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EFFECTS OF CHEMICAL FERTILIZER WITH RICE STRAW ON THE CARBON COMPOSITIONS OF TOBACCO-PLANTING SOIL

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Key words: Rice straw, Tobacco-planting soil, Humus component, Infrared spectrum

Abstract

This study explored the changes in carbon components of tobacco-planting soil by the application of rice straw as organic materials to replace chemical fertilizers partially. Flue-cured tobacco was applied to the soil as base fertilizer to investigate the mineralization of soil organic carbon during its growing period. At 0 d, the humic acid carbon (HA-C), humin carbon (HM-C), HU ratio, PQ value and HM-C/(HA-C + FA-C) were 31.67, 31.40, 60.05~~,~~ 28.01, and 27.75%, respectively which were higher than those of chemical fertilizer alone. At 30 d, the humus carbon (HE-C), HA-C, and fulvic acid carbon (FA-C) were 29.41, 20.97 and 30.49%, respectively. At 90 d, the A2920/1630 values were 227.43 and 232.32% higher than chemical fertilizer. Application of rice straw and decomposed rice straw with less fertilizer can increase the content of soil organic matter, HA-C, HM-C and FA-C in the tobacco-planting soil. This method increases the content of aliphatic chain hydrocarbons and reduces the amount of aromatic carbon, thus increasing aliphatic properties and decreasing the aromatic properties of soil. The treatment with chemical fertilizer reduction with decomposed rice straw also accelerates the formation and accumulation of stable components such as humic acid and humin and significantly improves the humification of soil humus.

Introduction

The application of chemical fertilizers can significantly improve crop yield and quality. A long-term application of chemical fertilizer alone destroys soil structure, which increases soil bulk density and reduces porosity and field capacity, resulting in soil compaction (Bronick and Lal 2005, Kaiser and Ellerbrock 2005), soil acidification (Blake *et al.* 2010), reduces the content of soil active organic matter (Xu *et al.* 2002) and enhance mobility of heavy metals (Blake *et al.* 1994). Straw contains nutrients needed for the growth and development of crops. Returning straw to farmland can improve the soil and address environmental problems caused by the unreasonable application of chemical fertilizers (Zhao and Qian 2009). Returning decomposed straw to farmland with a long history in China can improve the soil structure and soil fertility while boosting the yield and quality of the crop (Li *et al.* 2012). The mineralization of soil organic carbon is an important biological and chemical process in ecosystems, and its mineralization rate directly affects the supply and release of soil nutrients (Wu *et al.* 2016, Guo *et al.* 2018). However, direct return or return after the decomposition of straw to farmland can increase the content of soil organic carbon and improve its stability (Mandal *et al.* 2016, Li *et al.* 2021), which contributes to the improvement of crop yield and quality (Liu *et al.* 2021).

Long-term straw return can improve the contents of humic acid (HA) and humin (HM) in the soil and increase the proportion of HA in humus, thus stabilizing the soil humus component and improve soil fertility (Liu *et al.* 2015). According to an infrared spectrum analysis of the HA

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functional group composition, the addition of organic materials can enhance the aliphaticity and decrease the aromaticity, oxidizability and condensation of HA in soil (Chen *et al.* 2020). Few reports have been published on the dynamic characteristics of the humus component in tobacco-planting soils of straw return combined with infrared spectroscopy. In this experiment, to investigate the change characteristics of the carbon component of tobacco-planting soil after straw return for improving the tobacco-planting soil of long-term continuous cropping, rice straw and decomposed rice straw were used as organic materials to partially replace chemical fertilizers. This study can provide a theoretical basis for the resource utilization of straw, fertilizer reduction and soil conservation in the experimental region.

Materials and Methods

The experimental site is located in Shunhe Village, Jietou Town, Tengchong County, Baoshan City, Yunnan Province (98.63 E,25.42 N), with an average elevation of 1486.53 m. This area belongs to the subtropical humid monsoon climate, with an average annual rainfall of 1532.4 mm, relative humidity of 77 sunshine hour of 2091.8 h, and temperature of 15.4℃. The average daily temperature of flue-cured tobacco during the growing period was less than 24℃ (Zhenglong Liu, 2022). The test site is a typical yellow soil rice field with the following basic properties: pH of 5.16, organic matter of 45.46 g/kg, total nitrogen of 1.58 g/kg, alkali-hydrolyzable nitrogen of 159.25 mg/kg, available phosphorus of 20.07 mg/kg and rapidly available potassium of 95.92 mg/kg. The flue-cured tobacco variety was K326, and the planting density was 1100 plant/mu (1 mu= 0.0667 hectares). Transplanting required uniform growth of flue-cured tobacco seedlings, free of pests and diseases. The fertilizer for the test was a compound fertilizer specialized for flue-cured tobacco. The nutrient content was as follows: total nitrogen: 8%, available phosphorus: 16% and rapidly available potassium: 26%.

Rice straw was crushed through a 50 mesh sieve two months before the transplanting of flue-cured tobacco, and the water content was adjusted (hold it into a ball). Each ton of crop straw was added with 2 kg of urea (46. 2% of N) and 1 kg of decomposing agent (effective viable count in decomposing inoculants $\geq$ 50 million/g, mainly *Bacillus amyloliquefaciens*, *Trichoderma reesei* and *Saccharomyces cerevisiae*), mixed well and covered with plastic film. Water addition and turning were conducted once every other week to make the rice straw fully decomposed. Seven days before transplanting, organic materials and special compound fertilizer for flue-cured tobacco were applied in bands as a base fertilizer and turned on the ridge.

According to the calculated results of the nitrogen content of organic materials, chemical fertilizers were reduced by 20% based on conventional fertilization. The relative water content of organic materials was 9.86% for rice straw and 11.25% for decomposed rice straw, which were converted into actual dosage. Three treatments were set up in this experiment, and each treatment was replicated three times. A randomized block design with nine test plots of 46 m^2 each was adopted. There were four ridges in each plot, with a ridge width of 1.2 m and a length of 4.8 m. The treatments were T1: blank (conventional fertilization, 50 kg/667 m^2 of tobacco-specific compound fertilizer), T2: 20% rice straw + 80% tobacco-specific compound fertilizer and T3: 20% decomposed rice straw + 80% tobacco-specific compound fertilizer.

Sampling times were blank samples (CK, on the day of fertilization), 0 d after transplanting (7 d after fertilization), 30 d after transplanting (rosette stage), 60 d after transplanting (topping stage), and 90 d after transplanting (mature stage). Blank samples were measured by 5-point sampling method with diagonal sampling after air-drying. Rhizosphere soil samples of flue-cured tobacco were taken after transplanting, and indicators were measured after natural drying.

Soil water content and soil organic matter was measured by drying method and potassium dichromate volumetric method, respectively (Du and Gao 2006, Propa *et al.* 2021, Alam *et al.* 2024).

Determination of soil humus components i.e., total humus carbon (HE-C), extractable HE-C (HA + total fulvic acid carbon (FA-C)), humic acid carbon (HA-C), FA-C, humin carbon (HM-C), HA-C/FA-C, HM-C/(HA + total FA-C), and PQ values were determined according to references (Du *et al*. 2006).

The pressing potassium bromide troche method was used to determine infrared spectra of soils. The pressing potassium bromide troche method was used. The weight ratio of dried soil (sieved through 120 mesh) to dried potassium bromide was 1:100. A Nicolet IS10 FT-IR spectrometer was used for determination with a resolution of 4.0 cm^{-1}, a spectral scan range of 4000–400 cm^{-1} and a scan number of 32/64. Infrared spectroscopy software was used for automatic baseline correction, and the absorption peaks were integrated to calculate the relative percentage of each peak area. Relative absorption intensity (rA) = absorbance of the band (A)/sum of absorbance of each peak band (∑A) × 100. The infrared spectra of different treatments and their main characteristic absorption bands were compared (Li *et al.* 2021).

The tobacco leaves in each plot were baked according to the three-stage baking method after harvesting and were graded according to the National Standard for Flue-cured Tobacco Grade 42 (GB 2635-92). The tobacco yield and production of each plot were determined and calculated according to the quality grade of locally purchased flue-cured tobacco.

The infrared spectrograms were processed by Thermo Scientific OMNIC^{TM} 8.2 infrared processing software, and the statistical analysis of data variance was performed using SPSS18.0 software. The final data were organized, calculated and plotted using Excel 2013 and Origin 9.0 for analysis.

Results and Discussion

Rice straw’s nutrient content and the nutrient content of decomposed rice straw are shown in Table 1. It can be seen that the total carbon content of rice straw was 35.72% higher than that of decomposed rice straw. The C/N of rice straw was also higher than that of decomposed rice straw.

Table 1. Basic physical and chemical properties of plant materials.

Straw type	Carbon (%)	Total nitrogen (%)	C/N	Total phosphorus (%)	Total potassium (%)
Rice straw	53.35	1.03	51.80	0.21	1.17
Decomposed rice straw	39.31	1.67	23.54	0.25	1.28

As shown in Fig. 1, the trend of soil organic matter during the growth period of flue-cured tobacco suggests that the trend of soil organic matter content was increased initially first and then decreased slowly. The soil organic matter content before fertilization for flue-cured tobacco planting was 45.46 g/kg and after fertilization were 53.03, 64.07, and 64.03 g/kg. The organic matter contents of soil under the treatments with conventional fertilizer, combined application of rice straw, and combined application of decomposed rice straw were 16.65, 40.95 and 40.84% higher than that of the base soil, respectively. At the maturity stage of flue-cured tobacco, the organic matter content in the rhizosphere soil of T1, T2, and T3 treatments was basically the same as that in the blank soil, with no significant difference. For the different treatments in each period, the soil organic matter content was significantly higher in the treatments of fertilizer reduction combined with rice straw and decomposed rice straw application than in the treatments with conventional fertilizer at 0 and 30 d of flue-cured tobacco transplanting. At 0 d, the organic matter contents of the soil with rice straw and decomposed rice straw treatments are 20.83 and 20.73% higher than that of conventional fertilization treatments, respectively. At 30 d, the organic matter contents of the soil with rice straw and decomposed rice straw treatments are 14.28 and 12.27% higher than that of conventional fertilization treatments, respectively. At 60 and 90 d of transplanting, the organic matter content of the soil with combined application of rice straw was significantly higher than that of the soil with conventional fertilizer treatment by 11.05 and 10.11%, respectively. The organic matter content of the soil with the combined application of decomposed rice straw was not significantly different from that of the soil with conventional fertilization.

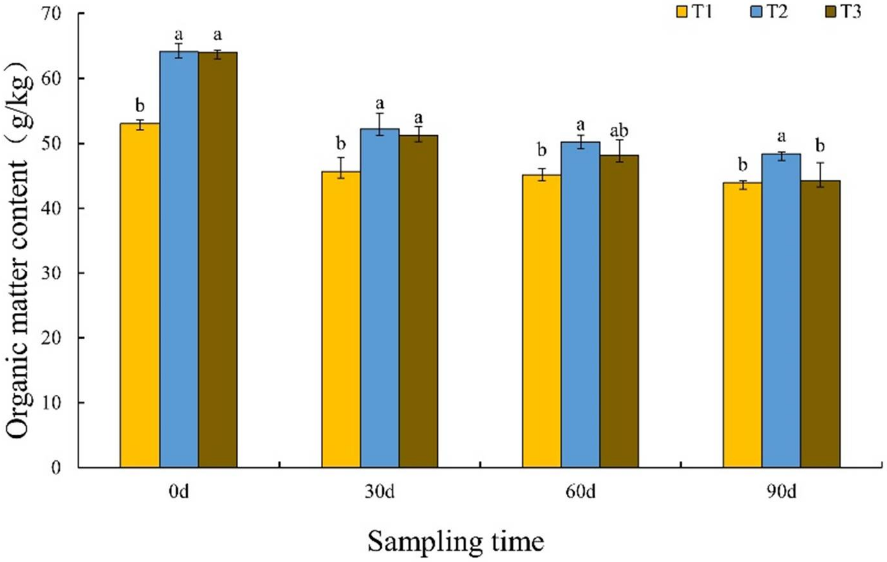

Fig. 1. Soil organic matter content of farmland during tobacco growth at different times. Different letters on the bar graphs represent significant levels of differences between treatments ($P < 0.05$), in all cases.

Soil extractable HE-C (HA + FA-C, HE-C) is an important component of soil humus and plays an important role in soil fertility and nutrient cycling (Zhou *et al.* 2021). As shown in Fig. 2, the content of extractable HE-C in the soil of each treatment showed a trend of increasing and then decreasing during the flue-cured tobacco growing period. At the mature stage of flue-cured tobacco, the HE-C content in each treatment tends to be stable. The conventional fertilization treatment reached the highest HE-C content in the soil at 0 d of tobacco transplanting, which was 9.38% higher than the blank soil HE-C content. The HE-C content reaches the highest under the treatment of fertilizer reduction combined with rice straw and decomposed rice straw application at 30 d of tobacco transplanting, with 37.50 and 25.00% higher than that of blank soil samples, respectively. At 0 and 30 d of flue-cured tobacco transplanting, the HE-C content under T2 treatment was significantly higher than that under T1 treatment by 11.43 and 29.41%, respectively. The HE-C content under T3 treatment was significantly higher than that under T1 treatment by 17.65% at 30 d of transplanting. There was no significant difference in HE-C content between treatments 60 d after transplanting.

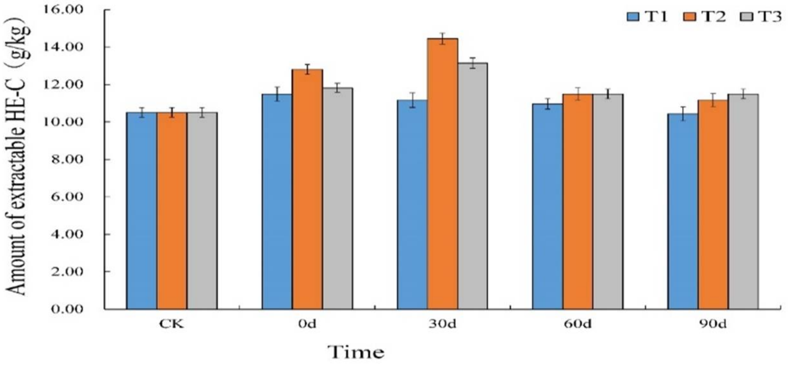

Fig. 2. HE-C content offarmland during tobacco growth.

HA is a component that is soluble in alkali but insoluble in acid and water during extraction (Zhang and Dou 2008). This component has an important role in the formation of soil structure (Johnsson *et al*. 1999). As shown in Fig. 3, the HA-C content in each treatment showed a trend of increasing and then decreasing during the growing period of flue-cured tobacco. The content of soil HA-C under conventional fertilization treatment reached the highest at 30 d after transplanting flue-cured tobacco but has no significant difference with other periods. The HA-C content of the soil under the treatment of fertilizer reduction combined with rice straw application reached the highest at 30 d of tobacco transplanting, significantly higher than the blank soil HA-C content (31.58%). The HA-C content of the soil under the treatment of fertilizer reduction combined with decomposed rice straw application reached the highest at 30 d of transplanting; its HA-C content at 0 and 30 d was significantly higher than that of blank soil by 38.60 and 31.58%, respectively. At 0 d of transplanting, the HA-C content of the soil under T3 treatment was significantly higher than that under T1 treatment by 31.67%. At 30 d of transplanting, the HA-C content of the soil under T2 and T3 treatments was significantly higher than that of T1 treatment by 20.97 and 20.97%, respectively. At the maturity stage of flue-cured tobacco, the HA-C content of the soil under T2 and T3 treatments was significantly higher than that of T1 treatment by 16.45 and 18.13%, respectively. During the growth period of flue-cured tobacco, the HA-C content of the soil under T1 treatment was low, and the HA-C content of the soil was lower under treatment without organic material than under treatment with organic material. This phenomenon indicates that straw

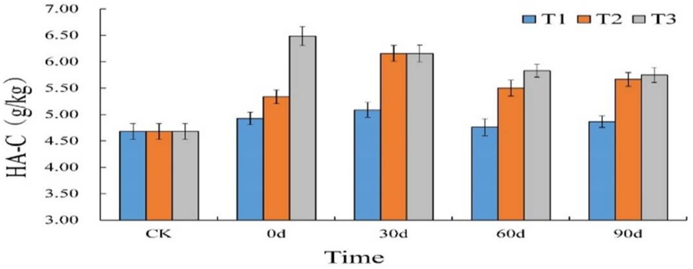

Fig. 3. HA-C content of farmland during tobacco growth.

return during the growing period of flue-cured tobacco can increase soil HA content and contribute to soil HA accumulation to a stable level. The HA content in stable humus components of decomposed rice straw was relatively high. It was gradually synthesized and decomposed with the growth and development of flue-cured tobacco and basically reaches a stable level at the maturity stage of flue-cured tobacco.

FA is a component that is soluble in alkali, acid and water during extraction (Zhang and Dou 2008). It plays an important role in the synthesis and decomposition of HA and is of great significance for the release of nutrients and the decomposition of minerals in the soil (Liu *et al*. 2015). The trend of soil FA-C content after fertilization increases and then decreases, with different trends for different treatments (Fig. 4). During the growth period of flue-cured tobacco, the soil FA-C content under treatment with chemical fertilizer varies less and was more stable. The FA-C content of the soil under the treatment of fertilizer reduction combined with rice straw application reaches the highest at 30 d of flue-cured tobacco transplanting and then tends to be stable. Its FA-C content is significantly higher than that of blank soil by 28.17 and 42.25% at 0 and 30 d of transplanting, respectively. The highest FA-C content was reached at 30 d of transplanting under the treatment of fertilizer reduction combined with decomposed rice straw application, significantly higher than that of the blank soil by 30.77%. The FA-C content of the soil under T2 treatment was significantly higher than that under T1 treatment by 36.49% during the fast-growing period of flue-cured tobacco. At 0 d of transplanting, the soil HA-C content reaches the highest under treatment with the combined application of decomposed rice straw, indicating that decomposed rice straw contains more stable humus components than rice straw. Returning decomposed rice straw to farmland can increase the HA content of the soil. At 30 d of transplanting, the HA-C and FA-C contents under treatment with combined application of rice straw are at high levels. The rise in ambient temperature during this period promotes the decomposition of rice straw, which increases the content of each humus component.

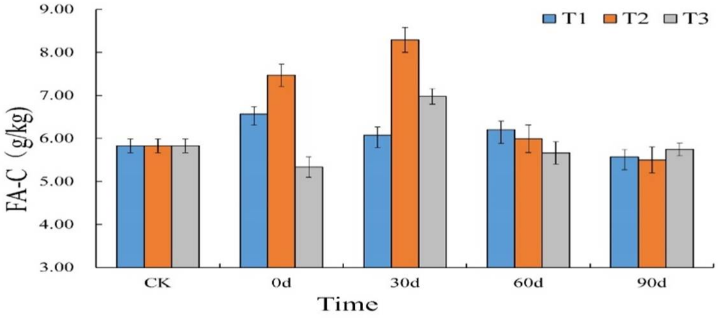

Fig. 4. FA-C content of farmland during tobacco growth.

HM is a component that is–insoluble in aqueous solutions pH (Zhang and Dou 2008). Compared with HA and FA, HM is a more stable humus component, capable of immobilizing nutrients such as C, N and S. Amino sugars and amino acids combined with HM are more effective for plant and microbial uptake (Johnsson *et al.* 1999). Fig. 5 showed that the trends of soil HM-C content in the three experimental treatments are basically the same. After fertilization, they all show a changing law of rising, then falling, and finally tending to be stable. At 0 d of flue-cured tobacco transplanting, the HM-C content of the soil under treatments with fertilizer alone, combined application of rice straw and combined application of decomposed rice straw was significantly higher than that of blank soil by 21.49, 53.61 and 59.64%, respectively. The HM-C content of the soil under T2 and T3 treatments was significantly higher than that under T1 treatment by 26.43 and 31.04%, except at 0 d of transplanting. For other sampling times, there were no significant differences between the treatments.

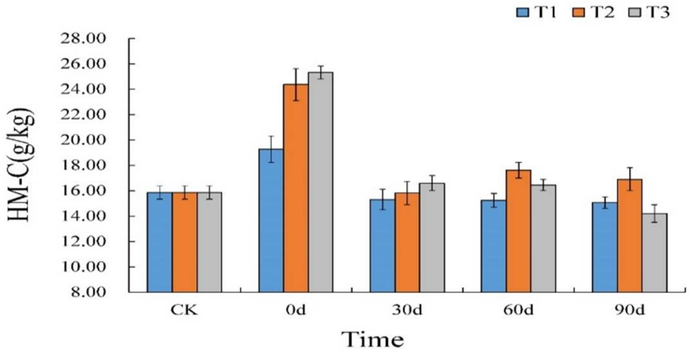

Fig. 5. HM-C content of farmland during tobacco growth.

By analyzing the humus fractions content, it can be seen from the differences between the humus components that the contents of HA-C, FA-C, and HM-C were quite different at 0 d of flue-cured tobacco transplanting. However, the difference in content between the components gradually decreases with the growth time. At the maturity stage of flue-cured tobacco, the content of HA-C and FA-C was similar under each treatment.

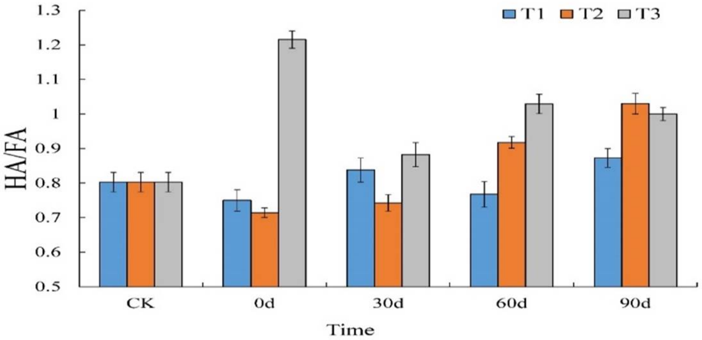

Fig. 6. HA/FA value of farmland during tobacco growth.

HA/FA represents the ratio of HA-C to FA-C, which reflects the degree of soil humification, aromatization, polymerization, and stability. PQ is the proportion of HA in the extractable humus component (HA + FA) and can reflect the humification degree of soil organic matter (Zou *et al.* 2013). The analysis of HA/FA and the PQ value of the soil (Figs 6 and 7) under different treatments showed that the trends of the two indicators were basically the same. During the growing period of flue-cured tobacco, HA/FA and PQ values under the single application of fertilizer treatment vary less and were basically in a stable state. The HA/FA and PQ values under the treatments with combined application of rice straw showed a gradual increase during the growing period of flue-cured tobacco. The HA/FA and PQ values of flue-cured tobacco mature stage were significantly higher than 0 d of transplanting by 44.18 and 21.76%, indicating that the accumulation rate of HA exceeds that of FA after rice straw return to farmland. The trend of

HA/FA and PQ values under treatment with combined application of decomposed rice straw reached the maximum at 0 d of transplanting (7 d of fertilization). The HA/FA and PQ values were significantly higher than those of the blank soil by 51.39 and 23.20% at 0 d of transplanting. The reason is that the transformation of HA and FA has tended to balance during the decomposition of decomposed rice straw. Their content is reduced gradually by the decomposition and transformation in the soil as the flue-cured tobacco grows.

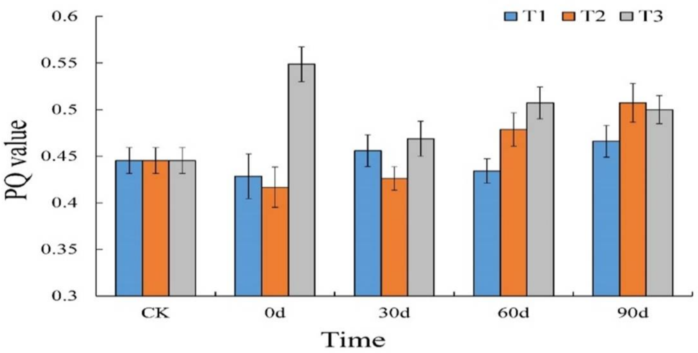

Fig. 7. PQ value of farmland during tobacco growth.

The HM-C/(HA+FA)-C ratio can be used as an indicator of soil humification, and a higher ratio indicates a higher degree of humification (Saikh *et al.* 1999). The variation pattern of the HM/(HA+FA)-C ratio in Fig. 8 showed that with the growth of flue-cured tobacco, the ratio shows a trend of decreasing, then increasing and finally stabilizing. The HM-C/(HA+FA)-C ratio under each treatment reaches its maximum at 7 d after fertilization. The HM-C/(HA+FA)-C ratios under T1, T2 and T3 treatments were significantly higher than those of the blank soil by 11.08, 26.04 and 41.90%, respectively. The ratio decreases during the fast-growing period of tobacco, probably because the growth of tobacco and the increase in temperature promote the transformation and decomposition between the various humus components of the soil. After the squaring period, the degree of humification tends to stabilize. By analyzing the differences between treatments, it can be seen that the (HA+FA)-C ratios of T2 and T3 treatments were significantly higher than those of T1 treatment by 13.46% and 27.75%, respectively, except for the 0 d of transplanting (7d of fertilization). There are no significant differences between treatments for other sampling times.

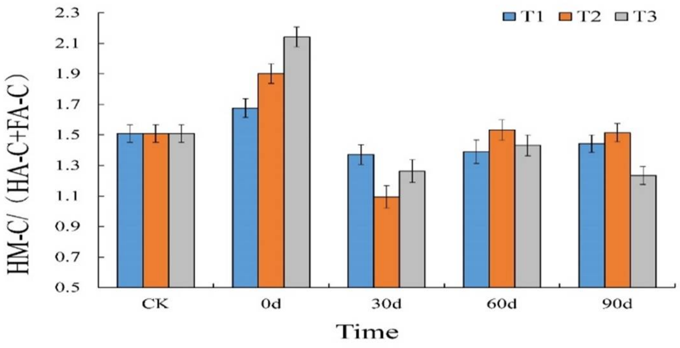

Fig. 8. HM-C/(HA-C+FA-C) value of farmland during tobacco growth.

The ratio of soil infrared spectral absorbance A2920/A1630 can reflect the aliphatic and aromatic properties of soil organic carbon (Zhang *et al*. 2016). To analyze the differences in the infrared spectra of soils with different treatments during the growing period of flue-cured tobacco, it was focused on comparing the changes in the intensity of absorption peaks at wavelengths of 2920 cm^{-1} and 1630 cm^{-1}. As shown in Figs 9 and 10, the variation of A2920/A1630 values for the single application of fertilizer was not significant during the growing period of flue-cured tobacco. The A2920/A1630 value under treatment with combined application of rice straw reaches the maximum at the squaring stage of flue-cured tobacco, which was significantly higher than that of blank soil by 227.44%. For the treatment with combined application of decomposed rice straw, the A2920/A1630 value of the rhizosphere soil of flue-cured tobacco reaches its maximum at the fast-growing period of tobacco, which is significantly higher than that of the blank soil by 439.39%. The A2920/A1630 value under T3 treatment is significantly higher than 439.39 and 341.93% in T1 and T2 treatments at 0 d of transplanting (7 d of fertilization). The A2920/A1630 value under T3 treatment was significantly higher than that under T1 and T2 treatments by 249.44 and 118.38% at 30 d of transplanting. After 60 d of transplanting, there was no significant difference in A2920/A1630 values between T2 and T3 treatments. At the maturity stage of flue-cured tobacco, the values under T2 and T3 treatments were significantly higher than that under T1 treatment by 227.43 and 232.32%. It can be seen that the A2920/A1630 value increases, the soil aromaticity decreases and the aliphaticity increases after the combined application of decomposed rice straw. Due to the decomposition of straw, the A2920/A1630 value under treatment with combined application of rice straw only reaches its maximum at the squaring stage of flue-cured tobacco, with a decrease in soil aromaticity and an increase in aliphaticity. This result indicated an increased content of soil aliphatic chain hydrocarbons and a decreased amount of aromatic carbon after the combined application of organic materials.

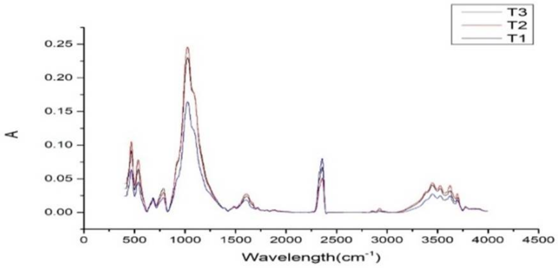

Fig. 9. Fourier infrared absorption spectroscopy of soil in 30 d (4000-310 cm^{-1}) of different treatments.

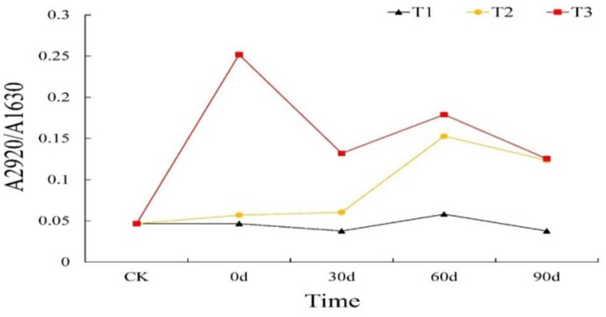

Fig. 10. A2920/A1630 value farmland during tobacco growth.

The organic matter content, humus components and the proportions between humus components in the soil after fertilization were analyzed. The infrared spectra of soil at A2920 cm^{-1} and A1630 cm^{-1} and the trend of their ratios were investigated. It can be seen that under the treatment of fertilizer application alone, soil organic matter, extractable HE-C, HA-C, HM-C contents and the A2920/A1630 ratio were not significantly different during the growth stage of flue-cured tobacco. The content and ratio of each indicator were lower than those under other treatments. At 0 d of flue-cured tobacco transplanting, HA-C, HM-C, HA/FA, PQ value and HM-C/HA-C + FA-C were 31.67, 31.40, 60.05, 28.01 and 27.75% higher under T3 treatment than under T1 treatment, respectively. At 30 d of transplanting, HE-C, HA-C and FA-C under T2 treatment were higher than those under T1 treatment by 29.41, 20.97 and 30.49%, respectively, indicating that the fertilizer reduction combined with organic materials can increase the content of organic matter, HA-C, HM-C and FA-C in tobacco-planting rhizosphere soil. The results are consistent with previous findings: The fertilizer reduction combined with the application of carbon-based organic fertilizer can increase the soil nutrient content, thus significantly enhancing the organic matter content of the cultivated soil (Zeng *et al*. 2021). The application of maize straw biochar increases the organic carbon content of both the surface and subsurface soils and their humus components to varying degrees (Zhang *et al*. 2016). The organic carbon content of the soil is higher in all the treatments with straw return than in treatments without straw return (Tian *et al*. 2010).

Under the treatment of fertilizer reduction with decomposed rice straw, all indicators reach their maximum values at 0 d of flue-cured tobacco transplanting (7 d after fertilization) except for extractable HE-C and FA-C, which reach their maximum values at 30 d after transplanting. In contrast, under treatment with the combined application of rice straw, each humus component reached the maximum value at 30 d of transplanting. The reason is that the proportion and content of stable humus components (HA and HM) increase after straw decomposition (Chen *et al*. 2009, Li *et al*. 2015). The decomposition process of directly returning straw to farmland conforms to the basic law of the degradation of macromolecular organic matter in the soil. The returned straw maintains suitable C/N environmental conditions for soil microorganisms. The small-molecule compound masses formed by mineralization and decomposition, followed by humic substances by humification under the action of lignin or its decomposed intermediates further illustrates that the formation and accumulation of stable components such as HA and HM can be accelerated by the treatment of fertilizer reduction combined with decomposed rice straw (Tian *et al*. 2010).

To further clarify the changes in soil carbon composition during the growing period of flue-cured tobacco and the mineralization pattern of soil carbon with fertilizer reduction combined with crop straw, the relative proportion of soil humus components and infrared spectra were analyzed. At 7 d after fertilization, the HA/FA, PQ value and HM/(HA+FA) at 7 d were significantly higher under the treatment of fertilizer reduction combined with decomposed rice straw than under treatment with fertilizer alone by 62.05 28.01 and 27.75%, respectively. It can be seen that fertilizer reduction combined with decomposed rice straw can significantly improve the humification degree of soil humus and increase the content of HA and HM to a stable level. Moreover, the analysis of the soil infrared spectra A2920/A1630 value shows that after the treatment with combined application of rice straw and decomposed rice straw, the aliphatic chain hydrocarbon content of the soil was elevated and the amount of aromatic carbon was reduced, with a decrease in aromaticity and an increase in aliphaticity.

Chemical fertilizer reduction with rice straw and decomposed rice straw can increase the content of organic matter, HA-C, HM-C and FA-C in the tobacco-planting rhizosphere soil, resulting in higher content of soil aliphatic chain hydrocarbons, reduced aromatic carbon, lower soil aromaticity and higher aliphaticity decomposed rice straw accelerates the formation and accumulation of stable components such as HA and HM, which can significantly improve the humification degree of soil humus and increase the content of HA and HM to a stable level.

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