Research Article

Tran Van Dung, Le Van Dang, Ngo Phuong Ngoc, Ngo Ngoc Hung*

Soil fertility and pomelo yield influenced by soil conservation practices

https://doi.org/10.1515/opag-2022-0181
received July 6, 2022; accepted February 10, 2023

Abstract: Exchangeable cations and soil nutrients leach out/lost in the raised bed soils system through irrigation water and rainwater. Cover crops or crop residue mulching are considered sustainable agricultural measures because they prevent soil degradation and compaction and increase the soil ecological diversity. However, the impact of these on soil quality in fruit orchards in the Vietnamese Mekong Delta is not well studied. The present work aimed to assess the effect of cover crops (grass, pinto peanut) and rice straw mulching on change in soil chemical properties and productivity of pomelo. The 3-year (2019–2021) field experiment was conducted at Phu Huu Commune, Chau Thanh District, Hau Giang Province, Vietnam. Four treatments, control (no-cover crop), grass cover crop, mulching with rice straw (MRS), and pinto peanut cover crop were used. Soil samples were collected from the depth of 0–20 and 20–40 cm for analyzing soil pH, total nitrogen (TN), total phosphorus (TP), available phosphorus (AP), and soil organic matter (SOM). Results showed that MRS or cover crop by pinto peanut significantly decreased soil acidity in the topsoil layer. Soil fertility properties (TN, TP, AP, and SOM) at the depth 0–20 cm were greatly improved after the application of the mulched rice straw and cover crop by legume, thus improving pomelo yield. Further study is required to understand the effects of the cover crop with pinto peanut and rice straw mulching on the physical and biological properties of soil as well as nutrient uptake of pomelo orchards.

Keywords: cover crop, pinto peanut, pomelo productivity, rice straw mulching, soil chemical properties

*** Corresponding author: Ngo Ngoc Hung,** Department of Soil Science, College of Agriculture, Can Tho University, Can Tho City, Vietnam, e-mail: ngochung@ctu.edu.vn, tel: +84-913-131-186
Tran Van Dung, Le Van Dang: Department of Soil Science, College of Agriculture, Can Tho University, Can Tho City, Vietnam
Ngo Phuong Ngoc: Department of Plant Physiology-Biochemistry, College of Agriculture, Can Tho University, Can Tho City, Vietnam

1 Introduction

The Vietnamese Mekong Delta (VMD) soils were formed and developed during the Holocene Epoch [1]. According to Minderhoud et al. [2], the VMD is also located higher than 0.8 m from the sea level. Therefore, to avoid waterlogging during the rainy season, farmers had to raise bed construction for the cultivated upland crop [3]. The raised bed technique is used to reclaim lowland clay soils with shallow water tables. Unlike traditional rice-based systems, which now provide a fairly low income, raised bed systems allow the cultivation of cash crops with high added value, such as fruits or vegetables [3].

Horticulture plays a vital role in improving the farmer's livelihood as well as in reducing the poverty in this area [4]. Notably, citrus is one of the most crucial fruit crops due to its high economic value. In 2019, the citrus cultivation area in the VMD was about 35,500 ha with an estimated production of 500,000 tones, occupying about 50% of the total region and 65% of total production in Vietnam [5]. Pomelo (*Citrus grandis* Osbeck) is an important citrus crop with respect to the economy as well as nutrition. It is well known for the vitamin C, polysaccharides, and phytochemicals present in the fruit [6]. However, pomelo yield in the VMD has decreased significantly in recent years [7].

The aging of raised bed soil is considered a key factor affecting growth and citrus yield [8], because exchangeable cations (potassium, magnesium, and calcium) easily move out of the soil surface during rainfall and irrigation in the old-raised bed systems [8]. Besides, the elevation of raised beds may increase soil erosion. In recent years, soil erosion and degradation in the raised bed system are key environmental problems in the Mekong Delta of Vietnam [9], especially in citrus orchards, leading to the loss of available nutrients through runoff, which is a major driver for soil fertility reduction [10].

Soil conservation measures (cover crops and mulching) are considered the best solution to reduce sediment runoff [11]. Soil quality indicators and soil fertility were greatly enhanced due to soil conservation practices [12,13]. According to Fang [14], total nitrogen (TN) and total phosphorous

Open Access. © 2023 the author(s), published by De Gruyter. This work is licensed under the Creative Commons Attribution 4.0 International License.

reduced significantly after the implementation of soil conservation practices. In addition, soil compaction greatly decreased after using permanent cover for soil conservation [15].

Cover crops are the best way to support soil microflora growth and activity, which directly affect nutrition mineralization in soil [16]. Furthermore, cover crops may reduce the effect of raindrops splattering on the ground leading to less erosion [17]. The loss of sediment and nutrients also decreases due to cover crops, thus improving soil quality fertility, resulting in increased crop yield [18]. Pinto peanut (*Arachis pintoi*) is among the leguminous crops, which are used for ground cover in the agricultural systems, because they are easy to cultivate and have the ability of biological nitrogen fixation [19].

The utilization of mulching materials is a soil conservation measure that decreases soil erosion, enhances soil fertility, and improves crop growth and productivity [20,21]. Rice straw mulching is a vital soil management technique of covering the soil surface to regulate soil temperature and decrease soil loss [22]. Moreover, it has a positive effect on increasing the soil organic matter (SOM) and microflora diversity, resulting in an improved soil-integrated fertility index [23].

We hypothesize that in a raised bed of VMD, the exchangeable cations in the soil are susceptible to leaching due to tropical conditions, resulting in highly acidic soils, while over-exploitation also leads to low fertility. Our previous study (unpublished data) showed that farmers in VMD use rice straw, legumes, and grass to cover the topsoil of their orchards. However, there have been no studies evaluating and comparing the effectiveness of the three conservation methods on the raised bed soil. Therefore, this study aimed to evaluate how conservation practices (rice straw mulch, leguminous, and non-leguminous cover crops) are used to improve soil acidity and nutrients as well as pomelo yield.

2 Materials and methods

2.1 Study site, soil, and climate

The field experiment was conducted in a pomelo orchard from January 2018 to January 2021. The pomelo orchard is located in Phu Huu commune, Chau Thanh district, Hau Giang province, Vietnam (9°54′30.3″N, 105°51′06.7″E).

The initial soil physicochemical properties, before conducting an experiment, are presented in Table 1.

Table 1: Initial soil quality before the experiment

Property	Value	
	0–20 cm	20–40 cm
pH_{H_2O} (1:2.5)	5.00	5.22
$P_{Bray\text{-}2}$ (mg P kg^{-1})	22.5	24.6
TP (%)	0.12	0.10
TN (%)	0.15	0.12
SOM (%)	1.46	1.28
Sand (%)	1.50	2.20
Silt (%)	52.0	49.5
Clay (%)	46.5	48.3
Soil textural class	Silty clay	Silty clay

Soil analyses indicated that the topsoil (0–20 cm) and subsoil (20–40 cm) layers were acidic (pH = 5.0–5.22), medium in available phosphorus (AP) (22.5–24.6 mg P kg^{-1}), low in TN (0.12–0.15%), low in SOM (1.28–1.46%), low in total phosphorus (TP) (0.10–0.12%), and silty clay in texture (46.5–48.0% clay, 1.50–2.20% sand, and 49.5–52.0% silt).

The average monthly rainfall from 2019 to 2021 at the study site was 175 mm, of which September usually had the highest rainfall (470 mm) and March had the lowest (10 mm). The meteorological data of the study location were presented in detail in our previous study [24].

2.2 Experimental design

The field trial was conducted in a randomized complete block design with four replications using the following groups: (1) control (no-cover crop); (2) cover crop by grass (CCG); (3) mulching with rice straw (MRS); and (4) cover crop by pinto peanut (CCP). In the present study, a “Da Xanh” 5-year-old pomelo orchard was used for trial. The fruit diameter of “Da Xanh” pomelo is from 20 to 25 cm, its average weight is 1.0–2.0 kg, and its skin is green. The distance between pomelo plants was 4.0 m × 4.5 m. The total area used for the experiment was about 1,500 m^2. All trees in the present study took carefully with conventional pesticides for pests and disease control as well as treated with chemical fertilizers. The fertilization rates were determined based on the recommendations of Can Tho University, Vietnam. Each tree received 800 g N, 500 g P, and 700 g K annually. All treatments followed the no-till practice.

The herbicide NIPHOSATE 480SL, used in the control plots, was a commercial product of Nicotex Co., Ltd., Vietnam. The concentration of glyphosate IPA salt was 480 g per liter. The herbicide was applied at a dose of

2,500 ml ha^{-1}. It was sprayed when the weeds grew to 8–10 cm (approximately 5 leaves). We used a hand sprayer (Mitsuyama TL-767) for the herbicide.

In the CCG treatment, Asiatic dayflower (*Commelina communis*) was used as cover crop. Asiatic dayflower was planted by cutting the seedling into cuttings of approximately 20 cm and spread evenly on the orchard surface and watered regularly. After a month, these grass cuttings grew roots and when 30 cm tall, the tops were cut (leaving only the base about 10 cm long) using Honda Grass Cutter GX35.

Pinto peanut was grown during January and July each year in CCP plots. Pinto peanut cuttings were prepared when pinto peanuts are in the cake stage, when leaves begin to turn yellowish, about 30–40 cm long. Pinto peanut was cultivated in a row; each cluster consisting of 2–3 cuttings spaced 10–15 cm apart. The cuttings were filled with soil thoroughly, pressed firmly for fast rooting, and irrigated lightly for enough moisture.

Rice straw was mulched two times per year in October and March in MRS treatment. A 2–2.5 cm layer of rice straw mulch was spread under the pomelo canopy, keeping the mulch 50–60 cm away from the trunks. The mulch was spread out far enough from the base of the plant to cover the entire root system. The total rice straw used for the experiment was 5.5 t ha^{-1} $year^{-1}$.

2.3 Soil sampling and analysis

To determine the chemical properties of the soil, soil samples were collected at the same time at the pomelo harvesting stage (January 2019, 2020, and 2021). In each treatment, a soil auger (diameter 3 cm) was used to collect five soil cores from the depths of 0–20 and 20–40 cm. Soil samples were collected around the canopy of trees. The soil was divided into subsamples of about 500 g after samples from the same depth were blended into one composite sample per depth. All soil samples were air-dried, crushed, and sieved using a 2 mm sieve to make samples suitable for laboratory analysis [25].

Soil pH in the 1:2.5 solution (soil:water) was determined using a digital pH meter [26]. Soil organic carbon was determined using the wet-oxidation method described by Walkley and Black [27]. Total N was determined using the semi-micro Kjeldahl method [28]. The levels of total P present in the soil samples were estimated using the ammonium phosphomolybdate method [29]. The available P was determined using the Bray-2 method [30].

2.4 Yield component and fruit productivity

The total number of fruits per tree was counted during each treatment at the harvest stage. After that, weight of all fruit per trees were measured by “Nhon Hoa” scale. The mean weight of fruit was determined based on the total weight (kg) of fruits per tree divided by the total number of fruits. Fruit yield (FY) (t ha^{-1}) was estimated using the number of fruits per tree multiplied by the mean weight of fruit and then by the plant density. In the current study, the pomelo density was estimated to be 555 trees ha^{-1}.

2.5 Statistical analysis

SPSS software (version 20.0) was used for data analysis. Variance analysis was used to compare the differences between means among the treatments using the Duncan test with statistical levels at 5 and 1%. The relationships between soil properties were determined by Pearson’s correlation coefficient.

3 Results

3.1 Impact of soil conservation practices on soil properties

3.1.1 Surface layer (0–20 cm)

Soil acidity and fertility in the topsoil layer significantly improved after implementing soil conservation measures during the 3-year experiment. In particular, MRS and CCP enhanced soil pH by about 0.52 and 0.74 units, respectively (Table 2) compared to the initial soil pH (Table 1). Soil pH also increased in the CCG treatment, but it was lower when compared with CCP and MRS. Moreover, the nutrients (TN, TP, and AP) in soil conservation practices were greater compared with no cover crop. The average TN, TP, and AP concentrations in MRS and CCP increased by 0.11, 0.11, and 0.018% respectively, when compared with the control treatment. Similarly, SOM was significantly ameliorated by the use of soil conservation practices. Although CCG improved soil fertility, the effect was lower when compared with MRS and CCP. Hence, cover crop by legume and MRS were the best measures for increasing the soil quality indicators to a depth of 0–20 cm.

Table 2: Influence of soil conservation measures on soil chemical properties in the topsoil layer (0–20 cm)

Years	Treatments	pH_{H_2O} (1:2.5)	TN (%)	TP (%)	SOM (%)	AP (mg kg^{-1})
2019	Control	$5.08^c \pm 0.04$	$0.14^b \pm 0.04$	$0.13^c \pm 0.03$	$1.41^c \pm 0.04$	$22.8^c \pm 0.96$
	CCG	$5.25^b \pm 0.08$	$0.18^a \pm 0.02$	$0.19^b \pm 0.03$	$1.53^b \pm 0.07$	$32.0^b \pm 2.94$
	MRS	$5.36^a \pm 0.07$	$0.22^a \pm 0.03$	$0.21^{ab} \pm 0.01$	$1.65^a \pm 0.06$	$36.7^a \pm 2.29$
	CCP	$5.38^a \pm 0.16$	$0.22^a \pm 0.03$	$0.23^a \pm 0.02$	$1.64^a \pm 0.06$	$36.1^a \pm 1.80$
	P_{value}	**	**	*	**	**
2020	Control	$5.04^c \pm 0.04$	$0.13^c \pm 0.02$	$0.15^b \pm 0.01$	$1.45^c \pm 0.04$	$21.5^c \pm 0.73$
	CCG	$5.33^b \pm 0.08$	$0.20^b \pm 0.02$	$0.22^a \pm 0.02$	$1.58^b \pm 0.03$	$34.6^b \pm 0.86$
	MRS	$5.48^a \pm 0.11$	$0.24^a \pm 0.02$	$0.24^a \pm 0.03$	$1.84^a \pm 0.08$	$40.5^a \pm 1.17$
	CCP	$5.53^a \pm 0.20$	$0.25^a \pm 0.02$	$0.24^a \pm 0.02$	$1.83^a \pm 0.06$	$42.1^a \pm 2.45$
	P_{value}	**	**	**	**	**
2021	Control	$4.97^c \pm 0.06$	$0.14^c \pm 0.02$	$0.15^c \pm 0.01$	$1.46^c \pm 0.05$	$21.8^c \pm 1.10$
	CCG	$5.37^b \pm 0.14$	$0.22^b \pm 0.02$	$0.25^b \pm 0.03$	$1.71^b \pm 0.03$	$38.9^b \pm 0.98$
	MRS	$5.52^a \pm 0.04$	$0.29^a \pm 0.02$	$0.30^a \pm 0.02$	$2.00^a \pm 0.13$	$43.4^a \pm 2.26$
	CCP	$5.74^a \pm 0.13$	$0.32^a \pm 0.03$	$0.32^a \pm 0.02$	$2.03^a \pm 0.06$	$43.0^a \pm 3.15$
	P_{value}	**	**	**	**	**

The different letters indicate the significant differences among treatments at $P < 0.05$ (*) and $P < 0.01$ (**). CCG — cover crop by grass; MRS — mulching with rice straw; CCP — cover crop by pinto peanut.

3.1.2 Subsurface layer (20–40 cm)

Table 3 shows the soil chemical properties at a depth of 20–40 cm in a pomelo orchard under different soil conservation practices. Soil pH, soil nutrients (TN, TP, and AP), and SOM content did not improve by the CCG, MRS, or CCP. The average pH, TN, TP, SOM, and AP values in the subsoil layer were 5.26, 0.14, 0.13, 1.27, and 0.025%, respectively. Moreover, soil fertility properties in the depth of 20–40 cm did not affect by conservation practices during 3 years (2019, 2020, and 2021) of the study.

3.2 Effect of soil conservation measures on yield of pomelo

The effects of conservation measures on yield component and productivity of fruit are presented in Table 4. The number of fruits per tree in the treatments with conservation practices CCP and MRS between 2019 and 2021 was significantly higher than those without it. The number of fruits tended to increase from 2019 to 2021 in all treatments. An increasing number of fruits per tree resulted in improving the FY. The average productivity of pomelo

Table 3: Effect of soil conservation practices on soil quality in the subsoil layer (20–40 cm)

Years	Treatments	pH_{H_2O} (1:2.5)	TN (%)	TP (%)	SOM (%)	AP (mg kg^{-1})
2019	Control	5.25 ± 0.05	0.13 ± 0.03	0.11 ± 0.01	1.25 ± 0.11	25.0 ± 1.78
	CCG	5.30 ± 0.05	0.14 ± 0.02	0.12 ± 0.03	1.25 ± 0.21	26.1 ± 1.46
	MRS	5.30 ± 0.12	0.14 ± 0.03	0.14 ± 0.03	1.24 ± 0.10	24.8 ± 3.12
	CCP	5.27 ± 0.18	0.13 ± 0.02	0.12 ± 0.03	1.26 ± 0.09	24.3 ± 2.57
	P_{value}	ns	ns	ns	ns	ns
2020	Control	5.25 ± 0.05	0.13 ± 0.03	0.12 ± 0.01	1.29 ± 0.03	24.8 ± 1.35
	CCG	5.29 ± 0.11	0.14 ± 0.02	0.14 ± 0.02	1.27 ± 0.15	25.0 ± 2.89
	MRS	5.25 ± 0.16	0.16 ± 0.03	0.15 ± 0.04	1.30 ± 0.11	25.3 ± 3.23
	CCP	5.28 ± 0.15	0.15 ± 0.04	0.15 ± 0.02	1.26 ± 0.07	24.6 ± 2.01
	P_{value}	ns	ns	ns	ns	ns
2021	Control	5.20 ± 0.08	0.14 ± 0.03	0.13 ± 0.03	1.28 ± 0.10	24.3 ± 1.02
	CCG	5.22 ± 0.09	0.14 ± 0.03	0.15 ± 0.03	1.31 ± 0.11	24.5 ± 2.87
	MRS	5.25 ± 0.07	0.15 ± 0.02	0.15 ± 0.04	1.25 ± 0.12	26.0 ± 0.93
	CCP	5.32 ± 0.12	0.17 ± 0.05	0.14 ± 0.03	1.30 ± 0.12	26.0 ± 1.21
	P_{value}	ns	ns	ns	ns	ns

ns — not significant; CCG — cover crop by grass; MRS — mulching with rice straw; CCP — cover crop by pinto peanut.

Table 4: Yield component and fruit productivity as affected by soil conservation measures

Years	Treatments	Number of fruits per tree	Mean weight of fruit (kg)	Fruit yield (t ha^{-1})	Compared with the control treatment	
					t ha^{-1}	%
2019	Control	$25.5^b \pm 1.05$	1.52 ± 0.07	$21.5^b \pm 1.64$	—	—
	CCG	$27.4^b \pm 0.81$	1.50 ± 0.08	$22.8^b \pm 1.00$	1.31	6.10
	MRS	$31.7^a \pm 1.94$	1.47 ± 0.07	$25.9^a \pm 2.39$	4.45	20.7
	CCP	$31.4^a \pm 1.12$	1.48 ± 0.09	$25.8^a \pm 2.07$	4.35	20.3
	P_{value}	**	ns	*		
2020	Control	$30.0^c \pm 1.92$	1.49 ± 0.08	$24.8^b \pm 1.31$	—	—
	CCG	$33.9^b \pm 1.31$	1.43 ± 0.10	$26.8^b \pm 1.17$	2.00	8.06
	MRS	$36.5^a \pm 0.44$	1.48 ± 0.08	$29.9^a \pm 1.34$	5.14	20.7
	CCP	$36.9^a \pm 0.97$	1.46 ± 0.07	$29.8^a \pm 2.02$	5.05	20.4
	P_{value}	**	ns	**		
2021	Control	$34.3^c \pm 0.88$	1.47 ± 0.07	$27.8^b \pm 0.79$	—	—
	CCG	$37.4^b \pm 1.33$	1.46 ± 0.11	$30.3^{ab} \pm 3.20$	2.41	8.67
	MRS	$40.8^a \pm 1.47$	1.47 ± 0.08	$33.3^a \pm 2.77$	5.46	19.6
	CCP	$41.2^a \pm 2.26$	1.47 ± 0.04	$33.5^a \pm 2.43$	5.69	20.4
	P_{value}	**	ns	*		

The different letters indicate the significant differences among treatments at $P < 0.05$ (*) and $P < 0.01$ (**); ns — not significant. CCG — cover crop by grass; MRS — mulching with rice straw; CCP — cover crop by pinto peanut.

increased to 5.0 t ha^{-1} in the CCP and MRS in the 3 consecutive years of research. CCG also improved the FY of pomelo about 2.0 t ha^{-1}. However, there was no statistically significant difference in pomelo productivity between the control and CCG. Table 4 indicates that there was no difference in the weight of fruit in the 3 consecutive years of research, with the average being 1.47 kg per fruit.

3.3 Matrix correlation between soil chemical properties and FY

3.3.1 Depth of 0–20 cm

There was a significantly positive correlation between soil chemical properties (pH, TN, TP, SOM, and AP) and the number of fruits per tree (Table 5), with the correlation coefficient of r = 0.65, 0.74, 0.76, 0.80, and 0.70, respectively. A positive correlation was recorded between soil quality and FY, including pH and FY (r = 0.63), TN and FY (r = 0.69), TP and FY (r = 0.71), SOM and FY (r = 0.74), and AP and FY (r = 0.65). Meanwhile, there was no significant correlation between soil fertility parameters and an average weight of fruit.

Highly positive correlation coefficients were observed between pH and TN (r = 0.80), pH and TP (r = 0.82), pH and SOM (r = 0.83), and pH and AP (r = 0.85). Similar to pH, there was a significant correlation between TN and TP, SOM, and AP (r = 0.86, 0.86, and 0.87, respectively). The content of SOM was positively correlated to the concentration of AP (r = 0.87). However, our study did not find any significant relationships between the mean

Table 5: Pearson correlation matrix between the soil quality properties of topsoil layer and fruit yield (n = 48)

	pH	TN	TP	SOM	AP	NF	WF	FY
pH	1	0.80**	0.82**	0.83**	0.85**	0.65**	−0.05	0.63**
TN		1	0.86**	0.86**	0.87**	0.74**	−0.15	0.69**
TP			1	0.86**	0.87**	0.76**	−0.15	0.71**
SOM				1	0.85**	0.80**	−0.15	0.74**
AP					1	0.70**	−0.13	0.65**
NF						1	−0.17	0.94**
WF							1	0.17
FY								1

** indicates significant difference at $P < 0.01$. pH, soil-to-water ratio (1:2.5); TN — total nitrogen; TP — total phosphorus; SOM — soil organic matter; AP — available phosphorus; NF — number of fruit per tree; WF — mean weight of fruit; FY — fruit yield.

weight of fruit and soil chemical properties as well as FY (Table 5).

3.3.2 Depth of 20–40 cm

Table 6 shows the relationship between soil quality in the subsoil layer (20–40 cm) and yield component and FY. There was no significant correlation between soil pH and soil nutrients (TN, TP, SOM, and AP). Soil pH was also not significantly related to NF (number of fruits per tree), WF (mean weight of fruit), and FY. There was no significant correlation between TN and other variables, except for TP ($r = 0.37$). A positive correlation was recorded between TP and NF ($r = 0.40$) and TP and FY ($r = 0.41$). The content of SOM and AP was not correlated with other soil chemical parameters as well as productivity of fruit. Similar to the Pearson correlation matrix of the topsoil layer, there was no relation between the mean weight of fruit and soil chemical properties at the depth of 20–40 cm (Table 6).

4 Discussion

According to Noland et al. [31] and Cruz et al. [32], soil conservation measures not only enhanced soil physico-chemical properties but also improved crop yield; we discovered that there was an improvement in SOM and soil nutrients (TN, TP, and AP) in pomelo plots with conservation practices at a depth of 0–20 cm (Table 2). The amount of SOM, TN, TP, and AP in treatments (MRS and CCP) is the highest compared with CCG and control.

Table 6: Pearson correlation matrix between the soil fertility properties of subsoil layer and fruit yield ($n = 48$)

	pH	TN	TP	SOM	AP	NF	WF	FY
pH	1	0.20	0.26	−0.16	0.07	−0.02	0.09	0.01
TN		1	0.37*	−0.10	0.22	0.26	0.05	0.28
TP			1	0.14	−0.07	0.40**	0.01	0.41**
SOM				1	0.34	0.08	0.08	0.10
AP					1	0.12	0.05	0.13
NF						1	−0.17	0.94**
WF							1	0.17
FY								1

* and ** indicate significant difference at $P < 0.05$ and $P < 0.01$, respectively. pH – soil-to-water ratio (1:2.5); TN – total nitrogen; TP – total phosphorus; SOM – soil organic matter; AP – available phosphorus; NF – number of fruits per tree; WF – mean weight of fruit; FY – fruit yield.

In addition, soil acidity declined greatly after MRS and CCP treatments.

Several studies have indicated that cover cropping and mulching significantly increased SOM and soil nutrient concentration [32–34]. According to Kogel-Knabner [35], plant biomass (leave, root, and stem) is the major parent material for SOM formation. In agricultural systems, leguminous crops contribute positively to improving the natural carbon pool in the soil [36]. Through various ways including contributing plant biomass and dead roots and nodules of legume [37], legumes can increase SOM. As well as this SOM can improve soil acidity [36], these materials contribute to the increase of soil nutrients. Cover crops with legumes enhance soil chemical P availability and adjust the pH [37]. Reduction of soil acidity is considered a helpful factor to promote soil microorganism activity, resulting in increased nutrient cycling processes as well as nutrient mineralization [38,39].

Previous studies have indicated that rice straw mulching utilization greatly increased soil organic carbon [40–42]. Rice straw is a rich carbon source that has several macronutrients (N, P, and K) essential for crop development. The TN, TP, and AP contents rose significantly by rice straw mulching utilization as indicated by the results. Improvement of soil nutrients and SOM may be due to the relationship between nutrients and carbon content in rice straw. In our previous study, the average concentrations of N, P, and K in rice straw ($n = 120$) that was cultivated in VMD were 6.20, 2.70, and 16.7 g kg^{-1}, respectively [43]. According to Hung et al. [44], rice straw contains carbon content ranging between 11.1 and 16.7%. Mulched rice straw increased soil pH by about 0.5 units in a 3-year field trial (Table 2). Samuel et al. [45] found that MRS increased pH about 1.6 unit when compared with the control treatment. The results of the study are in line with those of Yan et al. [46] and Fu et al. [47], stating that MRS enhances the soil health and available soil nutrients.

However, the use of soil conservation measures did not improve soil chemical properties at the subsoil layer (Table 3). This might have been due to the no-till system adopted in the present research decreasing transportation and accumulation of SOM and soil nutrients to the deeper layer (20–40 cm). Besides, the short duration experiment may be a reason leading to the soil quality not being affected even after conservation measures. This result is in agreement with the study conducted by Zhou et al. [40], reporting that soil fertility was not affected by rice straw mulching at a depth of 20–30 cm. Another study revealed that cover crop did not improve soil organic carbon in the subsoil layer [48].

There was a correlation between soil chemical properties in the topsoil layer and numbers of fruit per tree and FY (Table 5). These results might be due to the decomposition of green manure (biomass and root of legume and straw), which provide plenty of nutrients required for pomelo growth as well as increase the fruit set ratio, that led to an increased number of fruits per tree and pomelo productivity. There was a strong correlation between SOM, TN, and AP and citrus yield, considered as key factors for determining and assessing soil health in citrus orchards [49,50].

In the current study, treating with straw mulching and CCP markedly enhanced the effective number of fruits per tree (Table 4). As a result, the yield of fruit increased significantly when compared with the control treatment. Pomelo yield had a strong relationship with the numbers of fruit (Tables 5 and 6, r = 0.94). Several studies have reported that legume cover crops and mulching with straw substantially enhanced FY [51–53]. According to Acharya et al. [54], oat as a cover crop increased sorghum grain yield from 33 to 97%, when compared with no cover crop treatment. Another study also indicated that legume cover crop significantly improved wheat yield [55].

MRS in the current study increased FY to 20% compared with the control. The study agreed with the results reported by Noor et al. [56]; they concluded that maize yield and dry biomass increased by 18 and 20%, respectively, after being treated with straw mulching. A similar result also showed that straw mulching increased maize yield to 12.4% when compared with no mulching [57]. According to Hadaro et al. [58] and Retta et al. [59], soil conservation practices utilization positively affected soil fertility and soil nutrients availability, resulting in improved soil productivity, which directly influences the crop yield. The results were in agreement with the reports of Giacalone et al. [53], Scavo et al. [60], and Webber et al. [61]. They demonstrated that cover crop and mulching increased soil fertility and fruit crops compared with the control.

5 Conclusion

The results indicated that the use of soil conservation practices (cover crop by legume and MRS) improved soil quality in the surface layer, resulting in increased pomelo productivity up to 20% compared with the control treatment. However, soil fertility in the subsurface layer did not improve after the use of conservation measures in the 3 years of consecutive experiments. A positive correlation between soil quality indicators (SOM, TN, and AP) and FY was also noted. Therefore, they are considered factors improving pomelo productivity. These results are useful for the improvement of soil health as well as enhancing FY in citrus orchards cultivated in soils of the Mekong Delta, Vietnam. Thus, we recommend using cover crops with legumes or rice straw as the best option to increase soil fertility and FY. Further research is needed on the role of soil conservation practices in reducing soil compaction and nutrient loss under raised bed conditions.

Funding information: The authors state that no funding is involved.

Author contributions: N.N.H. and T.V.D. conceptualized and designed the experiment; L.V.D. conducted the experiments, collected, and analyzed samples; L.V.D., N.P.N., and T.V.D. analyzed the data and wrote the article – original draft; T.V.D., N.N.H., L.V.D., and N.P.N. reviewed, edited, and approved the final article. All authors have read and agreed to the published version of the article.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: All data generated or analyzed during this study are included in this published article

References

[1] Nguyen VL, Ta TKO, Tateishi M, Kobayashi I, Saito Y. Holocene evolutionof the Mekong river delta, Vietnam. J Geol Soc Jpn. 2021;111(11):XXI–I.

[2] Minderhoud PSJ, Coumou L, Erkens G, Middelkoop H, Stouthamer E. Mekong delta much lower than previously assumed in sea-level rise impact assessments. Nat Commun. 2019;10:3847. doi: 10.1038/s41467-019-11602-1.

[3] Can Tho University and IRD (Institut de Recherche pour le Développement). Agricultural diversification in the mekong river delta: raised beds management, marketing, and dynamics. DELTA Project - Mekong Delta: Research report n°3, Can Tho, Vietnam; 2001. p. 190.

[4] Thanh HX, Phuong DTT, Huong NT, Tacoli C. Urbanization and rural development in Vietnam's Mekong Delta Livelihood transformations in three fruit-growing settlements. Working Paper Series on Rural-Urban Interactions and Livelihood Strategies 2008; working paper 14.

[5] General Statistics Office. Statistical Yearbook of Viet Nam in 2019. Hanoi, Vietnam: Statistical Publishing House. 2020, p. 1036. ISBN 9786047515530.

[6] Matheyambath AC, Padmanabhan P, Paliyath G. Citrus fruits. In: Caballero B, Finglas PM, Toldrá F,editors. Encyclopedia of food and health. Cambridge, MA, USA: Academic Press; 2016. p. 136–140. doi: 10.1016/b978-0-12-384947-2.00165-3.

[7] Kieu NTT, Hung NN. Investigation of cultivation situation of Nam Roi pomelo grown in raised beds of alluvial soil in Hau Giang province. J Vietnam Agric Sci Technol. 2019;12(109):164–5.
[8] Quang PV, Guong VT. Chemical properties during different development stages of fruit orchards in the mekong delta (Vietnam). Agric Sci. 2011;2:375–81. doi: 10.4236/as.2011.23049.
[9] Mien TX, Khoi DD, Loc LX. Assessing potential soil degradation of Hau Giang province. Vietnam Sci Tech J Agri Rural Dev. 2018;21:30–7.
[10] Bashagaluke JB, Logah V, Opoku A, Sarkodie-Addo J, Quansah C. Soil nutrient loss through erosion: Impact of different cropping systems and soil amendments in Ghana. PLoS ONE. 2018;13(12):e0208250. doi: 10.1371/journal.pone.0208250.
[11] Barneveld RJ, van der Zee SE, Greipsland I, Kværnø SH, Stolte J. Prioritising areas for soil conservation measures in small agricultural catchments in Norway, using a connectivity index. Geoderma. 2019;340:325–36. doi: 10.1016/j.geoderma.2019.01.017.
[12] Xu QX, Wang TW, Cai CF, Li ZX, Shi ZH. Effects of soil conservation on soil properties of citrus orchards in the three-Gorges area, China. Land Degrad Dev. 2012;23(1):34–42. doi: 10.1002/ldr.1045.
[13] Belayneh M, Yirgu T, Tsegaye D. Effects of soil and water conservation practices on soil physicochemical properties in Gumara watershed, Upper Blue Nile Basin, Ethiopia. Ecol Process. 2019;8:36. doi: 10.1186/s13717-019-0188-2.
[14] Fang H. The effect of soil conservation measures on runoff, soil erosion, TN, and TP losses based on experimental runoff plots in Northern China. Water. 2021;13:2334. doi: 10.3390/w13172334.
[15] Capello G, Biddoccu M, Cavallo E. Permanent cover for soil and water conservation in mechanized vineyards: A study case in Piedmont, NW Italy. Ital J Agron. 2020;15(4):323–31. doi: 10.4081/ija.2020.1763.
[16] Adetunjia AT, Ncubeb B, Mulidzic R, Lewud FB. Management impact and benefit of cover crops on soil quality: A review. Soil Tillage Res. 2020;204:104717. doi: 10.1016/j.still.2020.104717.
[17] Sharma P, Singh A, Kahlon CS, Brar AS, Grover KK, Dia M, et al. The role of cover crops towards sustainable soil health and agriculture – A review paper. Am J Plant Sci. 2018;9(9):1935–51. doi: 10.4236/ajps.2018.99140.
[18] Kocira A, Staniak M, Tomaszewska M, Kornas R, Cymerman J, Panasiewicz K, et al. Legume cover crops as one of the elements of strategic weed management and soil quality improvement. A review. Agriculture. 2020;10(9):394. doi: 10.3390/agriculture10090394.
[19] Rose TJ, Kearney LJ, Morris S, Zwieten LV, Erler DV. Pinto peanut cover crop nitrogen contributions and potential to mitigate nitrous oxide emissions in subtropical coffee plantations. Sci Total Env. 2019;656:108–17. doi: 10.1016/j.scitotenv.2018.11.291.
[20] Qin W, Hu C, Oenema O. Soil mulching significantly enhances yields and water and nitrogen use efficiencies of maize and wheat: a meta-analysis. Sci Rep. 2015;5:16210. doi: 10.1038/srep16210.
[21] Singh VP, Jat R, Kumar V, Singh R. Mulches and their impact on floor management and performance of fruit crops: a review. Curr J Appl Sci Technol. 2020;39(36):62–78. doi: 10.9734/cjast/2020/v39i3631074.
[22] Liu Y, Wang J, Liu D, Li Z, Zhang G, Tao Y, et al. Straw mulching reduces the harmful effects of extreme hydrological and temperature conditions in citrus orchards. PLoS ONE. 2014;9(1):e87094. doi: 10.1371/journal.pone.0087094.
[23] Cao H, Ji M, Song J, Xun M, Fan W, Yang H. Rice-straw mat mulching improves the soil integrated fertility index of apple orchards on cinnamon soil and fluvo-aquic soil. Sci Horticulturae. 2021;278:109837. doi: 10.1016/j.scienta.2020.109837.
[24] Dung TV, Ngoc NP, Dang LV, Hung NN. Impact of cover crop and mulching on soil physical properties and soil nutrients in a citrus orchard. PeerJ. 2022;10:e14170. doi: 10.7717/peerj.14170.
[25] Houba VJG, Vanderlee JJ, Novozamsky I. Soil analysis procedures (soil and plant analysis, part 5B), a series of syllabi. 6th edn. Department of Soil Science and Plant Nutrition, Wageningen Agricultural University, The Netherlands; 1995.
[26] McLean EO. Soil pH and lime requirement. In: Page AL, Miller RH, Keeney DR, editors. Methods of soil analysis, part 2, chemical and microbiological properties. Madison: American Society of Agronomy Inc.; 1982. p. 199–224.
[27] Walkley AJ, Black IA. Estimation of soil organic carbon by the chromic acid titration method. Soil Sci. 1934;37:29–38.
[28] Sáez-Plaza P, Navas MJ, Wybraniec S, Michałowski T, Asuero AG. An overview of the Kjeldahl method of nitrogen determination. Part II. Sample preparation, working scale, instrumental finish, and quality control. Crit Rev Anal Chem. 2013;43(4):224–72. doi: 10.1080/10408347.2012.751787.
[29] Nagul EA. The molybdenum blue reaction for the determination of orthophosphate revisited: Opening the black box. Anal Chim Acta. 2015;890:60–82. doi: 10.1016/j.aca.2015.07.030.
[30] Bray RH, Kurtz LT. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 1945;59:39–45.
[31] Noland RL, Wells MS, Sheaffer CC, Baker JM, Martinson KL, Coulter JA. Establishment and function of cover crops interseeded into corn. Crop Sci. 2018;58:863–73. doi: 10.2135/cropsci2017.06.0375.
[32] Cruz AF, Pires MC, Nascimento LKB, Ramos MLG, Oliveira SA, Bassay B, et al. Cover cropping system and mulching can shape soil microbial status in fruit orchards. Sci Agric. 2020;77(4):e20180316. doi: 10.1590/1678-992X-2018-0316.
[33] Abdalla M, Hastings A, Cheng K, Yue Q, Chadwick D, et al. A critical review of the impact of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. Glob Change Biol. 2019;25:2530–43. doi: 10.1111/gcb.14644.
[34] Sánchez-Navarro V, Zornoza R, Faz Á, Fernández JA. Comparing legumes for use in multiple cropping to enhance soil organic carbon, soil fertility, aggregates stability and vegetables yields under semi-arid conditions. Sci Horticulturae. 2019;246:835–41. doi: 10.1016/j.scienta.2018.11.065.
[35] Kogel-Knabner I. The macromolecular organic composition of plant and microbial residues as inputs to soil organic matter. Soil Biol & Biochem. 2002;34(2):139–62. doi: 10.1016/S0038-0717(01)00158-4.
[36] Yuvaraj M, Pandiyan M, Gayathri P. Role of legumes in improving soil fertility status. In: Hasanuzzaman M, editor., Legume Crops – Prospects, Production and Uses. London, UK: IntechOpen; 2020. p. 1–8. doi: 10.5772/intechopen.93247.

[37] Panda P, Panda SK, Duary S, Mahapatra A, Maitra S. Legumes in cropping system for agricultural sustainability. Indian J Nat Sci. 2021;12(69):37363–72.
[38] Webb J, Bellamy P, Loveland PJ, Goodlass G. Crop residue returns and equilibrium soil organic carbon in England and Wales. Soil Sci Soc Am J. 2003;67:928–36. doi: 10.2136/sssaj2003.9280.
[39] Bolinder MA, Crotty F, Elsen A, Frac M, Kismányoky T, Lipiec J, et al. The effect of crop residues, cover crops, manures and nitrogen fertilization on soil organic carbon changes in agroecosystems: a synthesis of reviews. Mitig Adapt Strateg Glob Change. 2020;25:929–52. doi: 10.1007/s11027-020-09916-3.
[40] Zhou Z, Zeng X, Chen K, Li Z, Guo S, Shangguan Y, et al. Long-term straw mulch effects on crop yields and soil organic carbon fractions at different depths under a no-till system on the Chengdu Plain, China. J Soils Sediment. 2019;19:2143–52. doi: 10.1007/s11368-018-02234-x.
[41] Jin Z, Shah T, Zhang L, Liu H, Peng S, Nie L. Effect of straw returning on soil organic carbon in rice–wheat rotation system: A review. Food Energy Security. 2020;9(2):e200. doi: 10.1002/fes3.200.
[42] Huang W, Wu J, Pan X, Tan X, Zeng Y, Shi Q, et al. Effects of long-term straw return on soil organic carbon fractions and enzyme activities in a double-cropped rice paddy in South China. J Integr Agric. 2021;20:236–47. doi: 10.1016/S2095-3119(20)63347-0.
[43] Dang LV, Hung NN, Phuong LN. N, P, K uptake and fertilizers requirement of rice grown in acid sulphate soils of the Mekong Delta, Vietnam. Sci Technol J Agric Rural Dev. 2018;20:11–9.
[44] Hung NV, Maguyon MC, Migo MV, Quilloy R, Balingbing C, Chivenge P, et al. Rice straw overview: availability, properties, and management practices. In: Gummert M, Hung N, Chivenge P, Douthwaite B, editors. Sustainable Rice Straw Management. Cham: Springer; 2019. p. 1–13. doi: 10.1007/978-3-030-32373-8_1.
[45] Samuel H, Hamoudu R, Nepo NJ. Effect of mulching on soil physico-chemical properties of soil under semiarid of rain fed fersiallitic soil condition in Eastern of Rwanda. Int J Progressive Sci Technol. 2021;25(1):468–75.
[46] Yan W, Jiang J, Zhu L, Zhang L, Li H, Gu J. Straw mulching improves soil fertility and productivity of water spinach (*Ipomoea Aquatica* Forsk.) under Plastic Tunnel. Commun Soil Sci Plant Anal. 2021;52(22):2958–70. doi: 10.1080/00103624.2021.1971696.
[47] Fu B, Chen L, Huang H, Qu P, Wei Z. Impacts of crop residues on soil health: A review. Env Pollut Bioavailab. 2021;33(1):164–73. doi: 10.1080/26395940.2021.1948354.
[48] Tautges NE, Chiartas JL, Gaudin ACM, O'Green AT, Herrera I, Scow KM. Deep soil inventories reveal that impacts of cover crops and compost on soil carbon sequestration differ in surface and subsurface soils. Glob Chang Biol. 2019;25(11):3753–66. doi: 10.1111/gcb.14762.
[49] Dang LV, Ngoc NP, Hung NN. Soil quality and pomelo productivity as affected by chicken manure and cow dung. Sci World J. 2021;2021:6289695. doi: 10.1155/2021/6289695.
[50] Dang LV, Ngoc NP, Hung NN. 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. Appl Environ Soil Sci. 2022;2022(109):5747699. doi: 10.1155/2022/5747699.
[51] Demir Z, Işık D. Effects of cover crops on soil hydraulic properties and yield in a persimmon orchard. Bragantia Camp. 2019;78(4):596–605. doi: 10.1590/1678-4499.2010197.
[52] Fang L, Shi X, Zhang Y, Yang Y, Zhang X, Wang X, et al. The effects of ground cover management on fruit yield and quality: A meta-analysis. Arch Agron Soil Sci. 2021;68(13):1890–902. doi: 10.1080/03650340.2021.1937607.
[53] Giacalone G, Peano C, Isocrono D, Sottile F. Are cover crops affecting the quality and sustainability of fruit production? Agriculture. 2021;11:1201. doi: 10.3390/agriculture11121201.
[54] Acharya P, Ghimire R, Cho Y, Thapa VR, Sainju UM. Soil profile carbon, nitrogen, and crop yields affected by cover crops in semiarid regions. Nutr Cycl Agroecosyst. 2022;122:191–203. doi: 10.1007/s10705-022-10198-1.
[55] Cicek H, Entz MH, Thiessen Martens JR, Bullock PR. Productivity and nitrogen benefits of late-season legume cover crops in organic wheat production. Can J Plant Sci. 2014;94:771–83. doi: 10.4141/cjps2013-130.
[56] Noor MA, Nawaz MM, Ma W, Zhao M. Wheat straw mulch improves summer maize productivity and soil properties. Ital J Agron. 2021;16:1623. doi: 10.4081/ija.2020.1623.
[57] Yang Y, Wu J, Du YL, Gao C, Pan X, Tang DWS, et al. Short- and long-term straw mulching and subsoiling affect soil water, photosynthesis, and water use of wheat and maize. Front Agron. 2021;3:708075. doi: 10.3389/fagro.2021.708075.
[58] Hadaro M, Ayele T, Datt SP, Teshome R. Soil properties as affected by soil conservation practices and soil depths in uwite watershed, Hadero Tunto District, Southern Ethiopia. Appl Environ Soil Sci. 2021;2021:5542326. doi: 10.1155/2021/5542326.
[59] Retta MA, Addis HK, Beyene TF. Impact of soil and water conservation measures and slope position on selected soil attributes at a watershed scale. Appl Environ Soil Sci. 2022;2022:9743511. doi: 10.1155/2022/9743511.
[60] Scavo A, Fontanazza S, Restuccia A, Pesce GR, Abbate C, Mauromical G. The role of cover crops in improving soil fertility and plant nutritional status in temperate climates. A review. Agron Sustain Dev. 2022;42:93. doi: 10.1007/s13593-022-00825-0.
[61] Webber SM, Bailey AP, Huxley T, Potts SG, Lukac M. Traditional and cover crop-derived mulches enhance soil ecosystem services in apple orchards. Appl Soil Ecol. 2022;178:104569. doi: 10.1016/j.apsoil.2022.104569.