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

Tran Van Dung [1], **Ngo Phuong Ngoc** [2], **Le Van Dang** [1], **Ngo Ngoc Hung** [Corresp. 1]

[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

Corresponding Author: Ngo Ngoc Hung
Email address: ngochung@ctu.edu.vn

Background: Cover crops and mulching can ameliorate soil porosity and soil nutrient availability, but their effects on soil quality in the raised bed soils are less known. **Methods:** The field experiment was conducted in a pomelo orchard from 2019 to 2021, with an area of about 1500 m^2. The treatments included control (no cover crop), non-legume cover crop (*Commelina communis*), legume cover crop (*Arachis pintoi*), and rice straw mulching (*Oryza sativa* L.). Each year, soil samples were collected at four different layers (0–10 cm, 10–20 cm, 20–30 cm, 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 cm and 10–20 cm, was reduced remarkably by mulched rice straw and cover crop by a legume, thus, increasing soil porosity. 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 improved greatly in the second and third years. **Conclusions:** Legume cover crops and straw mulch enhanced soil health by increasing soil porosity and the availability of plant nutrients. These conservation practices are best beneficial for fruit orchards cultivated in the raised bed soils.

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

College of Agriculture, Can Tho University, Can Tho, Vietnam.

Corresponding Author:

Ngo Ngoc Hung

3/2 street, Can Tho city, 94000, Vietnam

Email address: ngochung@ctu.edu.vn

Abstract

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Conclusions: Legume cover crops and straw mulch enhanced soil health by increasing soil porosity and the availability of plant nutrients. These conservation practices are best beneficial for fruit orchards cultivated in the raised bed soils.

Keywords: available nutrients, Mekong Delta, pomelo orchard, soil conservation practices, soil compaction

Introduction

The loss of nutrients in the soil is considered a key problem for decreasing soil fertility in the fruit orchards grown in the raised bed soils (*Quang, 2013*). In the Vietnamese Mekong Delta

(VMD), soil compaction and soil degradation became more severe (*Ghyselinck, 2013*). Many studies have reported that reduced soil organic matter is a primary cause of increased soil bulk density (*Hossain et al., 2015*; *Athira et al., 2019*; *Dang et al., 2021*). 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. They are a great source of income for growers (*Viet, 2015*). However, the pomelo productivity cultivated on old raised soils has been reduced due to poor soil fertility and compaction (*Quang, 2013*). *Dang et al. (2022)* reported that soil acidity in the citrus orchards increased significantly with chemical fertilizers in the long term. Moreover, farmers often are not cover ground in their fruit orchards. This reason may decrease soil moisture and biological activity.

Soil conservation practices (mulching, cover cropping, crop rotation, etc.) are measures the farmer can apply to mitigate soil degradation and soil erosion (*Ogunsola et al., 2020*; *López-Vicente et al., 2020*). Conservation agriculture reduces 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 also decrease the pressure and velocity of runoff on the topsoil (*Kumawat et al., 2020*). According to *Page et al. (2020)*, conservation practices improved the soil's organic carbon content, soil structure, available water capacity, plant nutrient availability, soil biota activity, and crop productivity.

Cover cropping is a crop utilized mainly to decrease erosion, ameliorate soil porosity, enhance soil organic matter, weed control, pests and diseases management, and increase biodiversity (*Sharma et al. 2018*; *Das et al., 2021*). According to *Van Sambeek (2017)* and *Abdalla et al. (2019)*, cover crops attract pollinators leading to improve fruit set ratio, thus increasing plant productivity. There are two key cover crops, including legumes and non-legumes (*Abdalla et al., 2019*). Cover crops by legumes increase soil nutrients, especially total and available nitrogen because they can fix nitrogen biologically (*Möller et al., 2008*; *Kaye et al., 2019*; *MacMillan et al., 2022*). Meanwhile, the non-legume cover crops increase crop biomass and decrease soil loss from the surface layer (*Rühlemann & Schmidtke, 2016*; *Romdhane et al., 2019*).

Mulches comprise organic material (straw, litter, leaves death, etc.) spread over the soil surface to control weeds and reduce runoff (*Li et al., 2021*; *Khoramizadeh et al., 2021*). Mulches will help increase soil organic carbon, resulting in decreased soil compaction (*Iqbal et al., 2020*). The decomposition process of organic mulches releases many nutrients (*Ranjbar & Jalali, 2012*). These nutrients are in a form that is useful to plants (*Cattanio et al., 2008*) and might increase the uptake, improving crop productivity (*Singh et al., 2021*). Mulching also affects soil microorganism activity and the abundance of soil organisms (*Rodrigues da Silva et al., 2022*).

A previous study indicated that covering crops with legumes and mulched rice straw significantly increased soil organic carbon, total nitrogen, availability, and phosphorus (*Dung et al., 2022*). However, the effects of soil conservation practices on soil compaction and available nutrients (Ca, Mg, K, Cu, Fe, Zn, and Mn) did not report. Hence, this study aimed to evaluate soil conservation measures on soil bulk density, soil porosity, and soil nutrients in a pomelo orchard cultivated on alluvial soil of the Mekong Delta, Vietnam.

Materials & 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 WRB (2015).

The average annual rainfall from 2019 to 2021 at the study site was 1750 mm, with September and March usually receiving the highest (470 mm) and lowest (10 mm) rainfalls, respectively. Table 1 shows the initial physical and chemical properties.

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), non-legume cover crop (NLC), legume cover crop (LCC), and rice straw 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^{-1} yr^{-1}. At the beginning study, the pomelo plants were 3.0–3.4 m tall, and the canopy diameter was 2.8–3.1 m. All treatments accepted the no-till practice. Chemical fertilizers are applied in the same amount as pests and disease control (*Dung et al., 2022*).

Nicotex Co., Ltd., Vietnam, a commercial product, was used for weed management in the control plots. The herbicide with commercial named NIPHOSATE 480SL contains 480-gram 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 are controlled when they have about 8–10 cm tall (about 5–6 leaves).

Asiatic dayflower (*Commelina communis*) is utilized for NLC plots. Asiatic dayflower was cultivated by cuttings that were about 20 cm long. When the Asiatic dayflower has above 30 cm high, cutting the tops about 20 cm by 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.

Mulched rice straw was carried out twice per year (October and March). Rice straw was spread thickness a 2–2.5 cm around pomelo canopy. Spread the mulch out far enough from the base of the plant that it will cover the entire root system. The total rice straw used for the experiment was 5.5 t ha^{-1} yr^{-1}.

Soil collection and analysis

Soil physical

In order to determine soil bulk density (BD), soil sample rings of Eijkelkamp company were used to take the soil during 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 ratio of the mass of the dry soil per unit volume of the soil cores (*Mtyobile et al., 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:

$$\text{Total porosity } (\%) = 1 - \frac{(\text{Soil bulk density})}{2.65} \times 100 \ (1)$$

Soil chemical

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 zigzag 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 about 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 soils' 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).

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 $p < 0.01$ (**).

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 in three years of experiments. 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 higher than in the control and NLC plots. Using of NLC positively affected BD in the topsoil (0–10 cm) in 2020 and 2021 compared with the control treatment (Figure 1a). Similarly, a 10–20 cm BD was reduced by covering crops with pinto peanuts and mulching with rice straw (Figure 1b). Meanwhile, Figures 1a & b 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 utilization increased greatly soil porosity at two depths, 0–10 cm and 10–20 cm (Figure 2). Like BD, cover crop by non-legume or legume 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 mulched rice straw) enhanced soil porosity by about 5% and 3% at 0–10 and 10–20 cm (Figures 2a & b) after three 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 (Figures 2c & d).

Influence of soil conservation practices on soil nutrients

Topsoil layer (0–10 cm)

The concentrations of macroelements (Ca, K, and Mg) in soil did not improve in the first year when applying conservation practices, but 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 $cmol_c\ kg^{-1}$ in 2020 and 2021 compared with the control, respectively, and those in the LCC treatment were 0.29 and 0.38 $cmol_c\ kg^{-1}$. Likewise, the K concentration in RSM and LCC was enhanced by about 0.11 and 0.12 $cmol_c\ kg^{-1}$ in three years of experiments. By contrast, 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, in 2020 and 2021, the concentrations of Fe and Zn elevated greatly due to covering the crops with legumes and mulched with rice straw. 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 $cmol_c\ kg^{-1}$ compared with control in 2020 and 2021, respectively. Exchangeable Ca was significantly higher in RSM than in control. The exchangeable K^+ was greatly 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 about 1.5-fold greater in LCC and RSM than in no conservation treatment in two years (Table 3). Similarly, RSM and LCC enhanced available Zn by more than 10 mg kg^{-1} compared with control in the experiment of three years. In the current research, the concentrations of Mg, Cu, and Mn were not affected by soil conservation practices.

A depth of 20–30 cm

In a three-year study, conservation agriculture 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 in 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, respectively.

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 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 positive significant 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 (*Nawaz et al., 2013*). According to *Shaheb et al. (2021)*, soil conservation measures decreased soil compaction, resulting in increased root development and length. *Hakl (2007)* indicated that soil compaction reduced root biomass significantly. The reason might be decreased crop growth and yield because the plants did not uptake nutrients, preventing root growth (*Parlak & Parlak, 2011*). In this study, cover crop with pinto peanut and mulched rice straw reduced BD at depths of 0–10 cm and 10–20 cm about 0.10 g cm^{-3} and 0.08 g cm^{-3} in three years consecutively trial, respectively (Figure 1a & b). The current research is consistent with *Mondal et al. (2019)*, who reported that using conservation agriculture practices contributed to significantly reduced soil compaction. Similar results have also been reported by *Degu et al. (2019)*, *Ceylan (2020)*, and *Belayneh et al. (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 (Figure 2). Many studies have indicated a strong negative correlation between BD and total porosity (*Gebert et al., 2009*; *Kakaire et al., 2015*). In the present work, the use of cover crop and mulching decreased greatly BD. This reason may be reduced soil compaction, which improved total porosity. Moreover, our previous study showed that soil organic matter increased remarkably when applying cover by pinto peanut and mulched straw (*Dung et al., 2022*). Improvement of soil organic carbon is the main reason increase in total porosity (*Fukumasu et al., 2022*).

The first year of research evaluated covering crops and mulching treatments (Tables 2, 3, 4, & 5). 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. Conversely, these nutrients were not elevated at the depths of 20–30 and 30–40 cm compared with the control, except for exchangeable K at 30–40 cm in 2021. This contrast may be because the root of a plant used for cover is short, and all treatments followed the no-till practice. The results did not agree with that of *Haruna and Nkongolo (2020)* that conservation practices enhanced soil nutrients in 20–40 and 40–60 cm during the second year of study. 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 and improves soil health.

According to *Belayneh et al. (2019)*, high BD negatively affected soil nutrients due to decreased soil biological and biochemical processes, resulting in reduced soil fertility. Our study showed that soil has a high BD, which caused the availability of soil nutrients (Ca, K, Fe, and Zn) to decline. *Singh et al. (2020)* also indicated a negative correlation between BD and soil nutrients. Another study also revealed that strong negative correlation between BD and soil total microelements (*Chaudhary et al., 2013*). 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 ($r = 0.71$).

Conclusions

The use of soil conservation practices 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, available macronutrients (Ca, K, and Mg) and micronutrients (Cu, Fe, Zn, and Mn) were not affected by cover crop with legume and RSM. 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 legumes to cover crops or mulch because these practices can mitigate soil compaction and soil degradation. Moreover, they are considered for land use strategies that reduce the risk of environmental pollution as well as increase soil health.

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**: 2530–2543. doi:10.1111/gcb.14644

AOAC. 1990. Official methods of analysis. 15th Edition, Association of Official Analytical Chemist, Washington DC. 1990.

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, Yirgu T, Tsegaye D. 2019. Effects of soil and water conservation practices on soil physicochemical properties in Gumara watershed, Upper Blue Nile Basin, Ethiopia. *Ecol Process*., **8**: 36. doi.org/10.1186/s13717-019-0188-2

Belayneh M. 2019. The effects of soil conservation practices on selected soil health indicators. *C.O.R.N. NEWSLETTER*, 2018-01.

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: A. Kassam Ed. Advances in Conservation Agriculture Volume 1 Systems and Science (Cambridge: Burleigh Dodds). pp.179–248. DOI: 10.19103/AS.2019.0048.05

Cattanio JH, Kuehne R, Vlek PLG. 2008. Organic material decomposition and nutrient dynamics in a mulch system enriched with leguminous trees in the Amazon. *R. Bras. Ci. Solo.*, **32**:1073–1086. DOI: 10.1590/S0100-06832008000300016

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 pages.

Chaudhari PR, Ahire DV, Ahire VD, Chkravarty M, Maity S. 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *International Journal of Scientific and Research Publications*, **3**: 2250-3153.

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**: 6289695. doi.org/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**: 5747699. doi.org/10.1155/2022/5747699

Das B, Kandpal BK, Devi HL. 2021. Cover crops for orchard soil management. In cover crops and sustainable agriculture. CRC Press: BocaRaton, FL, USA, pp 147–168. DOI: 10.1201/9781003187301-10

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**: 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**: 351. doi.org/10.3390/f10040351

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

Gebert J, Rachor I, Bodrossy L. 2009. Composition and activity of methane oxidizing communities in landfill cover. Proceedings Sardinia 2009, Twelfth International Waste Management and Landfill Symposium S. Margherita di Pula, Cagliari, Italy; 5 - 9 October 2009.

Ghyselinck T. 2013. Temporal changes of physical soil properties under different land use systems and land management practices of alluvial soil in the Mekong Delta, Vietnam. Master thesis, Ghent University. 93 pages.

Hakl J, Šantrůček J, Kocourková D, and Fuksa P. 2007. The effect of the soil compaction on the contents of alfalfa root reserve nutrients in relation to the stand density and the amount of root biomass. *Soil & Water Res.,* **2**: 54–58.

Haruna SI, Nkongolo NV. 2020. Influence of cover crop, tillage, and crop rotation management on soil nutrients. *Agriculture*, **10(6)**: 225. doi.org/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**: 605–608.

Hossain MF, Chen W, Zhang Y. 2015. Bulk density of mineral and organic soils in the Canada's arctic and sub-arctic. *Information Processing in Agriculture*, **2**: 183–190. doi:10.1016/j.inpa.2015.09.001

Iqbal R, Raza M.A.S., 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. *Bull Natl Res Cent.,* **44**: 75. doi.org/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 Propertiesin. *Appl. Ecol. Environ. Sci.* **3**: 127–135.

Fukumasu 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.org/10.1111/ejss.13212

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.org/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**: 1060. https://doi.org/10.3390/land10101060

Kumawat A, Yadav D, Samadharmam K, Rashmi I. 2020. Soil and water conservation measures for agricultural sustainability. In R. S. Meena, & R. Datta (Eds.), Soil Moisture Importance. *IntechOpen*. 2020. doi.org/10.5772/intechopen.92895

Li R, Li Q, Pan L. 2021. Review of organic mulching effects on soil and water loss. *Arch. Agron. Soil Sci.,* **67**: 136–151. doi.org/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**: 230. doi.org/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. *Agrosyst Geosci Environ.*, **5**: e20244. DOI: 10.1002/agg2.20244

Möller K, Stinner W, Leithold G. 2008. Growth, composition, biological N_2 fixation and nutrient uptake of a leguminous cover crop mixture and the effect of their removal on field nitrogen balances and nitrate leaching risk. *Nutrient Cycling in Agroecosystems,* **82**: 233–249. doi:10.1007/s10705-008-9182-2

Mondal S, Das TK, Thomas P, Mishra AK, Bandyopadhyay KK, Aggarwal P, and 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 L, 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 & Water Res.,* **15**: 47−54. doi.org/10.17221/176/2018-SWR

Nawaz MF, Bourrié G, Trolard F. 2013. Soil compaction impact and modelling. A review. *Agron. Sustain. Dev.* **33**: 291–309. doi.org/10.1007/s13593-011-0071-8

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.

Ogunsola OA, Adeniyi OD, Adedokun VA. 2020. Soil management and conservation: an approach to mitigate and ameliorate soil contamination. In M. L. Larramendy, & S. Soloneski (Eds.), Soil Contamination - Threats and Sustainable Solutions. *IntechOpen*, 2020. doi.org/10.5772/intechopen.94526

Page KL, Dang YP, and 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. *Front. Sustain. Food Syst.,* **4**: 31. doi: 10.3389/fsufs.2020.00031

Parlak M., and Parlak AO. 2011. Effect of soil compaction on root growth and nutrient uptakeof forage crops. *J. Food Agric. Environ.,* **9**: 275–278.

Quang PV. 2013. Soil degradation of raised-beds on orchards in the Mekong delta - field and laboratory methods. TRITA LWR PhD thesis 1073. 46 pages.

Ranjbar F. Jalali M. 2012. Calcium, magnesium, sodium, and potassium release during decomposition of some organic residues. *Communications in Soil Science and Plant Analysis*, **43**: 645–659. doi:10.1080/00103624.2012.644005

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**: 263. doi.org/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. *Front. Microbiol.,* **10**: 1618. doi: 10.3389/fmicb.2019.01618

Rühlemann L, Schmidtke K. 2016. The suitability of non-legume cover crops for inorganic soil nitrogen immobilisation in the transition period to an organic no-till system. *Plant Production Science*, **19**: 105–124. doi:10.1080/1343943x.2015.1128098

Shaheb MR, Venkatesh R, Shearer SA. 2021. A Review on the effect of soil compaction and its management for sustainable crop production. *J. Biosyst. Eng.,* **46**: 417–439. doi.org/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**: 1935–1951. DOI: 10.4236/ajps.2018.99140

Singh PD, Kumar A, Dhyani BP, Kumar S, Singh A, Singh A. 2020. Relationship between compaction levels (bulk density) and chemical properties of different textured soil. *International Journal of Chemical Studies*, **8**: 179–183. doi.org/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**: 106539. doi.org/10.1016/j.agwat.2020.106539

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 soilquality indicators in the Missouri Salt River basin. *Journal of Soil and Water Conservation*, **70**: 232–246. doi.org/10.2489/jswc.70.4.232

Viet VH. 2015. Value chain analysis and competitiveness assessment of Da Xanh pomelo sector in Ben Tre, Vietnam. *Asian Soc. Sci*., **11**: 8–19.

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. *Agron. Sustain. Dev.,* **39**: 45. doi.org/10.1007/s13593-019-0590-2

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

Table 1 (on next page)

(on next page)

Basic soil physicochemical properties at the study location

Depth (cm)	pH_{H2O}	SOM (%)	Macronutrients ($cmol_c$ kg^{-1})			Trace elements (mg kg^{-1})				BD (g cm^{-3})
			Ca^{2+}	K^+	Mg^{2+}	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

Table 2(on next page)

Effect of soil conservation practices on nutrients availability in topsoil layer (0–10 cm)

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 $p < 0.05$ (*) and $p < 0.01$ (**); ns, not significant.

Years	Treatments	Macronutrients ($cmol_c\ kg^{-1}$)			Trace elements ($mg\ kg^{-1}$)			
		Ca^{2+}	K^{+}	Mg^{2+}	Cu	Fe	Zn	Mn
2019	Control	3.55	0.16	2.28	25.8	8.37	59.8	26.7
	NLC	3.52	0.17	2.30	26.7	8.63	58.0	26.9
	RSM	3.51	0.18	2.27	25.7	9.07	59.0	27.1
	LCC	3.54	0.17	2.26	24.9	8.70	59.5	27.1
	-*value*	ns	ns	ns	ns	ns	ns	ns
2020	Control	3.45b	0.15c	2.27	25.2	8.57b	53.1c	27.6
	NLC	3.60b	0.19b	2.34	26.5	10.2b	59.6b	27.8
	RSM	3.76a	0.23ab	2.30	26.3	13.6a	64.8ab	26.7
	LCC	3.74a	0.24a	2.30	27.5	13.4a	66.5a	26.8
	P-*value*	*	**	ns	ns	**	**	ns
2021	Control	3.47c	0.14c	2.33	26.2	8.79c	58.0b	27.1
	NLC	3.71b	0.23b	2.36	24.5	12.2b	65.7b	26.0
	RSM	3.86a	0.27a	2.29	24.8	15.4a	72.4a	26.0
	LCC	3.85a	0.28a	2.37	26.1	16.5a	72.9a	26.3
	P-*value*	**	**	ns	ns	**	**	ns

Table 3 (on next page)

The availability of plant nutrients influenced by conservation agriculture in subsurface layer (10–20 cm)

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 $p < 0.05$ (*) and $p < 0.01$ (**); ns, not significant.

Years	Treatments	Macronutrients ($cmol_c$ kg^{-1})			Trace elements (mg kg^{-1})			
		Ca^{2+}	K^{+}	Mg^{2+}	Cu	Fe	Zn	Mn
2019	Control	3.43	0.18	2.41	27.5	9.66	49.4b	27.0
	NLC	3.51	0.19	2.48	26.0	9.76	61.8a	25.6
	RSM	3.50	0.19	2.50	25.6	9.72	62.0a	25.6
	LCC	3.51	0.19	2.54	27.1	9.72	64.0a	26.7
	P_{-value}	ns	ns	ns	ns	ns	**	ns
2020	Control	3.42c	0.17b	2.35	27.0	8.98c	52.6b	26.6
	NLC	3.72b	0.22ab	2.37	26.1	11.6b	62.4a	25.6
	RSM	3.91ab	0.24a	2.37	27.5	13.4a	65.7a	26.0
	LCC	4.03a	0.25a	2.32	26.6	14.0a	65.5a	26.3
	P_{-value}	**	*	ns	ns	**	*	ns
2021	Control	3.41b	0.18b	2.41	27.2	9.11b	55.5b	26.5
	NLC	3.93a	0.24a	2.37	26.2	13.3a	62.3a	25.0
	RSM	4.10a	0.28a	2.33	25.9	14.1a	65.4a	26.8
	LCC	4.13a	0.27a	2.41	26.2	15.1a	65.7a	26.1
	P_{-value}	**	**	ns	ns	**	*	ns

Table 4 (on next page)

Influence of soil conservation practices on macro-micronutrients in the soil at a depth of 20–30 cm

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.

Years	Treatments	Macronutrients ($cmol_c$ kg^{-1})			Trace elements (mg kg^{-1})			
		Ca^{2+}	K^{+}	Mg^{2+}	Cu	Fe	Zn	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
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
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

Table 5 (on next page)

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

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.

Years	Treatments	Macronutrients ($cmol_c\ kg^{-1}$)			Trace elements ($mg\ kg^{-1}$)			
		Ca^{2+}	K^+	Mg^{2+}	Cu	Fe	Zn	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
	$P_{\text{-}value}$	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
	$P_{\text{-}value}$	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
	$P_{\text{-}value}$	ns	**	ns	ns	ns	ns	ns

Table 6(on next page)

Correlationship between soil physicochemical properties (n = 192)

** indicates a significant difference at $p < 0.01$

	BD	Ca	K	Mg	Cu	Fe	Zn	Mn
BD	1							
Ca	−0.74**	1						
K	−0.73**	0.74**	1					
Mg	−0.11	0.13	0.14	1				
Cu	−0.11	0.02	−0.07	0.10	1			
Fe	−0.79**	0.81**	0.86**	0.19	−0.06	1		
Zn	−0.69**	0.76**	0.69**	0.11	−0.06	0.82**	1	
Mn	0.22	−0.33	−0.26	−0.19	−0.01	−0.19	−0.17	1

Figure 1

Soil bulk density is influenced by soil conservation practices: a) 0–10 cm, b) 10–20 cm, c) 20–30 cm, d) 30–40 cm.

Different letters show a significant difference at $p < 0.01$ (**); ns is not significant. Error bars represent the standard deviation ($n = 4$). Control, no conservation practices; NLC, non-legume cover crop; RSM, rice straw mulching; LCC, legume cover crop.

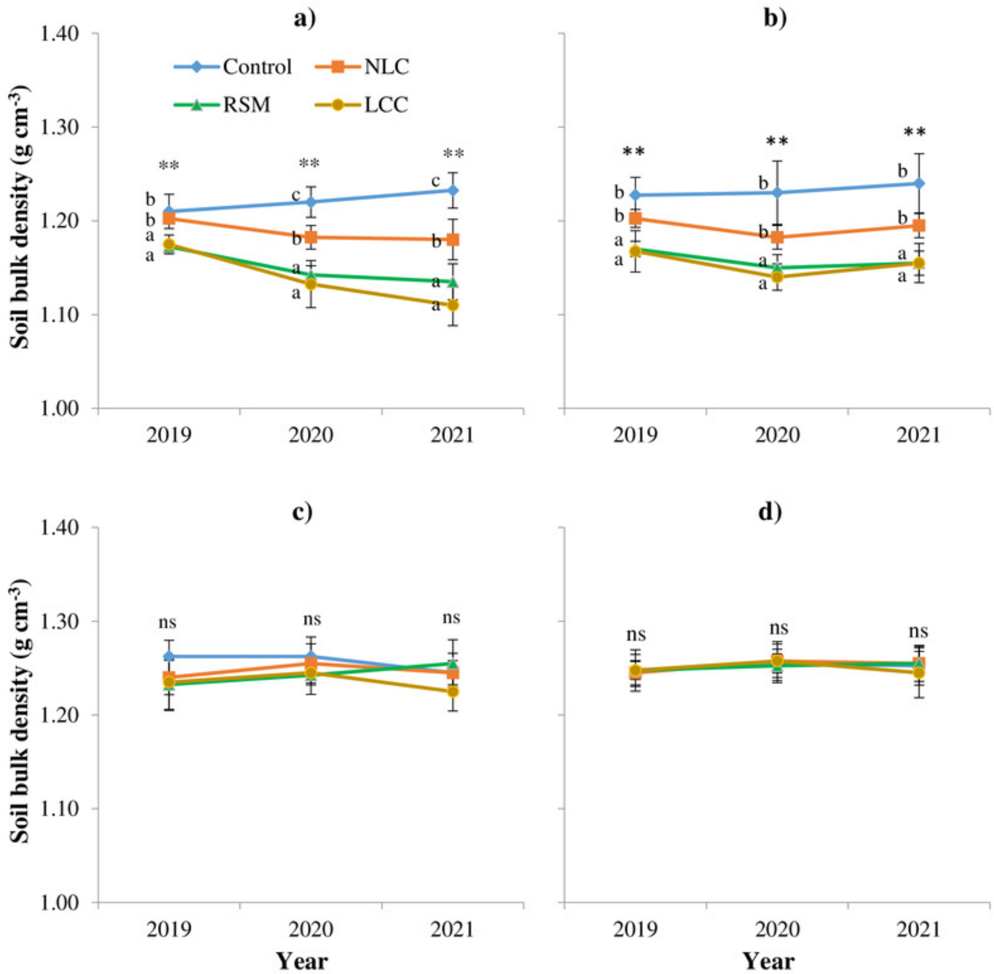
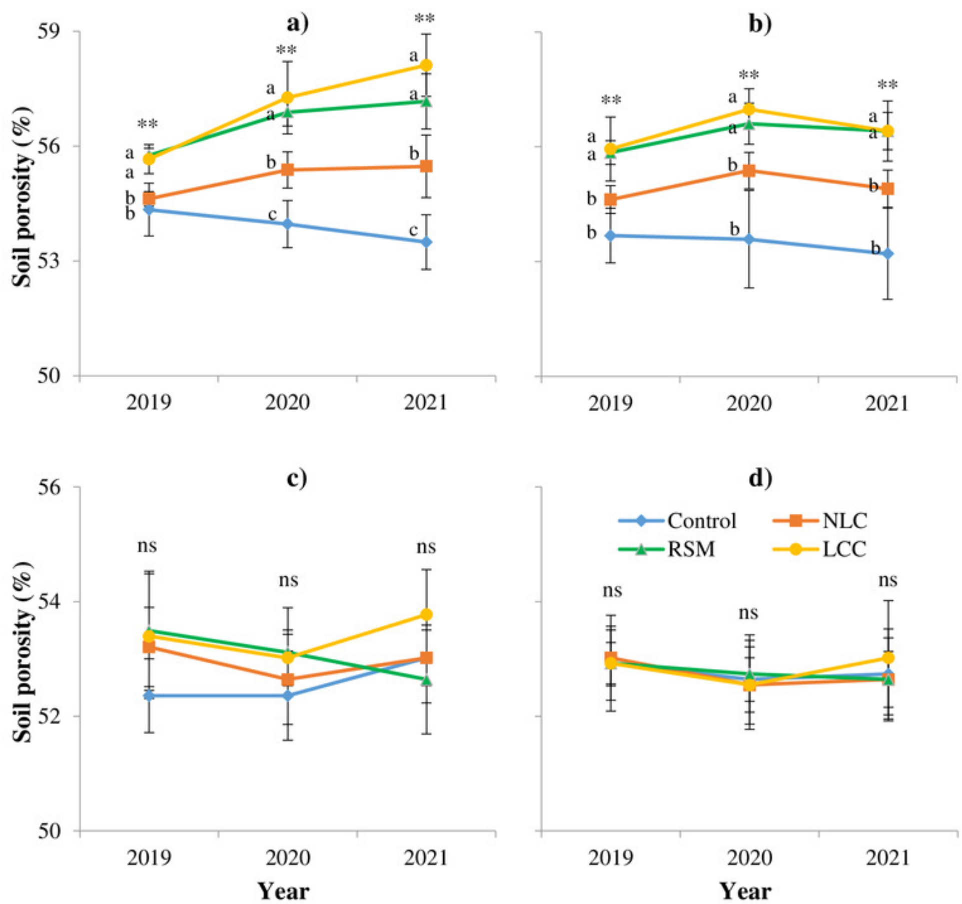

a)
b)
c)
d)
Control
NLC
RSM
LCC
Soil bulk density (g cm-3)
1.40
1.30
1.20
1.10
1.00
**
ns
2019
2020
2021
Year

Figure 2

Soil porosity is affected by soil conservation practices: a) 0–10 cm, b) 10–20 cm, c) 20–30 cm, d) 30–40 cm.

Different letters show a significant difference at $p < 0.01$ (**); ns is not significant. Error bars represent the standard deviation ($n = 4$). Control, no conservation practices; NLC, non-legume cover crop; RSM, rice straw mulching; LCC, legume cover crop


a)
b)
c)
d)
Soil porosity (%)
Year
Control
NLC
RSM
LCC
2019
2020
2021
**
ns
59
56
53
50
54
52