agronomy

MDPI

Article

Maize Straw Returning Approaches Affected Straw Decomposition and Soil Carbon and Nitrogen Storage in Northeast China

Ping Tian, Pengxiang Sui, Hongli Lian, Zhengyu Wang, Guangxin Meng, Yue Sun, Yingyan Wang, Yehan Su, Ziqi Ma, Hua Qi * and Ying Jiang *

College of Agronomy, Shenyang Agricultural University, Shenyang 110866, China; tianping23@stu.syau.edu.cn (P.T.); suipengxiang@stu.syau.edu.cn (P.S.); 2019200057@stu.syau.edu.cn (H.L.); wangzhengyu27@stu.syau.edu.cn (Z.W.); 20172202241@stu.syau.edu.cn (G.M.); 2017220244@stu.syau.edu.cn (Y.S.); wangyingyan@stu.syau.edu.cn (Y.W.); 2017220228@stu.syau.edu.cn (Y.S.); 2018240174@stu.syau.edu.cn (Z.M.)

* Correspondence: qihua10@syau.edu.cn (H.Q.); jiangying@syau.edu.cn (Y.J.); Tel.: +86-024-88487135 (Y.J.)

Received: 3 November 2019; Accepted: 25 November 2019; Published: 28 November 2019

check for updates

Abstract: The characterization of straw decomposition and the resulting carbon (C) and nitrogen (N) release is crucial for understanding the effects of different straw returning methods on the immobilization and cycling of soil organic carbon (SOC) and soil total nitrogen (STN). In 2017–2018, a field micro-plot experiment was carried out in northeastern China to investigate the effects of different straw returning approaches on straw decomposition, C release, N release, SOC, STN, and the soil C–N ratio. Six straw returning treatments were applied: straw mixed with soil (SM) and straw buried in the soil (SB) at soil depths of 10 (O), 30 (T), and 50 cm (F). The results indicate that the straw decomposition proportion (SD), C release, and N release in SM + O were higher than that in SM + T and SM + F. Moreover, SOC and STN concentrations and the soil C–N ratio were significantly enhanced by SM/B + O in the 0–20 cm soil layers, SM/B + T in the 20–30 cm soil layer, and SM/B + F in the 40–60 cm soil layers. In the 0–50 cm soil profile, the highest SOC stocks were obtained using SB + T. The STN stocks were also significantly affected by the straw returning depth, but the effect was inconsistent between the two years. SD had a positive relationship with SOC and STN in the 0–20 cm soil layers; conversely, they were negatively related in the 30–60 cm soil layers. The results of this study suggest that straw buried in the soil to a depth not exceeding 30 cm might be an optimal straw returning approach in northeastern China.

Keywords: crop residue incorporation; straw decomposition; residue C and N release; SOC and STN stocks

1. Introduction

Feeding the increasing population has required intensified conventional tillage and high nitrogen input for food production, resulting in the extensive loss of productive soil [1]. For instance, the massive loss of soil organic carbon (SOC) due to conventional tillage management has caused an increase in soil erosion and the destruction of soil structure [2], which, in turn, are related to the decreases in cropland productivity that are clearly observed in parts of developing countries [3]. The ongoing land degradation in northeast China—a key base of commodity grain, accounting for approximately 30% of maize of China [4]—has threatened sustainable crop production and even national food security [5]. Thus, for several years, maize producers have been encouraged to incorporate the resulting crop residue, which is a highly accessible form of organic matter, into agricultural soils to maintain the soil organic matter (SOM) content [6,7] and thus contribute to soil quality improvement [8] and identify the ill effects of burning maize residues in the field [9].

To date, maize straw incorporation by rotary or plow tillage remains the predominant approach for residue return because the surface retention with no-till systems is associated with low decay rates due to the low average temperature and low precipitation conditions in northeast China [10]. Different management practices result in the varying placement of crop residue in agricultural field soils; for example, residues can be incorporated into soil or surface mulch. Furthermore, in an agrosystem, the complex feedback between the climate, the soil type, and management factors make it difficult to predict the effects of crop residue placement on its decomposition rate and the ultimate fate of the derived nutrients [11]. In particular, the soil microenvironments for biological and chemical processes located in the soil surface differ from those in shallow or deep soils; thus, the depth also influences the decomposition and nutrient release of incorporated crop residues [12]. Recently, studies have shown that the decay rate and nutrient release of crop residues in the soil are site-specific because the decomposer community [13] and nutrient sources vary between the topsoil and subsoil [11,14,15]. Additionally, straw decomposition is accompanied by the release of straw-derived carbon and nitrogen, which, in turn, interact with the residue decomposition process [16,17]. Therefore, in the maize production of northeast China, it is critical to clarify the effects of different straw incorporation approaches on the decay proportion and straw-derived C and N release levels, as well as the interactions between the release levels and the soil content of C and N.

Straw returning methods not only affect the straw decomposition rate but also influence the cycle and immobilization of SOC and soil total nitrogen (STN) in field ecosystems [18]. The responses of SOC and STN dynamics to crop residue input can be influenced by many factors, such as the soil's moisture, temperature, and biochemical properties, which all vary depending on the straw returning method and the depth of soil incorporation [19]. Leaving crop residue on the soil surface tends to concentrate C on the soil surface, while incorporating straw residue into the soil by tillage is usually considered to contribute to C losses due to increased SOM decomposition rates [20] as tillage disturbs the soil's structural stability, redistributes organic matter, and influences the microbial activity throughout the soil profile [8]. However, several studies have also observed increases in SOC content in deeper layers from the incorporation of residues in the soil [21–23]; thus, the total SOC stored in the soil by surface retention may be the same as that resulting from incorporation approaches when the whole soil profile is studied [24]. In addition to the inconsistent effects on SOC content, the variable effect of straw incorporation management strategies on STN has also been emphasized [25,26]. Crop residues incorporated into the soil at different depths influence STN through highly complex mechanisms involving N mineralization and immobilization [27], as well as N leaching and denitrification losses in soil [18]. In addition, the concentration of STN has been statistically correlated with SOC content in general soil types [26], and the soil C–N ratio may reflect the interaction between SOC and STN under tillage practices for straw incorporation. Thus, it is necessary to investigate residues incorporated at various returning depths by sampling the entire plow depth to accurately assess the influence of residue incorporation practices on SOC, STN, and the soil C–N ratio [28].

Given this high variability, the effects of straw incorporation practices on SOC and STN stocks, as reported by the studies mentioned above, have been conflicting [25,26]. For instance, Xue et al. [29] investigated a paddy cropping system in southern China, and their results indicated that the application of residue with no-till farming enhanced the SOC and STN stocks in the 0–10 cm layer, whereas plow tillage increased the SOC and STN stocks in the 0–50 cm profile [29]. However, Dikgwatlhe et al. [26] observed no significant differences among straw returning treatments for SOC stocks in the 0–50 cm soil profile, but they noted that STN stocks increased [26]. Additionally, an earlier study reported that SOC and STN stocks in the 0–50 cm soil profile did not significantly differ between soils subjected to straw returning by rotary tillage and that by moldboard plow tillage [25]. The different findings for SOC and STN stocks among the previous studies are likely the result of variations in factors such as climate, soil type, and tillage intensity. To date, although the benefits of crop residue retention have been well documented in the previous literature, few studies have assessed the influence of straw returning practices on SOC and STN stocks. It is critical to obtain comprehensive knowledge of the effects of different returning methods and depths on SOC and STN dynamics and their correlation with the straw decay proportion in different soil layers. Therefore, the objectives of the present study were to (1) determine the effects of different straw returning methods and depths on the decomposition and C and N release proportions of maize straw residue, (2) evaluate the effects of straw returning approaches on SOC and STN stocks in the 0–50 cm soil profile, (3) investigate the response of SOC and STN concentrations in different soil layers on straw incorporation and their interactions with the straw decomposition ratio during the decay process, and (4) identify a suitable straw returning approach for the sustainability of maize production in northeastern China.

2. Materials and Methods

2.1. Site Description

The field experiment was conducted in 2017 and 2018 at the Experimental Station of Shenyang, Agricultural University, Shenyang, Liaoning province, China (41°82′ N, 123°56′ E; 43 m above sea level). This area is located in a flat region that is characterized by a sub-humid warm-temperate continental climate. The average annual temperature was 9.17 °C, with a frost-free period of 155–180 days. According to measurements taken before this study, the concentration of SOC, STN, available phosphorus, available potassium, and soil bulk density in the soil layer (0–20 cm) were 10.81g kg^{-1}, 0.92 g kg^{-1}, 51.17 mg kg^{-1}, 128.49 mg kg^{-1}, and 1.43 g cm^{-3}, respectively. The main crop in this region is spring maize (*Zea mays* L.), and the crop-planting pattern is one harvest per year. All the water required for crop growth was provided by natural precipitation in this study. During the experimental period, precipitation and temperature were measured using an automatic weather station (5TM, Decagon, Washington, USA) around the experimental site (Figure 1). The mean daily air temperature during the experiment was 9.26 and 9.09 °C; the highest temperatures were 26.36 and 27.21 °C, and the lowest temperatures were −8.77 and −12.20 °C in July and January 2017 and 2018, respectively. The total precipitation levels in 2017 and 2018 were 456.4 and 505.2 mm, 58.81% and 73.12% of which occurred from June to August, while 9.03% and 11.05% of the total precipitation occurred in May, which is a critical period for straw decomposition. The annual precipitation was lower than the mean annual precipitation of 714 mm [30], indicating that the experimental periods were seasons characterized by poor rainfall.

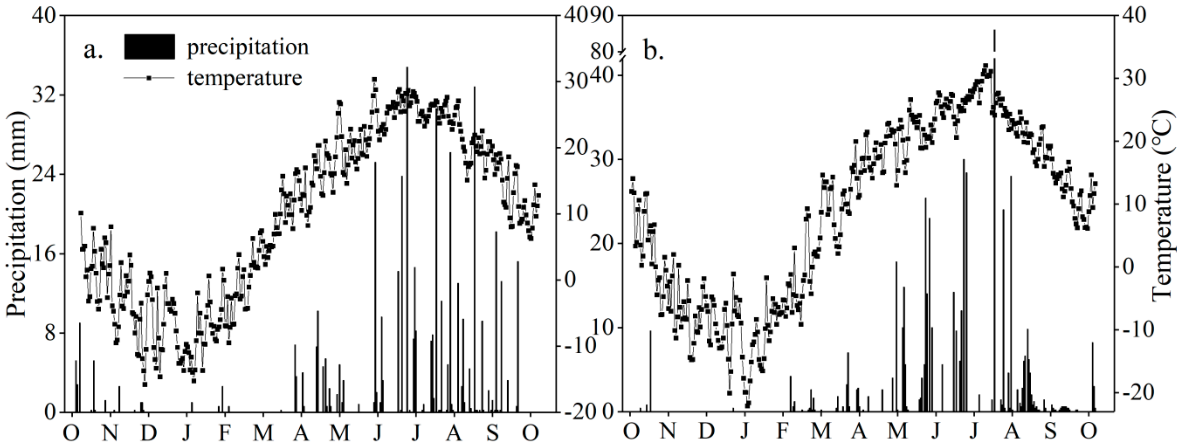

Figure 1. Mean daily precipitation and temperature during (**a**) October 2016–October 2017 and (**b**) October 2017–October 2018 at the experimental site.

2.2. Experimental Design

This study employed a two-factor (straw returning method, M; straw returning depth, D) design in randomized complete blocks with three replicates. Micro-plots [31] were used for six straw returning treatments: straw mixed (SM) with soil at a depth of 10, 30, and 50 cm (O, T, and F) and straw buried (SB) in soil at a depth of 10, 30, and 50 cm (O, T, and F). The SM and SB treatments as straw returning methods (M) were intended to simulate straw returning by rotary tillage and plow tillage in the field, respectively. All micro-plots were made by using stainless-steel plates (length, width, and height of $1.5 \times 1.2 \times 0.7$ m) without bottoms; undisturbed soil was employed in all the micro-plots. Before being returned into the soil, the maize straw was chopped into 3–5 cm pieces. The maize straw was then manually incorporated into the soil in the plots on 24 October 2016 and 24 October 2017. The C and N contents of the straw for incorporation were 9.51 g N kg^{-1} and 415.75 g C kg^{-1}(C–N = 44:1) in 2017 and 9.70 g N kg^{-1} and 443.01 g C kg^{-1}(C/N, 46:1) in 2018.

The C and N release dynamics of maize straw from different treatments were investigated by using the litterbag decomposition technique described by Varela et al. [32] and Xu et al. [18] with a few modifications. Briefly, air-dried straw (53 g per treatment in nylon bags, which is equivalent to the amount of straw returned to the field) was chopped and placed into nylon mesh bags (20×30 cm, 0.1 mm mesh). For the SM + O treatment, one nylon bag of straw was placed into the soil at a depth of 0–10 cm and a slope of 30°. For the SM + T and SM + F treatments, three and five nylon bags, respectively, with the same amount of straw (a total of 53 g of straw was equally separated into three or into five nylon bags) were set up with the same method per 10 cm of the soil profile. For the SB + O, SB + T, and SB + F treatments, one nylon bag loaded with 53 g of maize straw was placed in the 10, 30, and 50 cm soil layer, respectively, with no slope. All the litterbags had three replications. After crop harvest, the straw was collected from the litterbag and then shaken gently over a 1 mm sieve and spray-rinsed to remove the adhering soil. The straw samples were oven-dried in envelopes at 60 °C until the weight was constant. The samples were then weighed and ground to pass through a 0.15 mm sieve for further chemical analysis.

Basal fertilizer with 75 kg ha^{-1} N, 90 kg ha^{-1} P, and 90 kg ha^{-1} K was used when maize was sowed, and 150 kg ha^{-1} N was applied as topdressing around the middle of June. The variety of maize used was Zhengdan 958 (Jinboshi, Zhengzhou, China), and it was sowed at a rate of 67,500 plants ha^{-1} at the end of April and harvested at the end of September. The management practices for controlling pests, disease, and weeds were according to local practices for high-yield production.

2.3. Sampling and Analysis Methods

The weight loss of the straw in the nylon bag was assumed to be the amount of straw that decomposed during the experimental period and was calculated using Equation (1). The amount of N or C lost from the straw was calculated as the difference between the initial N or C contained in the input straw and the N or C recovered from the treated straw; it was determined using Equation (2).

$$\mathrm{SD} = \frac{\mathrm{W_0} - \mathrm{W_t}}{\mathrm{W_0}} \times 100\% \tag{1}$$

$$\mathrm{NR} = \frac{\mathrm{W_0} \times \mathrm{C_0} - \mathrm{W_t} \times C_t}{\mathrm{W_0} \times \mathrm{C_0}} \times 100\% \tag{2}$$

where SD is the straw decomposition proportion (%); NR is the nutrient release proportion (%); W_0 and W_t are the initial and remaining straw weights (g), respectively; and C_0 and C_t are the nutrient concentrations (g kg^{-1}) in the initial and remaining straw, respectively.

Soil sampling and analysis were performed immediately after harvest in 2017 and 2018. In each plot, six soil samples were collected using a coring tube (5 cm in diameter) from depths between 0 and 60 cm at 10 cm intervals. The soil samples that were collected from two points in each plot with replication were mixed to produce a composite sample. The samples were air-dried with plant stubbles and pebbles discarded and then ground through a 0.15 mm sieve for SOC and STN determination.

SOC and STN concentrations (g kg^{-1}) were determined using the $K_2Cr_2O_7$-H_2SO_4 digestion method [26] and the Kjeldahl method [33], respectively. The soil C–N ratio was calculated according to the values from the SOC and STN measurements. SOC and STN stocks were calculated by the equivalent soil mass (ESM) method to eliminate the uncertainties associated with the fixed-depth method and Equation (3) according to the description by Ellert et al. and Xue et al. [29,34].

$$M_{element} = \sum_{i=1}^{n} [M_{soil,\,i} \times conc_i + (M_{o,i} - M_{soil,i}) \times conc_{i+1}] \times 0.001 \quad (3)$$

where i is the soil layer (i = 1, 2, 3, 4, and 5 represent the 0–10, 10–20, 20–30, 30–40, and 40–50 cm soil layers, respectively); $M_{element}$ is the SOC or STN stocks (Mg ha^{-1}); $M_{soil,i}$ is soil mass per unit area in the ith layer (Mg ha^{-1}), which is calculated by Equation (4); $M_{o,i}$ is the equivalent soil mass of each layer; and $conc_i$ and $conc_{i+1}$ are the concentrations of SOC or STN in the ith and i+1th layers, respectively (g kg^{-1}).

$$M_{soil,\,i} = \rho_{b,\,I} \times T_i \times 10000 \quad (4)$$

where $M_{soil,i}$ is soil mass per unit area in the ith layer (Mg ha^{-1}), $\rho_{b,i}$ is soil bulk density in the ith layer (g cm^{-3}), and T_i is the thickness of the ith layer (m).

2.4. Statistical Analysis

The effects of the different treatments on all the data were analyzed by ANOVA using the SPSS 23.0 (SPSS Inc., Chicago, Illinois, USA) software, and effects of years were analysed separately. The SPSS procedure was used to analyze the variance and determine the statistical significance of the treatment. Duncan's multiple range test was used to compare the treatment means at a 95% confidence level.

3. Results

3.1. Straw Decomposition Proportion

The ANOVA results demonstrate that the straw returning depth had a consistently significant effect on the maize straw decomposition proportion in both study years, but the straw returning method and its interaction effects with the returning depth only exhibited a significant difference in 2017, with no significant differences observed in 2018 (Figure 2). Under the SM treatments, the straw decomposition proportion decreased with the increasing depth of maize residue incorporation (O, T, and F treatments), and the tendency was similar in 2017 and 2018. Compared with the SM + T and SM + F treatments, the breakdown of maize residue in the SM + O treatment was 5.81% and 9.14% higher in 2017, and 22.09% and 56.28% higher in 2018. In 2017, a slight variation in the residue decomposition proportion was found between the SB + O, SB + T, and SB + F treatments, whereas a significant reduction was observed between the same treatments in 2018, with a significant difference between the SB + T and SB + F treatments in 2018, but not 2017 ($P < 0.05$). Overall, the shallow residue incorporation (O treatment) had the highest decomposition proportion under the SM and SB management approaches in both seasons. Moreover, the maize straw decomposition proportion in 2017 was generally higher, ranging from 63.25% to 69.09% between the treatments, while the results in 2018 ranged from 39.82% to 62.23%.

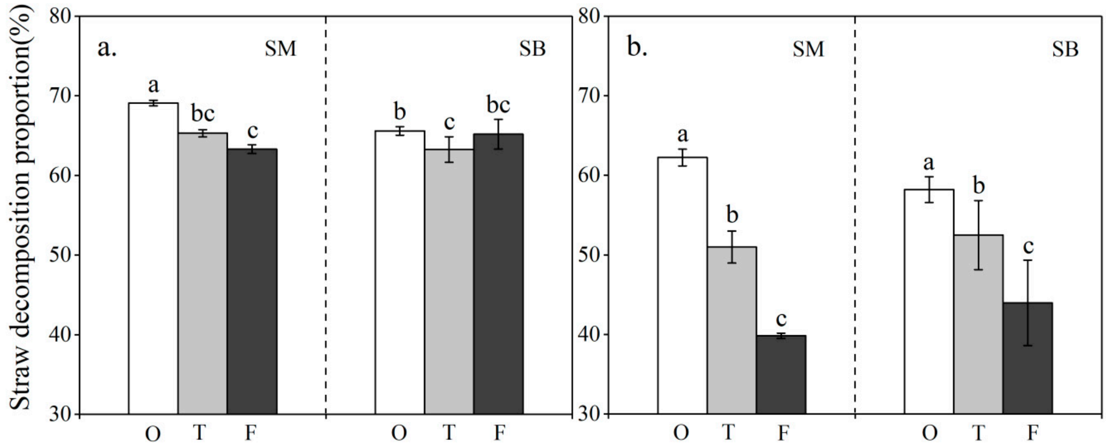

Figure 2. The effect of different straw returning management approaches on the straw decomposition proportion in (**a**) 2017 and (**b**) 2018. ANOVA results: straw returning depth (D) ***, straw returning method (M) *, D × M ** in 2017; D ***, M ns, D × M ns in 2018 (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; ns, not significant). SM and SB indicate straw mixed with soil and buried in soil, respectively, and O, T, and F indicate straw incorporated into the soil (mixed or buried) at depths of 10, 30, and 50 cm, respectively. The bars with different letters indicate statistically significant differences between treatments at $P < 0.05$.

3.2. Straw-Derived C and N Release

In both study years, the straw-derived C release proportion during the decay process was significantly influenced by the straw incorporation depth but not by the returning method. Their interaction effects differed significantly in 2017, but no difference between them was observed in 2018 (Figure 3). Generally, the proportion of C released by straw decay had a similar tendency to the straw decomposition indicator between treatments and between years. Additionally, in 2017, the C release proportion under the SM + O treatment was higher than that under the SM + T and SM + F treatments, but it only slightly fluctuated and lacked statistical significance under the SB treatments. In 2018, under SM and SB returning practices, the C release proportion significantly decreased (by 45.08–66.07% and 46.32–62.88%, respectively) as the depth of straw incorporation increased.

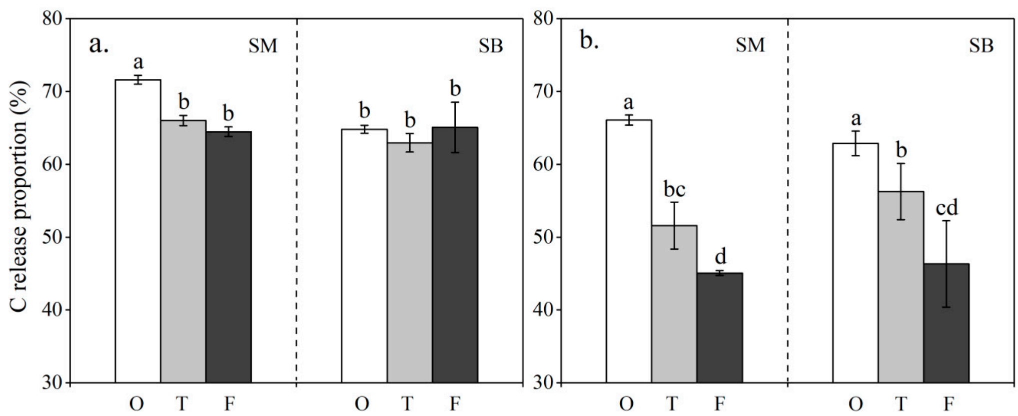

Figure 3. The effect of different straw returning management approaches on the straw carbon release proportion in (**a**) 2017 and (**b**) 2018. ANOVA results: straw returning depth (D) ***, straw returning method (M) ns, D × M ** in 2017; D ***, M ns, D × M ns in 2018 (** $P < 0.01$; *** $P < 0.001$; ns, not significant). SM and SB indicate that the straw was mixed with soil and buried in soil, respectively, and O, T, and F indicate that straw was incorporated into the soil (mixed or buried) at depths of 10, 30, and 50 cm, respectively. The bars with different letters indicate statistically significant differences between treatments in each year at $P < 0.05$.

In 2017, the proportion of straw-derived N release exhibited a decreasing tendency with incorporation depth under the SM treatments; the SM + F treatment was found to cause a significantly lower N release proportion than the SM + O treatment, but there was no difference between the returning depth treatments under SB management approaches. In 2018, the N release proportion under SM + O was 0.66-fold and 2.30-fold higher than the results under the SM + T and SM + F treatments, respectively. Under the SB treatment, the N release proportion under SB + O was significantly higher than that under the SB + T treatment, and there was no difference between SB + T and SB + F. Thus, according to the ANOVA results, the straw returning depth resulted in significant differences in the N release proportion in 2018 and no difference in 2017. The returning methods had no significant influence on straw-derived N release, but the interactive effects between the straw incorporation depth and the methods consistently showed significant differences in both experimental periods (Figure 4).

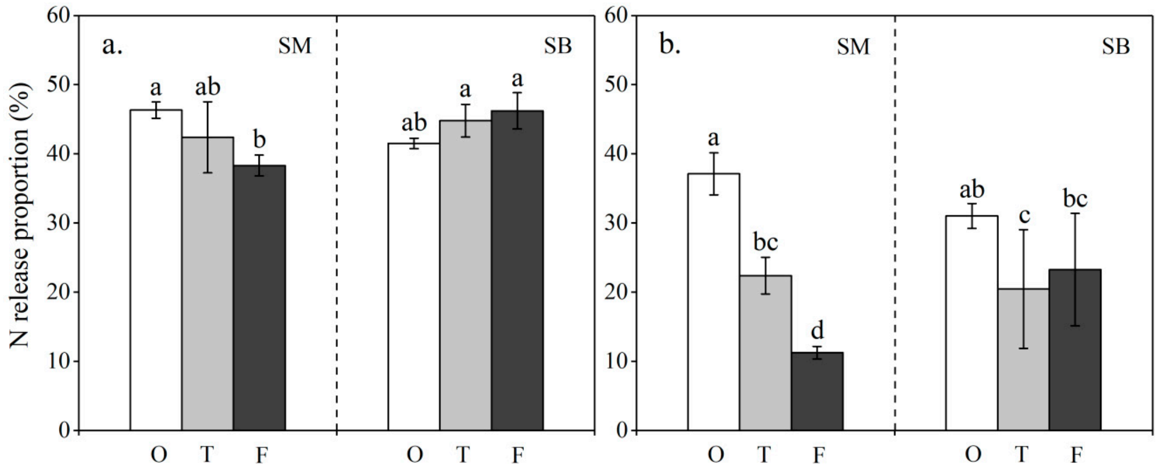

Figure 4. The effects of different straw returning management approaches on the straw nitrogen release proportion in (**a**) 2017 and (**b**) 2018. ANOVA results: straw returning depth (D) ns, straw returning method (M) ns, D × M ** in 2017; D ***, M ns, D × M * in 2018 (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; ns, not significant). SM and SB indicate that the straw was mixed with soil and buried in soil, respectively, and O, T, and F indicate that the straw was incorporated into the soil (mixed or buried) at depths of 10, 30, and 50 cm, respectively. The bars with different letters indicate statistically significant differences between the treatments in each study year at $P < 0.05$.

3.3. Soil Organic Carbon (SOC) and Soil Total Nitrogen (STN) Concentration

Regardless of whether the maize residue was mixed or buried in the soil, the SOC concentration throughout the soil profile (0–60 cm) was significantly affected by the straw returning approaches over the experimental period, but there was no difference between SM_{mean} and SB_{mean} in either study year (Figure 5). Generally, the changes in SOC concentration in the 0–60 cm soil profile in the SM and SB treatments followed a similar trend. In both study years, in the soil samples taken from a depth greater than 30 cm (the SM/B + O and SM/B + T treatments), the SOC concentration sharply decreased (Figure 5a,b,d,e), which caused a corresponding marked reduction in the SM_{mean} and SB_{mean} of the SOC content (Figure 5c,f); however, the same trend did not occur under the SM/B + F treatment. In the 0–20 cm soil layer, the SOC content under the SM/B + O treatment was significantly higher than that under the SM/B + T and SM/B + F treatments in both 2017 and 2018 ($P < 0.05$, Figure 5a,b,d,e). In both study years, the SOC content in the 20–30 cm soil layer was highest under the SM/B + T treatment, followed by that under the SM/B + O and SM/B + F treatments. In contrast, at depths below 30 cm, the SOC content was clearly higher under the SM/B + F treatment compared with that under the SM/B + O and SM/B + T treatments.

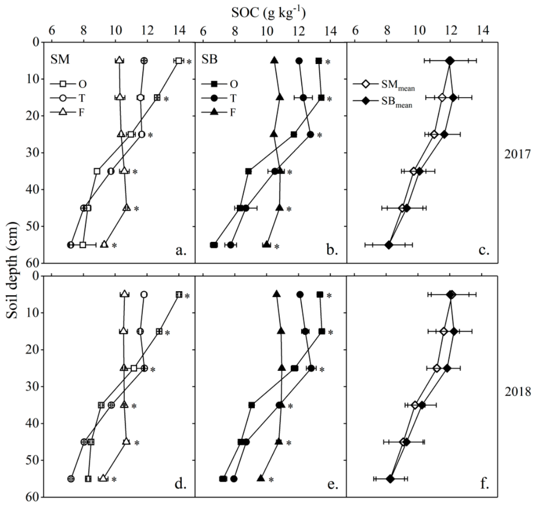

Figure 5. Soil organic carbon (SOC) content in the 0–60 cm soil profile under different straw returning strategies in (**a**–**c**) 2017 and (**d**–**f**) 2018. SM and SB indicate straw mixed with soil and buried in soil; O, T, and F indicate straw incorporated (mixed or buried) into the soil at depths of 10, 30, and 50 cm, respectively. SM_{mean} is the mean of SM + O, SM + T, and SM +F; SB_{mean} is the mean of SB + O, SB + T, and SB + F; * indicates significant differences ($P < 0.05$) between the straw incorporation depth treatments for the same soil layer.

The trends and significant differences in the STN concentration were generally similar to those of the SOC content between different straw returning treatments and soil layers in the 0–60 cm soil profile. In both years of the experiment, the average STN values for SM and SB were very close to each other and linearly decreased as the depth of the soil layers increased (Figure 6). In the 0–20 cm soil layer, the STN content under the SM/B + O treatment was significantly higher than that under the SM/B + T and SM/B + F treatments (Figure 6a,b,d,e). Under the SM/B + F treatment, in both years, the STN content tended to slightly fluctuate while gradually declining with increasing depth in the 0–60 cm soil profile; this pattern was similar to the changes in SOC content.

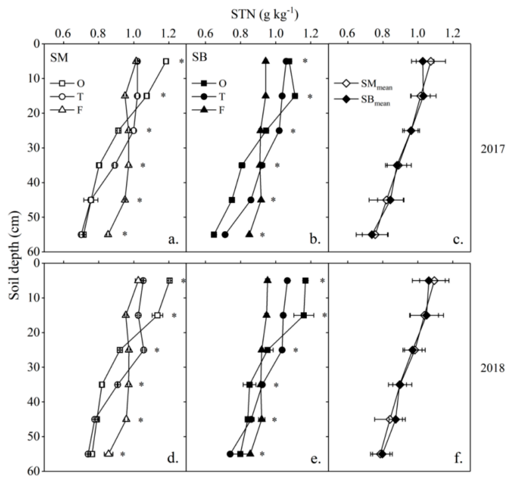

Figure 6. Soil total nitrogen (STN) content in the 0–60 cm soil profile under different straw returning strategies in (**a**–**c**) 2017 and (**d**–**f**) 2018. SM and SB indicate straw mixed with soil and buried in soil; O, T, and F indicate straw incorporated (mixed or buried) into the soil at depths of 10, 30, and 50 cm, respectively; SM_{mean} is the mean of SM + O, SM + T, and SM + F; SB_{mean} is the mean of SB + O, SB + T, and SB + F; * indicates significant difference ($P < 0.05$) between the straw incorporation depth treatments for the same soil layer.

3.4. Soil Organic Carbon (SOC) and Soil Total Nitrogen (STN) Stocks

The mean SOC stocks under the SB treatments were significantly higher than that under the SM treatments in the 10–20, 20–30, and 30–40 cm soil layers as well as the 0–50 cm soil profile in both study years and in the 40–50 cm soil layer in 2018 (Table 1). In the 0–50 cm soil profile, the highest SOC stocks among all treatments were obtained with SB + T, with values of 77.38 and 77.14 Mg ha^{-1} in 2017 and 2018, respectively. Moreover, the SOC stocks in different soil layers and the overall 0–50 cm soil profile were significantly influenced by the straw returning depth treatments. Of all the soil layers and straw returning depths, the highest SOC stocks were in the 0–20 and 30–50 cm soil layers under the SM/B + O and SM/B + F treatments, respectively.

The mean STN stock in the overall 0–50 cm soil profile did not significantly differ between the SM and SB treatments, but it significantly differed in the 0–10 cm soil layer in both years and in the 10–20 and 40–50 cm layers in 2017 and 2018, respectively (Table 1). In the 0–50 cm soil profile, among all the treatments, the STN stocks were the highest under SB + T (6.74 Mg ha^{-1}) and SB+O (6.76 Mg ha^{-1}) in 2017 and 2018, respectively. In both study seasons, similar to the SOC stocks, the STN stocks in the 0–50 cm soil profile, were strongly influenced by the straw incorporation depths. In the 0–20 cm soil layers, the STN stocks were greater under SM/B + O than those treated with SM/B + F; conversely, in the 30–50 cm soil layers, the STN stocks were higher under the SM/B + F treatments than those under the SM/B + O treatments. In both 2017 and 2018, of the three returning depth treatments in the SM incorporation system, the overall (i.e., in the 0–50 cm profile) STN stocks were the highest for SM + F. However, when the straw was treated using the SB approach, the overall STN stocks were higher under the SB + O/T treatments than the SB + F treatment.

Table 1. Soil Organic Carbon (SOC) and Soil Total Nitrogen (STN) stocks in the 0–50 cm profile under different straw returning approaches in 2017 and 2018.

Year	Treatment		SOC (Mg ha^{-1}), Depth (cm)						STN (Mg ha^{-1}), Depth (cm)					
			0–10	10–20	20–30	30–40	40–50	0–50	0–10	10–20	20–30	30–40	40–50	0–50
2017	SM	O	18.57 a	16.65 b	15.88 d	12.62 d	11.38 bc	75.10 b	1.57 a	1.41 b	1.32 d	1.15 d	1.04 d	6.49 b
		T	15.79 c	15.39 c	16.48 c	13.86 c	11.04 c	72.56 c	1.37 c	1.36 d	1.43 b	1.27 c	1.04 d	6.47 b
		F	13.73 d	13.67 e	15.04 e	15.11 ab	14.64 a	72.19 c	1.35 c	1.26 e	1.41 b	1.38 a	1.30 a	6.70 a
		Mean	16.03 A	15.24 B	15.80 B	13.86 B	12.35 A	73.28 B	1.43 A	1.34 B	1.39 A	1.27 A	1.13 A	6.56 A
	SB	O	17.79 b	17.83 a	16.92 b	12.64 d	11.37 bc	76.55 a	1.44 b	1.47 a	1.37 c	1.15 d	1.03 d	6.46 b
		T	16.13 c	16.41 b	18.15 a	14.80 b	11.89 b	77.38 a	1.42 b	1.38 c	1.46 a	1.31 b	1.17 c	6.74 a
		F	14.06 d	14.36 d	15.18 e	15.50 a	14.86 a	73.96 b	1.26 d	1.25 e	1.32 d	1.30 bc	1.26 b	6.39 c
		Mean	15.99 A	16.20 A	16.75 A	14.31 A	12.71 A	75.96 A	1.37 B	1.37 A	1.38 A	1.25 A	1.15 A	6.53 A
2018	SM	O	17.96 a	16.84 b	15.95 cd	12.93 d	11.54 c	75.22 c	1.55 a	1.49 a	1.32 c	1.16 d	1.07 d	6.59 bc
		T	15.23 d	15.42 c	16.50 bc	13.82 c	10.94 d	71.91 e	1.36 c	1.37 b	1.48 a	1.29 b	1.06 d	6.56 c
		F	13.66 e	13.99 e	15.09 e	15.03 b	14.43 a	72.20 e	1.32 d	1.27 c	1.39 b	1.38 a	1.29 a	6.65 abc
		Mean	15.62 A	15.42 B	15.85 B	13.93 B	12.30 B	73.11 B	1.41 A	1.38 A	1.40 A	1.28 A	1.14 B	6.61 A
	SB	O	17.21 b	17.88 a	16.75 b	12.82 d	11.35 c	76.01 b	1.51 b	1.54 a	1.36 b	1.21 c	1.14 c	6.76 a
		T	15.62 c	16.56 b	18.03 a	15.10 b	11.83 b	77.14 a	1.37 c	1.39 b	1.47 a	1.30 b	1.16 c	6.69 ab
		F	13.70 e	14.50 d	15.65 de	15.48 a	14.56 a	73.89 d	1.23 e	1.26 c	1.31 c	1.30 b	1.25 b	6.35 d
		Mean	15.51 A	16.31 A	16.81 A	14.47 A	12.58 A	75.68 A	1.37 B	1.40 A	1.38 A	1.27 A	1.18 A	6.60 A

ANOVA for SOC stocks (0–50 cm): straw returning depth (D) ***, straw returning method (M) ***, D × M ** in 2017, D ***, M ***, D × M *** in 2018. ANOVA for STN stocks (0–50 cm): D ***, M ns, D × M *** in 2017; D **, M ns, D × M *** in 2018 (** $P < 0.01$; *** $P < 0.001$; ns, not significant). SM and SB indicate that the straw was mixed with soil and buried in soil, and O, T, and F indicate that straw was incorporated (mixed or buried) into the soil at depths of 10, 30, and 50 cm, respectively. The different lowercase within column for each year indicate significant differences statistically ($P < 0.05$) between straw returning depths (O, T, and F) and different capital letters within column for each year indicate significant differences statistically ($P < 0.05$) between soil returning approaches (SM and SB).

3.5. Soil C–N Ratio

In both years, the straw returning depths had significant effects on the soil C–N ratio in the different soil layers of the 0–60 cm soil profile. The mean soil C–N ratio did not significantly differ between the SB and SM incorporation methods, except for that in the 10–20 cm soil layer in 2018 (Table 2). At the 0–10 and 10–20 cm soil depths, the highest soil C–N ratios were obtained using SB + O in 2017, SM + O in 2018, and SB + T in 2018. Of all treatments in this study, the soil C–N ratios were highest under the SB + T treatment in the 20–30 cm soil layer and the SB + F treatment in the 30–60 cm soil layers with a 10 cm interval. In both experimental seasons, the mean soil C–N ratio at different sampling depths was lower in the SM treatments than the SB treatments, except for in the 40–50 cm soil layer in 2018.

Table 2. Soil C–N ratio in the 0–60 cm profile under different straw returning approaches in 2017 and 2018.

Year	Treatment		Soil Depth (cm)					
			0–10	**10–20**	**20–30**	**30–40**	**40–50**	**50–60**
2017	SM	O	11.81 b	11.76 ab	12.03 b	11.02 b	10.92 abc	11.13 ab
		T	11.57 bc	11.35 bc	11.66 c	10.90 b	10.63 bc	10.27 b
		F	10.11 e	10.82 c	10.67 d	10.89 b	11.27 ab	10.89 ab
		Mean	11.16 A	11.31 A	11.46 A	10.93 A	10.94 A	10.76 A
	SB	O	12.33 a	12.10 a	12.38 a	10.96 b	11.07 ab	10.30 b
		T	11.35 cd	11.86 ab	12.50 a	11.41 ab	10.11 c	10.86 ab
		F	11.11 d	11.48 b	11.43 c	11.92 a	11.78 a	11.76 a
		Mean	11.60 A	11.81 A	12.10 A	11.43 A	10.99 A	10.97 A
2018	SM	O	11.65 a	11.26 bc	12.14 a	11.15 b	10.74 c	10.90 a
		T	11.22 b	11.29 bc	11.20 bc	10.75 c	10.36 b	9.76 b
		F	10.33 c	11.03 c	10.85 c	10.89 bc	11.18 b	10.81 a
		Mean	11.06 A	11.19 B	11.40 A	10.93 A	10.76 A	10.49 A
	SB	O	11.41 ab	11.62 ab	12.33 a	10.66 c	9.97 c	9.60 b
		T	11.34 b	11.91 a	12.35 a	11.69 a	10.14 bc	10.72 a
		F	11.14 b	11.50 abc	11.91 ab	11.93 a	11.70 a	11.27 a
		Mean	11.30 A	11.68 A	12.20 A	11.43 A	10.60 A	10.53 A

SM and SB indicate that straw was mixed with soil and buried in soil, and O, T, and F indicate that straw was incorporated into the soil (mixed or buried) at depths of 10, 30, and 50 cm, respectively. The different lowercase within column for each year indicate significant differences statistically ($P < 0.05$) between straw returning depths (O, T, and F) and different capital letters within column for each year indicate significant differences statistically ($P < 0.05$) between soil returning approaches (SM and SB).

3.6. Relationship Between the Straw Decomposition Proportion and the Soil Organic Carbon (SOC) and Soil Total Nitrogen (STN) Concentrations

Figures 7 and 8 show the fitted correlations between the straw decomposition proportion (SD) and the SOC and STN concentrations, respectively. The results indicate that the SD–SOC and SD–STN relationships had parallel tendencies throughout the 0–60 cm soil profile. In the 0–10 and 10–20 cm soil layers, SD had a significantly positive linear correlation with both SOC and STN, except for the result between SD and STN in the 0–10 cm soil layer. SD had significant parabolic relationships with both SOC and STN in the 20–30 cm soil layer. However, SD had significantly negative linear correlations between SOC and STN in the 30–40, 40–50, and 50–60 cm soil layers, except for the result between SD and SOC in the 50–60 cm soil layer.

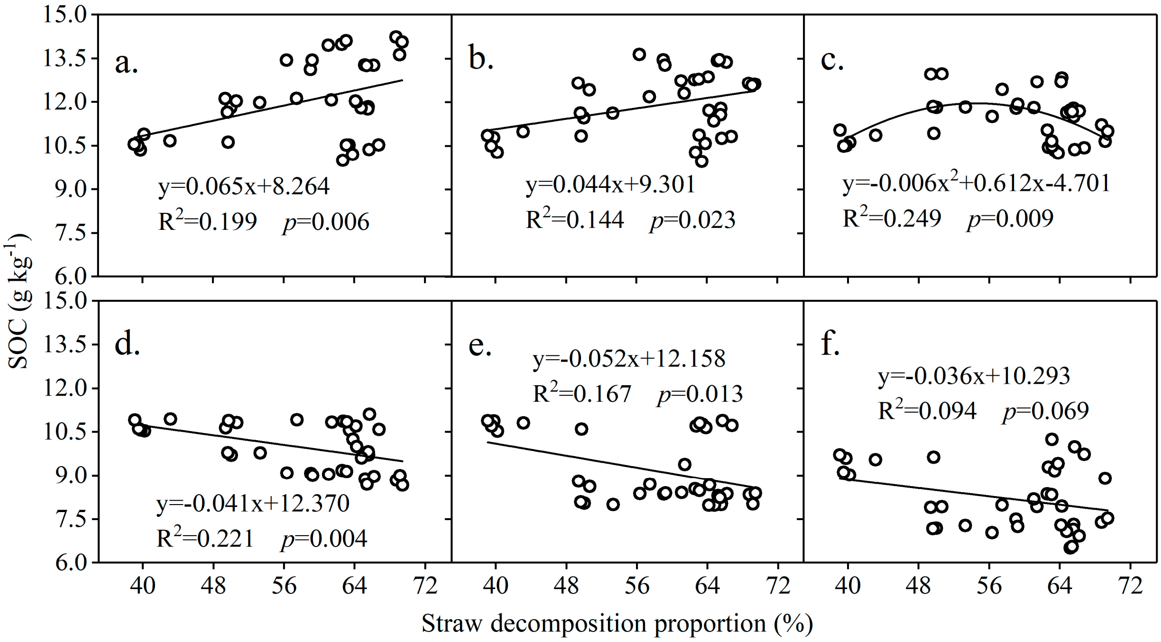

Figure 7. Relationships between the straw decomposition proportion and the SOC concentration at the soil depth of (**a**) 0–10 cm, (**b**)10–20 cm, (**c**) 20–30 cm, (**d**) 30–40 cm, (**e**) 40–50 cm, and (**f**) 50–60 cm (n = 36).

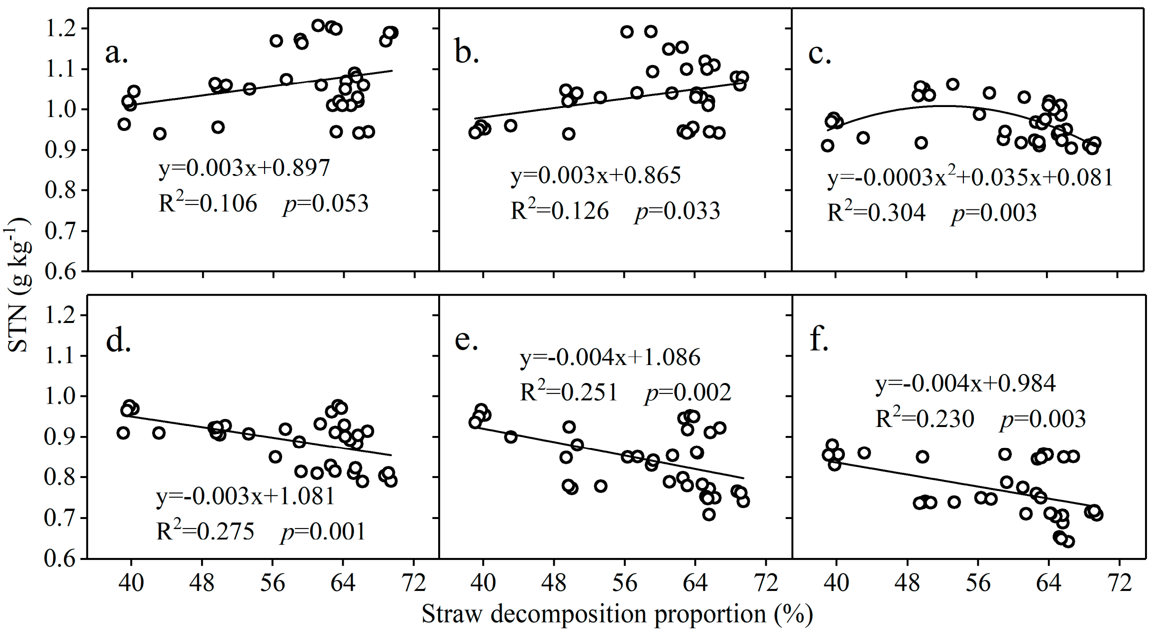

Figure 8. Relationships between the straw decomposition proportion and the STN concentration at the soil depth of (**a**) 0–10 cm, (**b**) 10–20 cm, (**c**) 20–30 cm, (**d**) 30–40 cm, (**e**) 40–50 cm, and (**f**) 50–60 cm (n = 36).

4. Discussion

4.1. Straw Decomposition Proportion and C/N Release

The straw decomposition process depends strongly on climatic environmental conditions; among all possible factors, temperature and precipitation are viewed as the primary factors that affect the process [19]. In the present study, the overall annual mass loss of the straw shows that the decomposition proportions were higher in 2017 relative to those in 2018 (Figure 2), likely because the mean air temperature in 2017 (9.26 °C) was higher than that in 2018 (9.09 °C). A previous study showed that a higher air temperature with appropriate precipitation contributed to crop residue decomposition [35]. The straw decomposition proportion was influenced by the returning methods, but the results were inconsistent between the two years, which indicates that annual conditions affected the straw decay process, as well. In addition, straw decomposition generally decreased as the returning depths increased, which is in agreement with previous litterbag studies [18,35,36]. These findings may be explained by the variations in the soil temperature and moisture [37], as well as differences in the community of straw decomposers [13], at the different straw incorporation depths used in this study.

The changing trend of C release among all treatments was extremely similar to the overall response observed in straw decomposition. On average, the C release proportions found in 2017 were higher than the measurements in 2018, with respective ranges of 62.96–71.62% and 45.08–66.07%. Similar to the C release derived from the decay of maize straw, the N release proportions from maize residue under the different treatments in 2017 were generally higher than the results in 2018, with ranges of 38.32–46.33% and 11.25–37.11%, respectively (Figure 4). This discrepancy implies that straw-derived N release during the decay process was dependent on annual conditions at various straw returning depths, whereas C release from straw incorporation was not as affected. Straw decomposition and the C and N release proportions were higher at shallower returning depths, which is primarily because deep tillage creates conditions that are more anaerobic compared with the conditions in shallow tillage, and anaerobes decompose less straw-derived C than aerobes [37].

4.2. Soil Organic Carbon (SOC), Soil Total Nitrogen (STN), and C–N Ratio

Straw distribution in the plow layer can change with different incorporation strategies; accordingly, straw distribution affects the spatial distributions of SOC and STN [38]. In this study, the SOC and STN contents were significantly high in soil layers close to the location of straw incorporation, regardless of the straw returning method (Figures 5 and 6). These findings are in agreement with an earlier study [25] that reported that farmland SOC and STN concentrations throughout the soil profile depended on the straw placement from the straw incorporation practice. In addition, Turmel et al. [8] pointed out that the SOC and STN levels can be controlled by organic matter inputs, native SOM decomposition rates, or both. We found that the C and N release levels were higher in treatments with straw incorporation at the shallowest depth (SM/B + O), and conversely, the C and N release levels were lower when straw incorporation was deeper (SM/B + F) (Figures 3 and 4). On the other hand, deep straw incorporation practices cause greater soil disturbance, resulting in increased native SOM mineralization relative to shallow straw treatments [39]. Thus, the C and N released from straw and native soil organic matter mineralization likely contributed to the distinctive SOC and STN behaviors between straw returning depth treatments in different soil layers, especially in the 0–20 cm and 40–60 cm soil layers.

The soil C–N ratio affects C and N cycling in an ecosystem, C and N interactions, and the stability of SOM in the soil profile [40,41]. Similar to SOC and STN, the soil C–N ratio in the different soil layers was significantly affected by straw returning depths; furthermore, the ratio was generally higher in soil layers close to the location of straw incorporation. These findings for the soil C–N ratio are in accord with the results reported in a previous study [38], which suggested that crop residues are conducive to an improvement in the soil C–N ratio. Such improvements may be explained by the higher straw-derived C release compared with N release in the present study (Figures 3 and 4). Additionally, the increasing C sequestration and net N mineralization that generally occur in a soil layer with a high C–N ratio due to straw incorporation may account for the difference in the soil C–N ratio between the straw returning treatments in the different soil layers investigated [27,42].

4.3. Soil Organic Carbon (SOC) and Soil Total Nitrogen (STN) Stocks

Similar to the SOC and STN concentrations reported above, SOC and STN stocks were significantly increased in soil layers close to the location of straw incorporation in both years of the study period. Furthermore, with the increasing depth in the overall 0–50 cm soil profile, both SOC and STN stocks under the SM/B + O treatments gradually diminished compared with those under SM/B + T and SM/B + F treatments. This result is supported by findings in previous studies [29,43,44] and mainly attributed to the higher straw-derived C and N release rates caused by the increased SOC and STN concentration associated with the SM/B + O treatments: thus, stocks in the upper soil improve, regardless of the changes in the soil bulk density (Figure S1). In addition, SOC and STN stocks tend to be uniformly distributed throughout the whole soil profile when straw incorporation is deeper, which is in accord with results from a previous study [26]. However, for the 0–50 cm soil profile, SOC stocks associated with SM/B + F were generally lower than the two treatments with a shallower straw return. This suggests that straw incorporation at depths greater than 30 cm may not favor C sequestration. Moreover, in both years, markedly higher SOC stocks were obtained using the SB returning method, indicating that the residue burying practice is a possible alternative method for straw incorporation in the present study area. These findings are likely related to another observation in this study: Straw incorporated into the deep subsoil layer was associated with accelerated SOM mineralization due to enhanced soil profile disturbance [39] and straw decomposition under poorly available nutrient conditions [45,46].

4.4. Relationships Between Straw Decomposition and Soil Organic Carbon (SOC) and Soil Total Nitrogen (STN) Concentrations

To provide further insight into the reason for the relatively low SOC stocks resulting from straw incorporation at a soil depth greater than 30 cm, we analyzed the relationship between the straw decay proportion (SD) and the SOC and STN concentrations in different soil layers using the overall data for both years. Similar changing trends of SOC and STN concentrations were correlated with the straw decay rate in the different soil layers (Figures 7 and 8). The correlation was positive and linear in the 0–20 cm soil layers but negative and linear in the 30–60 cm layers, while a parabolic relationship was revealed for the 20–30 cm soil layer. This strongly suggests the process of fresh straw input and decomposition generated priming effects (PEs), which define the changes in the SOM decomposition resulting from the addition of organic or mineral substances to the soil [47]. In a previous short-term study, in the topsoil (0–20 cm), negative PEs with C and N immobilization were usually found because microbes were provided with sufficient and available nutrients for decomposition [48]; therefore, the SOC and STN content increased as the SD increased. However, in the subsoil (30–60 cm), positive PEs might have resulted from the straw decaying process, especially in the late stage, during which, more recalcitrant C-derived from straw is decomposed in anaerobic conditions [37], and fewer nutrients are available [14], resulting in a trend that is opposite to that in the topsoil. These results suggest that the nutrient level in the subsoil needs to be considered when practicing deep straw incorporation in farmland.

5. Conclusions

When straw was mixed with soil, the straw decomposition proportion and C and N release markedly declined as the returning depth increased; however, they were variable between the two years when the straw was buried in the soil at different depths. Moreover, maize straw incorporated into the soil at 10, 30, and 50 cm depths tended to increase SOC and STN concentrations and the soil C–N ratio in the 0–20, 20–30, and 40–60 cm soil layers, regardless of the straw returning method employed. Thus, SOC and STN stocks in the 0–20 cm soil layers increased in the shallow straw returning approaches (SM/B + O), but straw buried at a depth of 50 cm strongly enriched them in the deep soil layers (30–50 cm). In the 0–50 cm soil profile, the highest SOC stocks were 77.38 Mg ha^{-1} in 2017 and 77.14 Mg ha^{-1} in 2018, which were both obtained using the SB + T treatment. Burying straw in the soil significantly increased the SOC stocks compared with mixing the straw with the soil. The STN stock was also significantly affected by the straw returning depth, but the effect was inconsistent between the two years. Interesting results for the interactions between the straw decomposition proportion and SOC and STN were found: They were positively correlated in the 0–20 cm soil layer but negatively correlated in the 30–60 cm soil layers. Taken together, our results indicate that straw could be incorporated into the soil, in practice, through plow tillage in northeastern China, and the incorporation depths not exceeding 30 cm may be beneficial for sustainable maize production systems considering soil quality conservation.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/9/12/818/s1, Figure S1: Changes in soil bulk density in the 0–60 cm profile under different straw returning approaches in 2017 and 2018. SM and SB indicate straw mixed with soil and buried in the soil; O, T, and F indicate straw incorporated into the soil (mixed or buried) at depths of 10, 30, and 50 cm, respectively. SM_{mean} is the mean of SM + O, SM + T, and SM + F; SB_{mean} is the mean of SB + O, SB + T, and SB + F; * indicates significant differences ($P < 0.05$) between straw incorporation depths (treatments) in the same soil layer.

Author Contributions: Designed and performed most of the experiments, analyzed the data and wrote the manuscript, P.T., H.Q., and Y.J.; helped with the data collection and analysis, editing of the manuscript as well, H.L., Z.W., G.M., Y.S. (Yue Sun), Y.W., Y.S. (Yehan Su), Z.M. and P.S. All authors read and approved the manuscript.

Funding: This research was funded by the Special Fund for Agro-scientific Research in the Public Interest (201503116); The National Key Research and Development Program of China (2016YFD0300801, 2016YFD0300103).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. FAO Soil Health. *Technologies that Save and Grow*; FAO: Rome, Italy, 2011.
2. Melero, S.; López-Garrido, R.; Murillo, J.M.; Moreno, F. Conservation tillage: Short- and long-term effects on soil carbon fractions and enzymatic activities under Mediterranean conditions. *Soil Tillage Res.* **2009**, *104*, 292–298. [CrossRef]
3. Kaisuer, J. Wounding Earth's fragile skin. *Science* **2004**, *304*, 1616–1618. [CrossRef] [PubMed]
4. Yin, X.G.; Olesen, J.E.; Wang, M.; Kersebaum, K.C.; Chen, H.; Baby, S.; Öztürk, I.; Chen, F. Adapting maize production to drought in the Northeast Farming Region of China. *Eur. J. Agron.* **2016**, *77*, 47–58. [CrossRef]
5. Liu, X.B.; Zhang, X.Y.; Herbert, S.J. Feeding China's growing needs for grain. *Nature* **2010**, *465*, 420. [CrossRef] [PubMed]
6. Freibauer, A.; Rounsevell, M.D.A.; Smith, P.; Verhagen, J. Carbon sequestration in the agricultural soils of Europe. *Geoderma* **2004**, *122*, 1–23. [CrossRef]
7. Lu, F.; Wang, X.K.; Han, B.; Ou Yang, Z.Y.; Duan, X.N.; Zheng, H.; Miao, H. Soil carbon sequestrations by nitrogen fertilizer application, straw return and no-tillage in China's cropland. *Glob. Change Biol.* **2009**, *15*, 281–305. [CrossRef]
8. Turmel, M.S.; Speratti, A.; Baudron, F.; Verhulst, N.; Govaerts, B. Crop residue management and soil health: A systems analysis. *Agric. Syst.* **2015**, *134*, 6–16. [CrossRef]
9. Zhang, X.X.; Ma, F. Emergy Evaluation of Different Straw Reuse Technologies in Northeast China. *Sustainability* **2015**, *7*, 11360–11377. [CrossRef]
10. Tian, P.; Jiang, Y.; Sun, Y.; Ma, Z.Q.; Sui, P.X.; Mei, N.; Qi, H. Effect of straw return methods on maize straw decomposition and soil nutrients contents. *Chin. J. Eco-Agric.* **2019**, *27*, 100–108, (in Chinese with English abstract).
11. Helgason, B.L.; Gregorich, E.G.; Janzen, H.H.; Ellert, B.H.; Lorenz, N.; Dick, R.P. Long-term microbial retention of residue C is site-specific and depends on residue placement. *Soil Biol. Biochem.* **2014**, *68*, 231–240. [CrossRef]
12. Cookson, W.R.; Beare, M.H.; Wilson, P.E. Effects of prior crop residue management on microbial properties and crop residue decomposition. *Appl. Soil Ecol.* **1998**, *7*, 179–188. [CrossRef]
13. Osono, T. Role of phyllosphere fungi of forest trees in the development of decomposer fungal communities and decomposition processes of leaf litter. *Can. J. Microbiol.* **2006**, *52*, 701–716. [CrossRef] [PubMed]
14. Fontaine, S.; Barot, S.; Barré, P.; Bdioui, N.; Mary, B.; Rumpel, C. Stability of organic carbon in deep soil layers controlled by fresh carbon supply. *Nature* **2007**, *450*, 277–280. [CrossRef] [PubMed]
15. Yadvinder-Singh; Gupta, R.K.; Jagmohan-Singh; Gurpreet-Singh; Gobinder-Singh; Ladha, J.K. Placement effects on rice residue decomposition and nutrient dynamics on two soil types during wheat cropping in rice–wheat system in northwestern India. *Nutr. Cycl. Agroecosyst.* **2010**, *88*, 471–480. [CrossRef]

16. Curtin, D.; Selles, F.; Wang, H.; Campbell, C.A.; Biederbeck, V.O. Carbon dioxide emissions and transformation of soil carbon and nitrogen during wheat straw decomposition. *Soil Sci. Soc. Am. J.* **1998**, *62*, 1035–1041. [CrossRef]
17. Gómez-Muñoz, B.; Hatch, D.J.; Bol, R.; García-Ruiz, R. Nutrient dynamics during decomposition of the residues from a sown legume or ruderal plant cover in an olive oil orchard. *Agric. Ecosyst. Environ.* **2014**, *184*, 115–123. [CrossRef]
18. Xu, Y.H.; Chen, Z.M.; Fontaine, S.; Wang, W.J.; Luo, J.F.; Fan, J.L.; Ding, W.X. Dominant effects of organic carbon chemistry on decomposition dynamics of crop residues in a Mollisol. *Soil Biol. Biochem.* **2017**, *115*, 221–232. [CrossRef]
19. Bradford, M.A.; Berg, B.; Maynard, D.S.; Wieder, W.R.; Wood, S.A. Understanding the dominant controls on litter decomposition. *J. Ecol.* **2016**, *104*, 229–238. [CrossRef]
20. Reicosky, D.C. *Tillage-induced CO2 emissions and carbon sequestration: Effect of secondary tillage and compaction*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2003; pp. 291–300.
21. Yang, X.M.; Wander, M.M. Tillage effects on soil organic carbon distribution and storage in a silt loam soil in Illinois. *Soil Tillage Res.* **1999**, *52*, 1–9. [CrossRef]
22. Jantalia, C.P.; Resck, D.V.S.; Alves, B.J.R.; Zotarelli, L.; Urquiaga, S.; Boddey, R.M. Tillage effect on C stocks of a clayey Oxisol under a soybean-based crop rotation in the Brazilian Cerrado region. *Soil Tillage Res.* **2007**, *95*, 97–109. [CrossRef]
23. Dong, W.X.; Hu, C.S.; Chen, S.Y.; Zhang, Y.M. Tillage and residue management effects on soil carbon and CO_2 emission in a wheat–corn double-cropping system. *Nutr. Cycl. Agroecosyst.* **2009**, *83*, 27–37. [CrossRef]
24. Poirier, V.; Angers, D.A.; Rochette, P.; Chantigny, M.H.; Ziadi, N.; Tremblay, G.; Fortin, J. Interactive effects of tillage and mineral fertilization on soil carbon profiles. *Soil Sci. Soc. Am. J.* **2009**, *73*, 255–261. [CrossRef]
25. Du, Z.L.; Ren, T.S.; Hu, C.S. Tillage and Residue Removal Effects on Soil Carbon and Nitrogen Storage in the North China Plain. *Soil Sci. Soc. Am. J.* **2010**, *74*, 196–202. [CrossRef]
26. Dikgwatlhe, S.B.; Chen, Z.D.; Lal, R.; Zhang, H.L.; Chen, F. Changes in soil organic carbon and nitrogen as affected by tillage and residue management under wheat–maize cropping system in the North China Plain. *Soil Tillage Res.* **2014**, *144*, 110–118. [CrossRef]
27. Laird, D.A.; Chang, C.W. Long-term impacts of residue harvesting on soil quality. *Soil Tillage Res.* **2013**, *134*, 33–40. [CrossRef]
28. Vanden Bygaart, A.J.; Angers, D.A. Towards accurate measurements of soil organic carbon stock change in agroecosystems. *Can. J. Soil Sci.* **2006**, *86*, 465–471. [CrossRef]
29. Xue, J.F.; Pu, C.; Liu, S.L.; Chen, Z.D.; Chen, F.; Xiao, X.P.; Lal, R.; Zhang, H.L. Effects of tillage systems on soil organic carbon and total nitrogen in a double paddy cropping system in Southern China. *Soil Tillage Res.* **2015**, *153*, 161–168. [CrossRef]
30. You, D.B.; Tian, P.; Sui, P.X.; Zhang, W.K.; Yang, B.; Qi, H. Short-term effects of tillage and residue on spring maize yield through regulating root-shoot ratio in Northeast China. *Sci. Rep.* **2017**, *7*, 13314. [CrossRef]
31. Jin, X.X.; An, T.T.; Aaron, R.G.; Li, S.Y.; Timothy, F.; Wang, J.K. Enhanced conversion of newly-added maize straw to soil microbial biomass C under plastic film mulching and organic manure management. *Geoderma* **2018**, *313*, 154–162. [CrossRef]
32. Varela, M.F.; Scianca, C.M.; Taboada, M.A.; Rubio, G. Cover crop effects on soybean residue decomposition and P release in no-tillage systems of Argentina. *Soil Tillage Res.* **2014**, *143*, 59–66. [CrossRef]
33. Mei, N.; Yang, B.; Tian, P.; Jiang, Y.; Sui, P.X.; Sun, D.Q.; Zhang, Z.P.; Qi, H. Using a modified soil quality index to evaluate densely tilled soils with different yields in Northeast China. *Environ. Sci. Pollut. Res.* **2019**, *26*, 13867–13877. [CrossRef] [PubMed]
34. Ellert, B.H.; Bettany, J.R. Calculation of organic matter and nutrients stored in soils under contrasting management regimes. *Can. J. Soil Sci.* **1995**, *75*, 529–538. [CrossRef]
35. Wang, X.Y.; Sun, B.; Mao, J.D.; Sui, Y.Y.; Cao, X.Y. Structural convergence of maize and wheat straw during two-year decomposition under different climate conditions. *Environ. Sci. Technol.* **2012**, *46*, 7159–7165. [CrossRef] [PubMed]
36. Grandy, A.S.; Salam, D.S.; Wickings, K.; McDaniel, M.D.; Culman, S.W.; Snapp, S.S. Soil respiration and litter decomposition responses to nitrogen fertilization rate in no-till corn systems. *Agric. Ecosyst. Environ.* **2013**, *179*, 35–40. [CrossRef]

37. Devêvre, O.C.; Horwáth, W.R. Decomposition of rice straw and microbial carbon use efficiency under different soil temperatures and moistures. *Soil Biol. Biochem.* **2000**, *32*, 1773–1785. [CrossRef]
38. Puget, P.; Lal, R. Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. *Soil Tillage Res.* **2005**, *80*, 201–213. [CrossRef]
39. Hiel, M.P.; Barbieux, S.; Pierreux, J.; Olivier, C.; Lobet, G.; Roisin, C.; Garré, S.; Colinet, G.; Bodson, B.; Dumont, B. Impact of crop residue management on crop production and soil chemistry after seven years of crop rotation in temperate climate, loamy soils. *PeerJ* **2018**, *6*, e4836. [CrossRef]
40. Russell, A.E.; Laird, D.A.; Parkin, T.B.; Mallarino, A.P. Impact of Nitrogen Fertilization and Cropping System on Carbon Sequestration in Midwestern Mollisols. *Soil Sci. Soc. Am. J.* **2005**, *69*, 413–422. [CrossRef]
41. Tong, C.L.; Xiao, H.A.; Tang, G.R.; Wang, H.Q.; Huang, T.P.; Xia, H.A.; Keith, S.J.; Li, Y.; Liu, S.L.; Wu, J.S. Long-term fertilizer effects on organic carbon and total nitrogen and coupling relationships of C and N in paddy soils in subtropical China. *Soil Tillage Res.* **2009**, *106*, 8–14. [CrossRef]
42. Kramer, S.; Marhan, S.; Haslwimmer, H.; Ruess, L.; Kandeler, E. Temporal variation in surface and subsoil abundance and function of the soil microbial community in an arable soil. *Soil Biol. Biochem.* **2013**, *61*, 76–85. [CrossRef]
43. Lou, Y.L.; Xu, M.G.; Chen, X.N.; He, X.H.; Zhao, K. Stratification of soil organic C, N and C:N ratio as affected by conservation tillage in two maize fields of China. *Catena* **2012**, *95*, 124–130. [CrossRef]
44. Maillard, É.; McConkey, B.G.; Luce, M.S.; Angers, D.A.; Fan, J.L. Crop rotation tillage system and precipitation regime effects on soil carbon stocks over 1 to 30 years in Saskatchewan, Canada. *Soil Tillage Res.* **2018**, *177*, 97–104. [CrossRef]
45. Hao, M.D.; Fan, J.; Wang, X.R.; Pen, L.F.; Lai, L. Effect of Fertilization on Soil Fertility and Wheat Yield of Dryland in the Loess Plateau. *Pedosphere* **2005**, *15*, 189–195.
46. Sá, J.C.M.; Lal, R. Stratification ratio of soil organic matter pools as an indicator of carbon sequestration in a tillage chronosequence on a Brazilian Oxisol. *Soil Tillage Res.* **2009**, *103*, 46–56. [CrossRef]
47. Kuzyakov, Y.; Friedel, J.K.; Stahr, K. Review of mechanisms and quantification of priming effects. *Soil Biol. Biochem.* **2000**, *32*, 1485–1498. [CrossRef]
48. Tian, Q.X.; Yang, X.L.; Wang, X.G.; Liao, C.; Li, Q.X.; Wang, M.; Wu, Y.; Liu, F. Microbial community mediated response of organic carbon mineralization to labile carbon and nitrogen addition in topsoil and subsoil. *Biogeochemistry* **2016**, *128*, 125–139. [CrossRef]