-4.
AOAC. 1990. Official methods of analysis. Fifteenth Edition. Washington DC: Association of Official Analytical Chemist.
Athira M, Jagadeeswaran R, Kumaraperumal R. 2019. Influence of soil organic matter on bulk density in Coimbatore soils. International Journal of Chemical Studies 7:3520–3523.
Belayneh M. 2019. The effects of soil conservation practices on selected soil health indicators. C.O. R.N. NEWSLETTER. 2018-01.
Belayneh M, Yirgu T, Tsegaye D. 2019. Effects of soil and water conservation practices on soil physicochemical properties in Gumara watershed, Upper Blue Nile Basin, Ethiopia. Ecological Processes 8(1):36 DOI 10.1186/s13717-019-0188-2.
Calegari A, Tiecher T, Wutke EB, Canalli LB, Bunch R, Santos DR. 2020. The role and management of soil mulch and cover crops in Conservation Agriculture systems. In: Kassam A,
ed. *Advances in Conservation Agriculture Volume 1 Systems and Science.* Cambridge: Burleigh Dodds, 179–248.

Cao H, Jia M, Song J, Xun M, Fan W, Yang H. 2021. Rice-straw mat mulching improves the soil integrated fertility index of apple orchards on cinnamon soil and fluvo-aquic soil. * Scientia Horticulturae 278*:109837 DOI 10.1016/j.scienta.2020.109837.

Ceylan S. 2020. Effects of soil conservation practices on soil properties in a cotton and soybean system in West Tennessee. Master’s Thesis, University of Tennessee, 124.

Dang LV, Hung NN. 2021. Assessment of soil quality on organic fertilizers applied to the pomelo orchards in Hau Giang. *Journal of Agriculture, Science and Technology & Rural Development* 23:17–25.

Dang LV, Ngoc NP, Hung NN. 2021. Soil quality and pomelo productivity as affected by chicken manure and cow dung. *The Scientific World Journal* 2021(12):6289695 DOI 10.1155/2021/6289695.

Dang LV, Ngoc NP, Hung NN. 2022. Effects of biochar, lime, and compost applications on soil physicochemical properties and yield of pomelo (*Citrus grandis* Osbeck) in alluvial soil of the Mekong Delta. *Applied and Environmental Soil Science* 2022(109):5747699 DOI 10.1155/2022/5747699.

Das B, Kandpal BK, Devi HL. 2021. Cover crops for orchard soil management. In: *Cover Crops and Sustainable Agriculture*. BocaRaton, FL, USA: CRC Press, 147–168.

Degu M, Melese A, Tena W. 2019. Effects of soil conservation practice and crop rotation on selected soil physicochemical properties: the case of Dembecha District, Northwestern Ethiopia. *Applied and Environmental Soil Science* 2019(6):6910879 DOI 10.1155/2019/6910879.

Duan A, Lei J, Hu X, Zhang J, Du H, Zhang X, Guo W, Sun J. 2019. Effects of planting density on soil bulk density, pH and nutrients of unthinned chinese fir mature stands in south subtropical region of China. *Forests* 10(4):351 DOI 10.3390/f10040351.

Dung TV, Hung NN, Dang LV, Ngoc NP. 2022. Soil fertility and pomelo yield influenced by soil conservation practices. *Open Agriculture*. (Under review).

Dung TV, Qui NV, Dang LV, Toan LP, Hung NN. 2020. Morphological and physico-chemical properties of the raised-bed soils cultivated with 5 Roi pomelo in Chau Thanh district – Hau Giang province. *Can Tho University Journal of Science* 56:130–137.

Freidenreich A, Dattamudi S, Li Y, Jayachandran K. 2022. Influence of leguminous cover crops on soil chemical and biological properties in a no-till tropical fruit orchard. *Land* 11(6):932 DOI 10.3390/land11060932.

Fukumasa J, Jarvis N, Koestel J, Kätterer T, Larsbo M. 2022. Relations between soil organic carbon content and the pore size distribution for an arable topsoil with large variations in soil properties. *European Journal of Soil Science* 73(1):e13212 DOI 10.1111/ejss.13212.

Gürsoy S. 2021. Soil compaction due to increased machinery intensity in agricultural production: its main causes, effects and management. In: Ahmad F, Sultan M, eds. *Technology in Agriculture*. London: IntechOpen.

Haruna SI, Nkongolo NV. 2020. Influence of cover crop, tillage, and crop rotation management on soil nutrients. *Agriculture* 10(6):225 DOI 10.3390/agriculture10060225.

Hendershot WH, Duquette M. 1986. Simple barium chloride method for determining cation exchange capacity and exchangeable cations. *Soil Science Society of America Journal* 50(3):605–608 DOI 10.2136/sssaj1986.03615995005000030013x.

Imran I, Amanullah A, Al-Tawaha AR. 2022. Indigenous organic resources utilization, application methods and sowing time replenish soil nitrogen and increase maize yield and total
dry biomass. *Journal of Plant Nutrition* **45**(18):2859–2876

DOI 10.1080/01904167.2022.2067055.

Iqbal R, Raza MAS, Valipour M, Saleem MF, Zaheer MS, Ahmad S, Toleikiene M, Haider I, Aslam MU, Nazar MA. 2020. Potential agricultural and environmental benefits of mulches—a review. *Bulletin of the National Research Centre* **44**(1):75

DOI 10.1186/s42269-020-00290-3.

Jat HS, Datta A, Sharma PC, Kumar V, Yadav AK, Choudhary M, Choudhary V, Gathala MK, Sharma DK, Jat ML, Yaduvanshi NPS, Singh G, McDonald A. 2018. Assessing soil properties and nutrient availability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems of North-West India. *Archives of Agronomy and Soil Science* **64**(4):531–545

DOI 10.1080/03650340.2017.1359415.

Kakaire J, Makokha GL, Mwanjalolo M, Mensah AK, Emmanuel M. 2015. Effects of mulching on soil hydro-physical properties. *Applied Ecology and Environmental Sciences* **3**:127–135

DOI 10.12691/aees-3-5-1.

Kaye J, Finney D, White C, Bradley B, Schipanski M, Alonso-Ayuso M, Hunter M, Burgess M, Mejia C. 2019. Managing nitrogen through cover crop species selection in the U.S. mid-Atlantic. *PLOS ONE* **14**:e0215448

DOI 10.1371/journal.pone.0215448.

Khoramizadeh A, Jourgholami M, Jafari M, Venanzi R, Tavankar F, Picchio R. 2021. Soil restoration through the application of organic mulch following skidding operations causing vehicle induced compaction in the Hyrcanian Forests, Northern Iran. *Land* **10**(10):1060

DOI 10.3390/land10101060.

Kieu NTT, Hung NN. 2019. Investigation of cultivation situation of Nam Roi pomelo grown in raised beds of alluvial soil in Hau Giang province. *Journal of Vietnam Agricultural Science and Technology* **12**:164–165.

Kumawat A, Yadav D, Samadharmam K, Rashmi I. 2020. Soil and water conservation measures for agricultural sustainability. In: Meena RS, Datta R, eds. *Soil Moisture Importance*. London: IntechOpen.

Li R, Li Q, Pan L. 2021. Review of organic mulching effects on soil and water loss. *Archives of Agronomy and Soil Science* **67**(1):136–151

DOI 10.1080/03650340.2020.1718111.

López-Vicente M, Calvo-Seas E, Álvarez S, Cerdà A. 2020. Effectiveness of cover crops to reduce loss of soil organic matter in a Rainfed Vineyard. *Land* **9**(7):230

DOI 10.3390/land9070230.

MacMillan J, Adams CB, Hinson PO, DeLaune PB, Rajan N, Trostle C. 2022. Biological nitrogen fixation of cool-season legumes in agronomic systems of the Southern Great Plains. *Agrosystems, Geosciences & Environment* **5**(1):e20244

DOI 10.1002/agg2.20244.

Mondal S, Das TK, Thomas P, Mishra AK, Bandyopadhyay KK, Aggarwal P, Chakraborty D. 2019. Effect of conservation agriculture on soil hydro-physical properties, total and particulate organic carbon and root morphology in wheat (*Triticum aestivum*) under rice (*Oryza sativa*)-wheat system. *Indian Journal of Agricultural Sciences* **89**:46–55.

Mtyobile M, Muzangwa I, Mnkeni PNS. 2020. Tillage and crop rotation effects on soil carbon and selected soil physical properties in a Haplic Cambisol in Eastern Cape, South Africa. *Soil and Water Research* **15**(No. 1):47–54

DOI 10.17221/176/2018-SWR.

Novozamsky I, van Eck R, Houba VJG, *van der Lee JJ*. 1986. Use of inductively coupled plasma atomic emission spectrometry for determination of iron, aluminium and phosphorus in Tamm’s soil extracts. *Netherlands Journal of Agricultural Science* **34**:185–191

DOI 10.18174/njas.v34i2.16803.

Ogunsola OA, Adeniyi OD, Adedokun VA. 2020. Soil management and conservation: an approach to mitigate and ameliorate soil contamination. In: Larramendy ML, Soloneski S, eds. *Soil Contamination – Threats and Sustainable Solutions*. London: IntechOpen.
Onwuka MI, Ejikeme AL, Uzoma O, Oguike PC. 2020. Land-use change effects on soil quality at Umudike area, Abia state, South-East Nigeria. *Nigerian Agricultural Journal* 51:109–118 DOI 10.13140/RG.2.2.16798.56644.

Page KL, Dang YP, Dalal RC. 2020. The ability of conservation agriculture to conserve soil organic carbon and the subsequent impact on soil physical, chemical, and biological properties and yield. *Frontiers in Sustainable Food Systems* 4:31 DOI 10.3389/fsufs.2020.00031.

Paul PLC, Bell RW, Barrett-Lennard EG, Kabir E. 2021. Impact of rice straw mulch on soil physical properties, sunflower root distribution and yield in a salt-affected clay-textured soil. *Agriculture* 11(3):264 DOI 10.3390/agriculture11030264.

Recha JW, Olale KO, Sila AM, Ambaw G, Radeny M, Solomon D. 2022. Measuring soil quality indicators under different climate-smart land uses across east African climate-smart villages. *Agronomy* 12(2):530 DOI 10.3390/agronomy12020530.

Rodrigues da Silva LJ, Feitosa de Souza TA, Klestadt Laurindo L, Freitas H, Costa Campos MC. 2022. Decomposition rate of organic residues and soil organisms’ abundance in a Subtropical Pyrus pyrifolia field. *Agronomy* 12(2):263 DOI 10.3390/agronomy12020263.

Romdhane S, Spor A, Busset H, Falchetto L, Martin J, Bizouard F, Bru D, Breuil MC, Philippot L, Cordeau S. 2019. Cover crop management practices rather than composition of cover crop mixtures affect bacterial communities in no-till agroecosystems. *Frontiers in Microbiology* 10:1618 DOI 10.3389/fmicb.2019.01618.

Shaheb MR, Venkatesh R, Shearer SA. 2021. A review on the effect of soil compaction and its management for sustainable crop production. *Journal of Biosystems Engineering* 46(4):417–439 DOI 10.1007/s42853-021-00117-7.

Sharma P, Singh A, Kahlon CS, Brar AS, Grover KK, Dia M, Steiner RL. 2018. The role of cover crops towards sustainable soil health and agriculture—a review paper. *American Journal of Plant Sciences* 9(09):1935–1951 DOI 10.4236/ajps.2018.99140.

Singh PD, Kumar A, Dhyani BP, Kumar S, Shahi UP, Singh A, Singh A. 2020. Relationship between compaction levels (bulk density) and chemical properties of different textured soil. *International Journal of Chemical Studies* 8(5):179–183 DOI 10.22271/chemi.2020.v8.i5c.10294.

Singh SP, Mahapatra BS, Pramanick B, Yadav VR. 2021. Effect of irrigation levels, planting methods and mulching on nutrient uptake, yield, quality, water and fertilizer productivity of field mustard (*Brassica rapa* L.) under sandy loam soil. *Agricultural Water Management* 244(190):106539 DOI 10.1016/j.agwat.2020.106539.

Thu NNA, Hieu NT, Hoa NV, Thuy TTT. 2018. Evaluation of bacterial antagonists for controlling *Phytophthora palmivora* and *Fusarium solani* causing root rot disease on citrus in greenhouse condition. *Journal of Vietnam Agricultural Science and Technology* 1:73–78.

Van Sambeek J. 2017. Cover crops to improve soil health and pollinator habitat in nut orchards. *Missouri Nut Growers Association (MGNA) Newsletter* 17:6–12.

Veum K, Kremer R, Sudduth K, Kitchen N, Lerch R, Baffaut C, Stott D, Karlen D, Sadler E. 2015. Conservation effects on soil quality indicators in the Missouri Salt River basin. *Journal of Soil and Water Conservation* 70(4):232–246 DOI 10.2489/jswc.70.4.232.

Vincent-Caboud L, Casagrande M, David C, Ryan MR, Silva EM, Peigne J. 2019. Using mulch from cover crops to facilitate organic no-till soybean and maize production—a review. *Agronomy for Sustainable Development* 39(5):45 DOI 10.1007/s13593-019-0590-2.

World Reference Base for Soil Resources. 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports. FAO, 203.