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Identification of Soil Properties and Their Effects on Crop Production under the Influence of Tillage and Residue Treatment in Western Canada

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ABSTRACT. Soil provides crucial nutrients and water for the growth of canola, which is one of the most essential economic crops for prairie province in Canada. Therefore, effective and efficient methods are required to modify soil properties to improve crop development. This study systematically analyzed the combined effects of tillage operation and crop residue management on soil features. Thus, the relationship between soil properties and crop yield was also evaluated. More specifically, Aftermarket chopper treatment could cause relatively higher soil moisture and temperature, while the Original Equipment Manufacturer (OEM) treatment could also result in dramatically higher soil organic matter (SOM) loss than Aftermarket treatment. The significantly more soil water and slightly higher soil temperature created by Aftermarket treatment was beneficial for crop yield. Although OEM treatment could cause more SOM loss, the final crop yield through this method was still lower than that using Aftermarket treatment, implying that the influence of SOM loss on crop growth remained contestable. Meanwhile, Fourier-transform infrared (FTIR) spectra showed the peaks of amides and carboxylic acids was declined during the growth of canola, which indicated that these organic contents played an essential role in the crop development. Finally, the Aftermarket * Harrow treatment was more suitable for canola cultivation, with largest amount of crop harvest and short loss of soil organic contents in the meantime.

Keywords: soil, crop residue management, tillage, soil organic matter

1. Introduction

Canola (*Brassica napus* L. 'Invigor L233P') as a vital commercial commodity is one of the most important feedstocks of edible oil for Canadian farmers in the past few decades (Daun et al., 2011). For the year 2020, approximately 18.7 million tonnes of canola seed were produced from Canada, while over 20 million tonnes of canola seed, oil, and meal was exported (Dolatabadian et al., 2022). Because of the indispensable role of canola products (e.g., oil and meal) on agriculture (e.g., animal husbandry) and industry, various sectors have taken efforts to explore effective and efficient strategies to improve the yield and quality of canola.

Crop residue management (CRM), one environmentally friendly method for improving soil fertility, was introduced for canola cultivation. It could be described that utilization crop residues obtained from last season to cover the soil are utilized to enhance the growth of crop in next cultivation (Liu et al., 2021; Xin et al., 2021). As a result of maintaining the soil organic matter (SOM) levels, enhancing nutrient cycling and retention, CRM could improve soil productivity to increase the crop yield (Hillel and Hatfield, 2005). Besides, the dry matter of residue might further restrict water-lost by runoff or evaporation, which could increase water available for transpiration of crop (Goss et al., 2017). CRM could not only alter the nutrient distribution within the soil profile, but also changed the chemical and physical properties of the soil.

Tillage is also an effective treatment for the improvement of crop production. It could significantly affect the soil characteristics, such as soil water conservation capacity, soil temperature and infiltration through mechanical agitation of the soil (Borrelli et al., 2020). This mechanical manipulation could increase the porosity of the soil and facilitate soil gaseous exchange, eradicate the weed and reduce the detrimental effect of agrochemical production (Nawaz et al., 2021). It could be divided into two categories: primary and secondary tillage (Lobb, 2008). Primary is the first mechanical manipulation of soil at the end of one cropping season, which is also the most intensive form of tillage. Harrowing or secondary tillage practice is another mechanical cultivation method that is applied to the crop pro-

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duction (Hussain et al., 2018). It could prepare the seedbed for crop planting.

SOM has a critical role to play in soil fertility and significantly affect the soil properties and function (Baumann et al., 2016). It provides bioavailable carbon for soil microbiota, which can fix atmospheric nitrogen through converting it to plant-available nutrients for crops (Kallenbach et al., 2016). Hence, it is necessary to make effort to increase SOM levels for crop plant. On the one hand, it has been reported the aboveground by-product from last season could facilitate the carbon sequestration and SOM formation (Li et al., 2017). On the other hand, physical manipulation, tillage, has negative effects on organic matter concentrations but increases the organic matter turnover rates (Balesdent et al., 2000). The combination of CRM and different types of mechanical manipulation would have complex impacts on the quantity and quality of SOM, which could further influence the crop yield and quality.

The contribution of Canada prairie to the global market is enormous within the local harsh natural conditions (Huang et al., 2021; Strelkov et al., 2020). However, there is lack of research on the characterization of soil and its influence on the growth of canola within the plants for Canadian prairie during the processes of CRM and tillage. Therefore, the objective of this study is to explore (1) the changes of soil properties within a Canadian prairie region under different treatment of tillage and CRM, (2) the influence of various soil characteristics on the canola production, and (3) FTIR characteristics of organic change in soil within the specific region and treatment of tillage and CRM.

2. Materials and Methods

2.1. Study Area of Canola Cultivation

Chernozemic soil is the dominant soil across the prairie regions and widely located at Alberta, Saskatchewan, and Manitoba in Canada (Huang et al., 2021). The studied area, with the acreage of approximately 1 km^2, was located at Saint-Front in the Saskatchewan, which was also a main part of Dark Brown Chernozem Zone in Canada. For identifying the effects of interaction of post-harvest operation and crop residue management, this field was divided into six main parts (Figure S1). They were, OEM * Harrow (OH), OEM * Tilled (OT), OEM * Check (OC), Aftermarket * Harrow (AH), Aftermarket * Tilled (AT), and Aftermarket * Check (AC), respectively. The signal "*" used here represents the connection of post-harvest operation and crop residue management. More specifically, the Original Equipment Manufacturer (OEM) and Aftermarket (AFT) are two types of choppers for wheat harvest. Generally, these 2 choppers have similar seeding depths of around 1 inch (2.5 cm), but the seeding place by OEM chopper trends slightly deeper. Besides, the OEM chopper tend to create more bunches of straw, while with Aftermarket chopper, the heavier and lighter residue area of the field could be more easily distinguished. Harrow, Tilled and Check are different types of post-harvest treatments. Among them, Check means observation of the widest spread in field finish post-seeding between the two choppers without any other physical post-harvest operation. In addition, last wheat harvest at this trial field started on October 18, 2018, whereas the post-harvest treatments occurred on October 23 in the same year. Then, the L233P canola variety was seeded on May 21, 2019. A 9.80 inches (24.9 cm) row spacing was used, and the seeding process in the depth at around 0.75 inches (1.9 cm) was conducted by a Bourg-Ault, 3320 Series Para-link Hoe Drill. Finally, the canola harvests in this period took place on October 23, 2019.

2.2. Data Collection and Characteristic

Soil samples were collected at the depth of 0 to 6 inches (0 to 15.24 cm) at each cultivation count. They were then labeled as: AH, AT, AC, OH, OT and OC.

Soil moisture: After weighted, these as-collected samples were dried at 149 °F (65 °C) for 40 hours. Then, they are weighted to determine the accurate soil-water percentage. The calculation formula was listed as follows:

$$W_m = W_1 + W_2 \tag{1}$$

where W_m represents the soil moisture in each sample; W_1 and W_2 is assigned to the weight of soil before and after drying process, respectively.

Soil organic: Gravimetric analysis is a quantitative analysis method to determine the content of organic matter in soil by weighing the change in soil mass before and after combustion or the mass of carbon dioxide (CO_2) produced. It is usually divided into dry oxidation, wet oxidation, and loss-on-ignition (LOI). Law. The first two methods are to measure the organic carbon content by detecting the amount of CO_2, and the latter is to measure the organic carbon content by the weight loss of the soil before and after burning. The soil organic weight was measured through LOI approach. More specifically, after weighted, the soil sample, with completely soil-water removal at 105 °C, was directly burned at a temperature of 550 °C using a Muffle furnace (Box Furnace, BF518866A-a, Lindberg/Blue M). The organic matter content was calculated from the weight lost after burning, with equation shown as follows:

$$W_o = W_{s1} + W_{s2} \tag{2}$$

where W_o means the SOM level of soil samples; W_{s1} and W_{s2} represent the weight of samples before and after burning, respectively.

The crop yield was obtained through weighing the harvested wheat. Results were then divided by the acreage of each part (1 BU/AC = 3.04 ton/hectare), when corrected to a 10.0% seed moisture content. The plant's emergency represents real-time seedlings in the chaff row. Besides, the FTIR for soil samples were conducted with Tensor 27, 121000, Bruker OPTIX GmbH.

3. Results

3.1. Soil Properties

Soil water has considerable effect on the microbial respiration, which could influence the biomass activity (Cook and Orchard, 2008). Then, such microbial activity could further systematically and complicatedly affect the growth and development of canola. In addition, crop can directly extract soil through root system (Holzman et al., 2014). It also has been widely reported that soil moisture is critical to crop yield (Nairizi and Rydzewski, 1977; Rossato et al., 2017). Therefore, it is necessary to measure the soil-water status (soil moisture). As shown in Figure 1A, the crop residue has strong impact on soil moisture. More specifically, the soil moisture of OEM * Check was the lowest compare with that of other cultivated fields. Such less-than-desirable water-soil status would cause relatively lower microbial activity and less crop yield. Besides, the soil moisture of the fields with Aftermarket treatment was generally higher than that of fields with OEM treatment. This result might be due to the relatively deeper seeding by OEM chopper treatment which could increase the soil surface exposed to sunlight and hence facilitate the water evaporation. Meanwhile, physical operation, including Tilled and Harrow, seemed have random impact on soil moisture. The field with Aftermarket * Check enjoyed the higher soil-water contents, while the soil-water status in OEM * Check remained the lowest. More experiments were required to explore the physical operation influence.

Soil temperature plays an essential role in the expansion and permeation through the soil of crop root, which is crucial to the growth and development of canola (Kaspar and Bland, 1992). Even if the changes in soil temperature is relatively low, it still has strong effects on the development of root system (McMichael and Burke, 1998). As for Figure 1B, the soil temperature in the fields with Aftermarket chopper treatment was generally higher than that in the farmland with OEM treatment. It was mainly because the seeding depth settled by Aftermarket treatment were relatively shorter than that from OEM treatment, which could more effectively maintain the soil temperature. Moreover, the physical tillage (Tilled and Harrow) was proved to be helpful and useful for temperature maintenance, and the soil temperature in the field with OEM treatment and no physical operation was the lowest. Considering the complicated and varied effects of soil temperature on crop yield, it’s hard to conclude that the Aftermarket treatment was superior to OEM treatment and more indicators were required for conclusion.

Soil organic matter can storage the terrestrial carbon and is essential to the farmland fertility, agroecosystem function, and ecosystem productivity (Pan et al., 2009). However, the relationship between soil organic matter and crop yield still remains contentious due to varied conditions of local soils, climate, and farming systems (Oldfield et al., 2019). Therefore, this paper not only collected the SOM level of each farmland count, but also recorded the SOM loss during the crop growing process. According to Figure 1C, the farmland counts with Aftermarket * Tilled (11.94 g/g) and OEM * Harrow (11.97 g/g) possessed the highest SOM level among all first collection samples. However, as for the second collection in OEM * Harrow, the SOM level was dramatically reduced to 7.34 g/g which was also the least level among all second samples. The largest SOM loss (approximately 4.64 g/g) in this area might result from the high microbial activity and nutrient absorption of commercial crop. In addition, the SOM loss in field Aftermarket * Harrow (0.70 g/g), Aftermarket * Check (0.87 g/g) and OEM * Check (1.08 g/g) was relatively lower, which might cause undesirable impact on the development of canola and crop yield. In summary, OEM treatment could lead to larger SOM loss compared with Aftermarket treatment, while Check without any physical agricultural operation would decline the SOM loss during crop cultivation. As all the soil sample has already been characterized, the analyses of canola development and crop yield were necessary and required to explore the relationship between soil properties and canola productivity within a Canadian prairie region.

3.2. Canola Growth Features and Crop Yield

The plant emergency of canola was analyzed under different factors, to identify the impact of soil properties on crop early development. Specifically, significant factor A represent the residues choppers treatment (Aftermarket and OEM), whereas factor B was assigned to varied physical post-harvest treatment (Harrow, Tilled and Check). As shown in Figure 2A, the crop seedling emergency was significantly affected by Factor A. The plant emergency in counts treated by OEM chopper was higher than that with Aftermarket treatment. Besides, physical operation is another factor on the seedling emergency. Harrow could dramatically increase the plants emergency and the P value in the area under OEM * Harrow treatment reached the highest (average 75.75 plants) in the early development stage of canola. In the contrary, Tilled treatment has significant negative effects on seedling emergency, whereas the lowest P value occurred in the field under Aftermarket * Tilled treatment (average 30 plants). Check operation was also beneficial for crop growth, but its impact was relatively lower than Harrow treatment.

The moisture corrected yield was one of the most important indicators for the identification of canola development and decided most of the crop industrial income. A 2 × 3 factorial design was utilized for the evaluation of the coefficient effects of choppers treatment and post-harvest operation on canola crop yield. According to the Figure 2B, no significant difference in crop yield was observed under the combined treatment: OEM * Tilled, Aftermarket * Harrow, and Aftermarket * Tilled (approximately 55 BU/AC). Among these 3 combined treatments, the soil moisture of Aftermarket * Tilled was relatively lower (11.96 g/g), while its initial SOM level was considerably higher (11.94 g/g). Besides, Aftermarket * Tilled and OEM * Tilled could cause much more SOM loss (1.95 and 2.21 g/g, respectively) with the similar crop yield, compared to Aftermarket * Harrow (approximately 0.70 g/g). This result demonstrated that although SOM was essential to the sustainability and health of soil, the specific effects of SOM level and SOM loss on crop yield remained contestable. It also proved that Aftermarket * Harrow was the more ideal combined treatment which could produce a large amount of commercial canola and maintain soil fertility in the meantime. In addition, Check operation generated relatively smaller amount of canola, with average crop yield of 53.0 BU/AC under OEM * Check and 53.2 BU/AC under Aftermarket * Check. Even if this operation was more beneficial to protection of soil fertility, the inferior crop yield and canola emergency indicated that Check operation was not suitable for

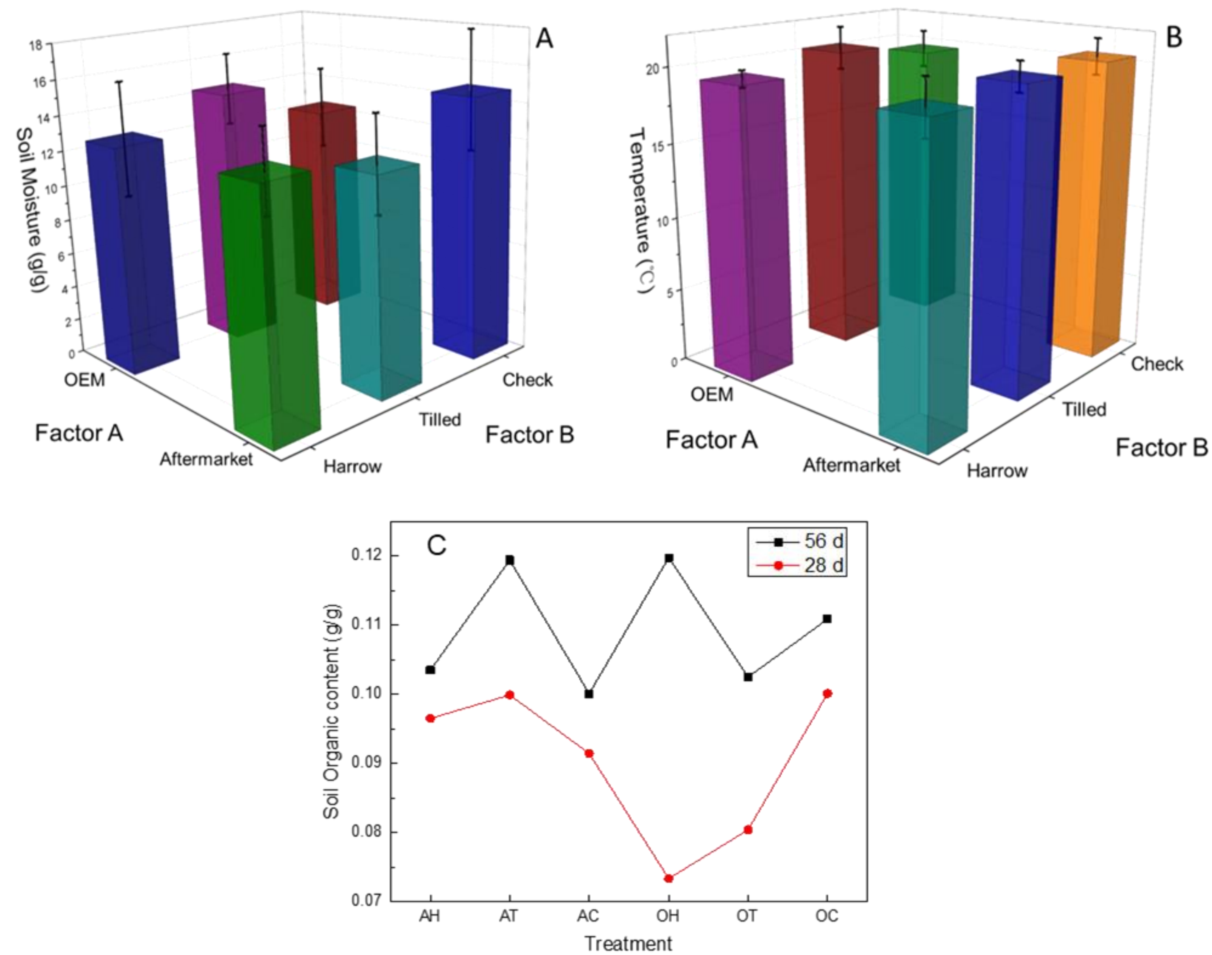

Figure 1. Soil moisture (A) and temperature (B) of each farmland field; (C) the soil organic matter (SOM) after sampling twice (AH: Aftermarket * Harrow, AT: Aftermarket * Tilled, AC: Aftermarket * Check, OH: OEM * Harrow, OT: OEM * Tilled, and OC: OEM * Check).

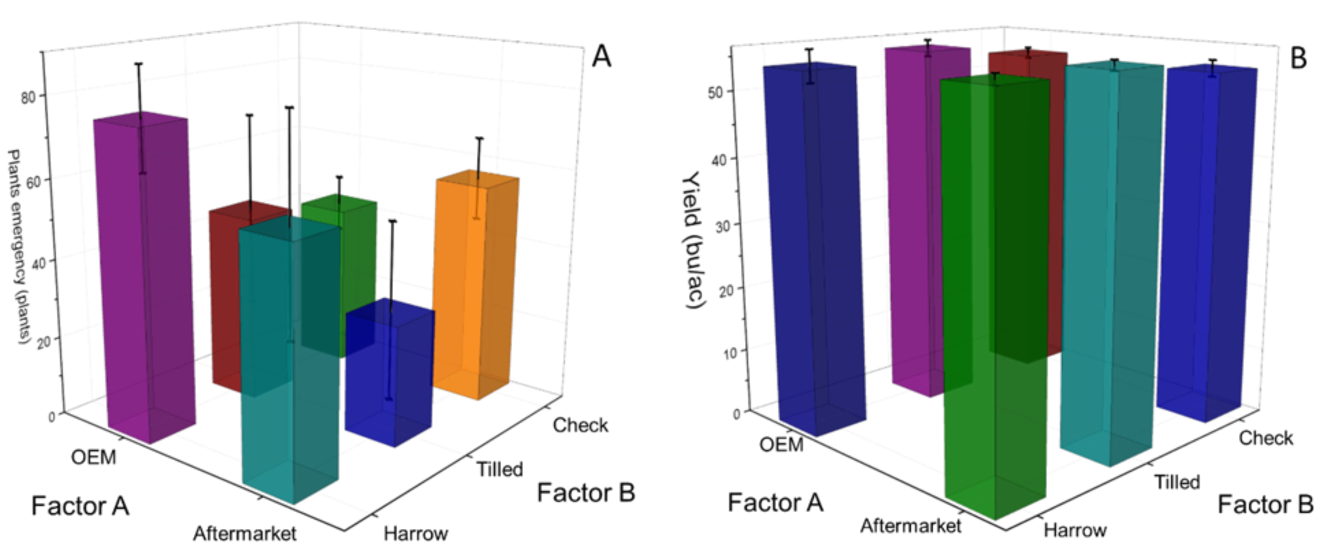

Figure 2. 3D column for (A) plant emergence in each count and (B) moisture corrected yield.

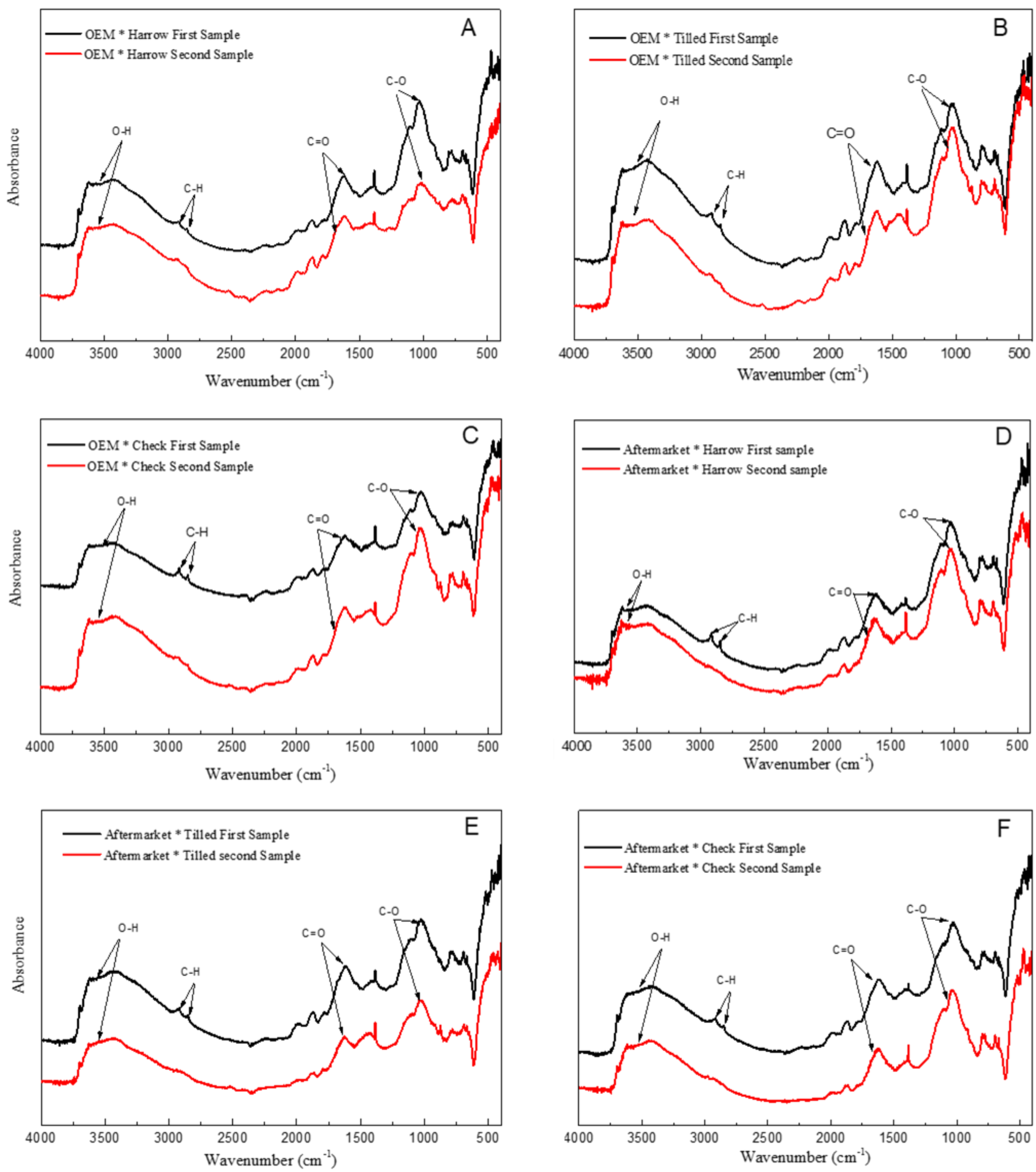

Figure 3. The FTIR spectrum of soil after sampling twice for (A) OEM * Harrow, (B) OEM * Tilled, (C) OEM * Tilled, (D) Aftermarket * Harrow, (E) Aftermarket * Tilled, and (F) Aftermarket * Check.

the growth and development of canola.

3.3. FTIR Spectra of Soil Sample

FTIR spectroscopy was the ideal technique for interpretation and analysis of heterogeneous constituents of arable soil (Xing et al., 2016). It can identify the functional groups of the minerals and organic matters of soil. According to the Figure 3, almost all FTIR spectra share the similar specific peaks within the same wavelength. Normally, these similar spectral signals could be divided into three main absorption intervals:

1) 4000 ~ 2500 cm^{-1}: The peaks at around 3600 cm^{-1} resulted from the O-H stretching of clay minerals (Xing et al., 2016). A broad band at 3500 ~ 3200 cm^{-1} was attributed to hydroxyl (O-H) groups and N-H of water, alcohols, and phenols (Heller et al., 2015). Meanwhile, two small peaks at around 2925 and 2858 cm^{-1}, which superimposed on the O-H broad band, were assigned

to asymmetric and symmetric stretching vibration of C-H bonds of methyl and aliphatic alkyl groups (Cocozza et al., 2003; Heller et al., 2015; Baumann et al., 2016).

2) 2500 ~ 1200 cm^{-1}: the region of 1610 ~ 1750 cm^{-1} was attributed to aromatic C=O stretching and C=C stretching from amides, carboxylic acids, carboxylates, ketones, aldehydes and esters (Inbar et al., 1990; Xing et al., 2016).

3) 1200 ~ 400 cm^{-1}: peaks at around 1200 ~ 1000 cm^{-1} were possibly assigned to stretching vibrations of C-O bonds in polysaccharides and carbohydrates, or inorganic Si-O bonds from silicates in soil minerals (Ellerbrock and Gerke, 2004; Artz et al., 2008; Pedersen et al., 2011).

As shown in Figure 3, C-H bond was detected in first soil samples from all cultivated fields, while intensity of its peaks was much lower in second samples and even it was not discovered in several counts. These results indicated that organic components, including amides and carboxylic acids, were significantly declined during the decomposition process. It was also proved by previous section, as the weight of organic matters of second samples was relatively lower than that of first sample to varying extent. Generally, the absorbance of C-H groups would increase with the rise of the intensity in the region of 1610 ~ 1750 cm^{-1}, which represent C=C and C=O (Xin et al., 2021). However, as for OEM * Check (Figure 3C), the amount of Carbonyl group (1610 ~ 1750 cm^{-1}) was much higher in second sample than fist sample. Such opposite results might be due to the enhance oil oxidative degradation. Besides, the stronger intensity of C-O band (1200 ~ 1000 cm^{-1}) of OEM * Check second sample might result from the increasing amount of the polysaccharides and carbohydrates. The accumulation of the carbohydrates indicated lower biomass and bacteria activity compared with other cultivated fields and thus less nutrients was provided for the growth of canola, which further cause lower crop yield and plants emergency in OEM * Check. Similar phenomenon could also be observed in Aftermarket * Check, demonstrating that physical operating, such as harrow and tilled, could significantly facilitate the biomass activity.

4. Conclusion

The post-harvest treatment (OEM and Aftermarket chopper) and physical tillage operation had strong impact on the soil properties. In detail, Aftermarket chopper treatment could cause relatively higher soil moisture and temperature than OEM treatment. These results were probably due to the slightly deeper seeding by OEM treatment, which could lead to more exposure of soil and thus more water evaporation and temperature lost. Besides, the OEM treatment could also result in dramatically higher SOM loss than Aftermarket treatment. Tillage operation was also a significant factor for organic matter lost. Check operation was benefit to SOM maintenance, whereas Tilled operation could lead to a large decrease in organic content. As for the crop development, Aftermarket treatment would increase soil moisture and soil temperature, which had a positive impact on the crop yield. Although OEM treatment could generate more SOM loss, the final crop yield through this method was still lower than that using Aftermarket treatment, implying that the influence of SOM loss on crop growth remained contestable. Meanwhile, FTIR spectra showed a significant decrease in the number of amides and carboxylic acids between first sample and second sample. It indicated that these organic contents played an essential role in the canola development. In conclusion, the Aftermarket * Harrow treatment was beneficial for canola yield and sustainable develop, as it could create large amount of crop harvest and maintain the soil organic contents in the meantime.

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