sustainability

Article

Application of Corn Straw and Woody Peat to Improve the Absorption and Utilization of ^{15}N-Urea by Maize

Chenming Lin [1], Sen Dou [1,*], Mahmoud Gamal Mohamed Abd El-Rahim [1,2], Xin Liu [1], Dong Wu [1], Rui Ma [1], Yifeng Zhang [1], Xianbao Yin [1], Cen Tan [1] and Shuai Xie [1]

1 College of Resource and Environmental Science, Jilin Agricultural University, Changchun 130118, China; 17743127218@163.com (C.L.); mahmoudsosci2070@yahoo.com (M.G.M.A.E.-R.); lx18686444461@163.com (X.L.); wudong01@caas.cn (D.W.); marui@mary.wecom.work (R.M.); yifengzhang@jlau.edu.cn (Y.Z.); yinxianbao@163.com (X.Y.); tancen@jlau.edu.can (C.T.); 20181130@mails.jlau.edu.cn (S.X.)
2 Soils and Water Department, Faculty of Agriculture, Al-Azhar University, Assiut 71524, Egypt
* Correspondence: dousen@jlau.edu.cn

check for updates

Citation: Lin, C.; Dou, S.; El-Rahim, M.G.M.A.; Liu, X.; Wu, D.; Ma, R.; Zhang, Y.; Yin, X.; Tan, C.; Xie, S. Application of Corn Straw and Woody Peat to Improve the Absorption and Utilization of ^{15}N-Urea by Maize. *Sustainability* **2022**, *14*, 820. https://doi.org/10.3390/su14020820

Academic Editors: Othmane Merah, Purushothaman Chirakkuzhyil Abhilash, Magdi T. Abdelhamid, Hailin Zhang and Bachar Zebib

Received: 20 November 2021
Accepted: 31 December 2021
Published: 12 January 2022

Abstract: Increasing nitrogen fertilizer use efficiency has become an environmental and economic demand in order to minimize losses of nitrogen and maximize the output from nitrogen added. The application of organic amendments with N fertilizers could be proposed as an important economic and environmental practice for improving N fertilizer use. A two-year field experiment was carried out using the ^{15}N tracer technique to study the impact of corn straw and woody peat application on uptake and utilization of N fertilizer by maize plant. Three treatments were set up: CK (^{15}N labeled urea alone), CS (^{15}N labeled urea + crushed corn straw) and WP (^{15}N labeled urea+ crushed woody peat). The results showed that, as compared to CK, both straw and peat treatments led to (i) an increase in yield of maize, ^{15}N urea utilization rate, and residual ^{15}N urea remained in soil by 11.20% and 19.47%, 18.62% and 58.99%, 41.77% and 59.45%, respectively, but (ii) a decrease in the total loss rate by 6.21% and 16.83% ($p < 0.05$), respectively over the two seasons. Moreover, the significantly highest effect was recorded with woody peat application rather than that with corn straw. Our study suggests that corn straw and woody peat can be used as organic fertilizers to increase maize yields, promote nitrogen fertilizer balance sheet, reduce the leaching of N fertilizer into the subsurface soil layer, and facilitate the further absorption and utilization of soil residual nitrogen. Therefore, the application of humified organic material play a crucial role in N utilization efficiency enhancement.

Keywords: corn straw; woody peat; ^{15}N labeling technology; yield; fertilizer nitrogen whereabouts

1. Introduction

Nitrogen fertilizer is widely used in agricultural production and of vital importance in increasing crop yield [1]. However, in recent years, excessive use of chemical fertilizers in farming has led to a decline in soil quality [2], thus resulting in a decline in nitrogen use efficiency and a waste of resources, as well as a series of environmental problems such as soil acidification, greenhouse gas emissions and water eutrophication [3–5]. Using organic fertilizer to improve the input of soil organic carbon [6] is a new way to improve nitrogen use efficiency by adjusting soil C/N ratio and promoting effective transformation of N fertilizer in soil organic N pool [7,8]. Therefore, it is of great significance to clarify the relationship between the application of organic fertilizer effect and the use of ^{15}N fertilizer for scientific evaluation of its fertilizer effect in soil.

Corn straw is rich in carbon (C), nitrogen (N), phosphorus (P), potassium (K) and other elements [9,10], straw returning to field can improve soil fertility and increase crop yield [11,12]. Previous findings showed that straw returning can improve soil fertility and fertilizer supply, and increase the utilization rate of nitrogen fertilizer by crops [6,13,14].

Therefore, application of corn straw has become an important technical means to improve soil environment, crop yield and quality, nitrogen fertilizer use efficiency.

Woody peat is a substance formed naturally through complex biogeochemical processes over hundreds of millions of years. It possesses a stable structure and is rich in organic matter and nutrients, with large storage capacity and light weight [15–18]. Humic acid is the main component of humic matter in woody peat with a high humification degree [8]. Previous findings showed that humus acid synergistic fertilizers can promote crop growth, increase yield, improve fertilizer efficiency, and soil nutrient availability [19]. In recent years, woody peat has been widely used to rapidly improve soil fertility [20–22], therefore, it is a valuable resource with positive significance for agriculture, and environmental protection.

Application of corn straw (CS) and woody peat (WP) in soil can significantly improve nitrogen use efficiency. However, there is a lack of systematic analysis and comparison between straw and peat application on nitrogen use efficiency and soil nitrogen residues. The effects of maize straw and woody peat on the utilization and residue of nitrogen fertilizer in soil were studied by the temporal and spatial variation of urea-^{15}N in two consecutive cropping seasons. This study aimed to investigate: (1) The effect of two year application of CS and WP on dry matter weight and yield of maize. (2) The effects of application of CS and WP on absorption, utilization and distribution of ^{15}N urea, distribution and loss of ^{15}N urea in soil during tow plantation seasons of maize. (3) The difference in ^{15}N use efficiency and residual ^{15}N remained in soil after CS and WP application was compared in two years of maize production. This study can provide basic understandings for clarifying the relationship between application of corn straw and peat and nitrogen use efficiency, provide theoretical and practical basis for application of corn straw and woody peat to improve crop growth, and increase nitrogen use efficiency.

2. Materials and Methods

2.1. Experimental Site

The study was carried out in the research experiments station of Jilin Agricultural University (43°48′43.57″ N, 125°23′38.50″ E), Jilin province, Changchun, China. The soil was classified as a black soil (i.e., Chernozem based on world reference base for soil resources, 2014). It belongs to the continental monsoon climate of the North Temperate Zone, with an average temperature of 23 °C, annual frost-free period of 140–150 days, annual rainfall of 500–600 mm, sunshine of 2600 h, annual accumulated temperature of 3200 °C, and altitude of 213 m. The soil properties were: pH 6.84, organic matter (OM) 26.43 g kg^{-1}, total nitrogen (N) 1.16 g kg^{-1}, available potassium (K) 98.93 mg kg^{-1}, available phosphorus (P) 28.89 mg kg^{-1}, and alkali-hydrolyzable nitrogen (NH_4-N) 99.95 mg kg^{-1}.

2.2. The Tested Materials

The corn straw was obtained from the experimental field of Jilin Agricultural University in October 2016, air dried, crushed, and then passed through a 5 mm mesh sieve before application. Woody peat was provided by the Ministry of Land and Resources, air dried, crushed and then passed through 5 mm sieve. The basic characteristics of the corn straw and the woody peat were: total N 11.91 and 7.03 g kg^{-1}, OM 457.58 and 549.73 g kg^{-1}, H 62.61 and 59.02 mg kg^{-1}, C/N 44.82 and 91.56, and the H/C 1.84 and 1.29, respectively.

2.3. The Applied Fertilizer

Urea ^{15}N, 5.15% abundance, 46.7% N was purchased from Shanghai Chemical Research Institute. Phosphate and potassium fertilizers were applied in form of P_2O_5, and K_2O, respectively, and purchased from humus laboratory of Jilin Agricultural University.

2.4. Experiment Setup

The experiment was conducted in 22 April 2017. Three treatments were setup: CK (^{15}N labeled urea alone), CS (^{15}N labeled urea + crushed corn straw) and WP (^{15}N labeled urea+ crushed woody peat), with three replicates for each treatment. After sorting out the soil, the PVC pipe with a diameter of 40 cm and a height of 65 cm was embedded in the soil depth of 0–60cm (Figure 1). The above part of the soil in the PVC pipe (0–20 cm) was taken out and evenly mixed with corn straw and woody peat (10,000 kg hm^{-2} for 0–20 cm soil layer) that had been sieved through 40 mesh sieve, and the evenly mixed soil-corn straw and soil-woody peat matrix were backfilled in the original state, respectively.

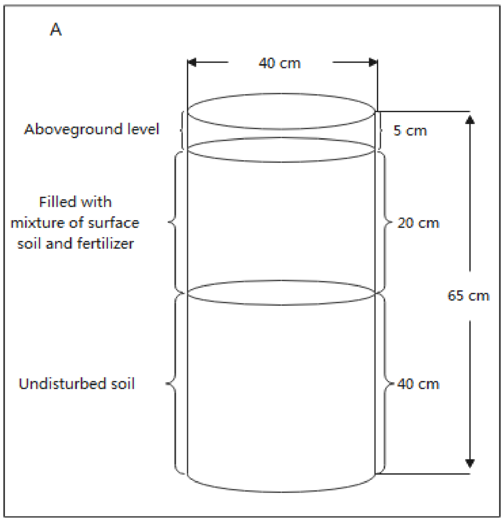

Figure 1. Schematic diagram of the soil column used for maize cultivation and the experimental plot. A, a diagram showing how columns were filled with soil.

The corn variety of Xiangyu 998 was used with only one plant/tube (60,000 plants hm^{-2}). N, P and K fertilizer were applied before sowing. Nitrogen fertilizer was ^{15}N-labeled urea, and the N dosage was 225 kg hm^{-2}. The application amount of phosphate fertilizer (P_2O_5) was 120 kg hm^{-2}, and potassium fertilizer (K_2O) was 60 kg hm^{-2}. The fertilizers were mixed in the 0–10 cm soil layer, at the center of the PVC tube, and the radius was 10 cm.

2.5. The Sample Collection

(1) On 22 September 2017 and 22 September 2018, the above ground parts of corn were harvest, and the plants were divided into five parts: leaf, stem, bract, cob and grain. All the corns were placed in a 65 °C oven and dried to constant weight. The samples were crushed with a 24,000 rpm mill (FW100 tianjin Test Company), and the samples were screened through 100 mesh and sealed.

(2) After the corn harvest on 22 September 2017 and 22 September 2018, the plant residues were removed from the soil surface, then the soil was divided into 6 layers (0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, 40–50 cm, 50–60 cm) and sampled with a soil remover with a diameter of 1 cm. The collected soil samples were air-dried in a dust-free room, and then were ground in a mortar, screened through a 100-mesh sieve, and kept sealed.

2.6. Determination of ^{15}N Abundance of Samples

The total N of maize organs samples was measured by elemental analyzer (vario ISOTOPE, Germany). In addition, Isoprime 100 mass spectrometer instrument (Elementaar Analyser Systeme. GmbH Inc., Hamburg, Germany) was employed to determine the ^{15}N abandance.

Using a 100 mesh sieve, 1.0–1.5 mg of each maize part sample and 25–30 mg of soil samples was weighted to determine the total ^{15}N abundance.

2.7. Calculation and Data Analysis

The utilization efficiency of ^{15}N fertilizer by maize ($^{15}NUR\%$), and the residual ^{15}N remained in soil were calculated according to [23].

The ^{15}N utilization efficiency for corn plant was calculated as follows:

$$\begin{aligned} &^{15}NUR\% = Npf/Nf \times 100 \\ &Npf = NP \times Npff \\ &Npff\% = Npp/Nppf \times 100 \end{aligned} \tag{1}$$

where Npf is the amount of ^{15}N absorbed by the plant (g PVC pipe^{-1}), Nf is the amount of ^{15}N fertilizer applied to the soil (g PVC pipe^{-1}), NP is the amount of total nitrogen absorbed by plants (g pot^{-1}), Npff% is the percentage of total plant nitrogen from fertilizer, Npp is the atomic percentage of ^{15}N fertilizer in plants exceeds and Nppf is the atomic percentage of ^{15}N-labled fertilizer.

The ^{15}N remained rate for the soil ($^{15}NRR\%$) was calculated as follows:

$$\begin{aligned} &^{15}NUR\% = Nsf/Nf \times 100 \\ &Nsf = Ns \times Nsff \\ &Nsff\% = Nss/Nssf \times 100 \end{aligned} \tag{2}$$

Nsf is the amount of nitrogen in the soil from ^{15}N fertilizer (g PVC pipe^{-1}), Nf: the amount of ^{15}N fertilizer application (g PVC pipe^{-1}), Ns is the amount of total nitrogen of soil (g PVC pipe^{-1}), Nsff% is the percentage of total soil nitrogen from fertilizer, Nss: the ^{15}N atoms of total nitrogen in the soil exceed, and Nssf: the ^{15}N-labeled fertilizer atomic excess.

The ^{15}N loss rate ($^{15}NLR\%$) was calculated as follows:

$$^{15}NLR\% = 100 - {}^{15}NUR - {}^{15}NUR \tag{3}$$

Microsoft Office Excel 2016 software was used for data analysis and processing. SPSS Statistics 17.0 was used for statistical analysis and difference significance test with Tukey's test at $p < 0.05$.

3. Results

3.1. Effects of Corn Straw and Peat Application on Maize Yield

Effects of corn straw and peat application on corn yield are shown in Figure 2. The results showed that the grain yield recorded for all treatments was significantly highest over the two growing seasons (2017 and 2018), followed by stem leaf, and bract ones". However, among all the treatments, WP recorded the highest total aboveground yield followed by CS and CK. The yield of maize grains treated with WP and CS increased compared with CK, by 20.07% and 9.96%, 18.88% and 12.41%, during 2017 and 2018, respectively.

3.2. Effects of Application of Corn Straw and Peat on Total Nitrogen in Maize Plant

The application of CS and WP increased the total nitrogen content of maize ($p < 0.05$), as shown in Table 1. The total nitrogen content in grains and leaves of all treatments in 2017 and 2018 was the highest, which was ranged between 40.05–44.86% and 22.97–29.99%, respectively, and represents 66.74 and 70.04% of the total nitrogen content in both season, respectively. However, among all the treatments, WP recorded the highest total above-ground yield followed by CS and CK. The yield of maize grains treated with WP and CS increased compared with CK, by 20.07% and 9.96%, 18.88% and 12.41%, during 2017 and 2018, respectively.

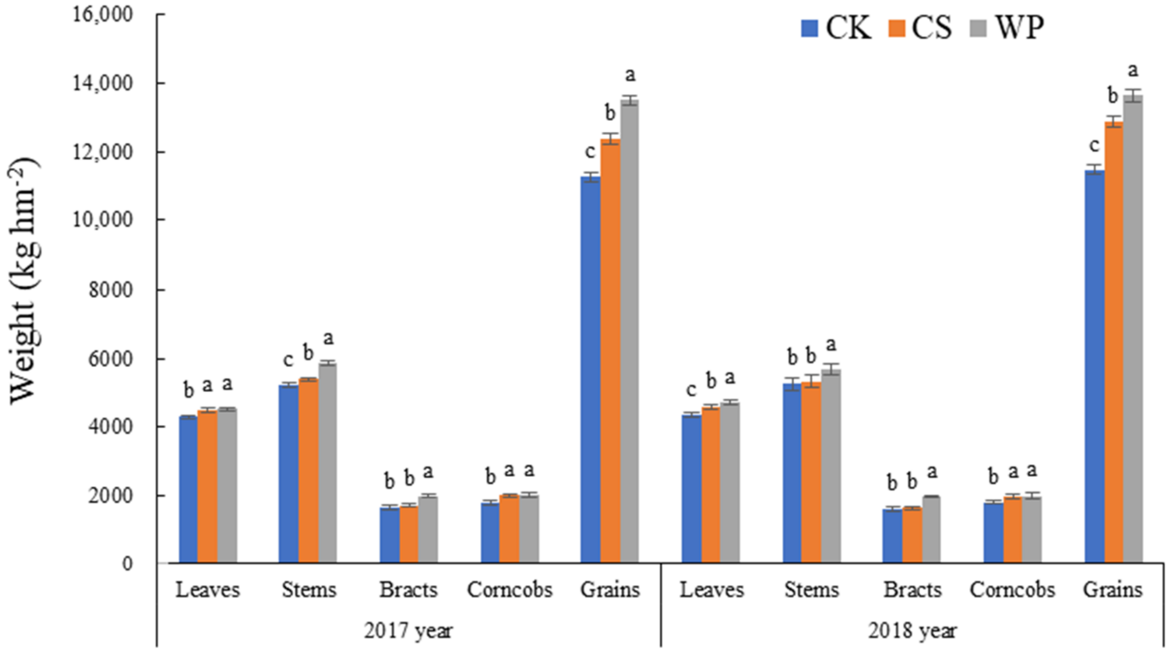

Figure 2. Effect of application of corn straw (CS) and woody peat (WP) on maize yield compared with the control (CK). Note: CK represents ^{15}N labeled urea applied alone; WP represents 0–20 cm soil layer, mixed with crushed woody peat +^{15}N labeled urea; CS represents 0–20 cm soil layer mixed with crushed corn straw and ^{15}N labeled urea. Different letters in the same column indicate significant difference at 0.05.

Table 1. Effect of application of corn straw and woody peat on the total nitrogen content in different organs (g/kg).

Year	Treatment	Leaves	Stems	Bracts	Corncobs	Grains
	CK	5.42 ± 0.23 ^{c}	2.15 ± 0.16 ^{b}	3.07 ± 0.23 ^{b}	2.35 ± 0.24 ^{b}	10.30 ± 0.25 ^{c}
2017	CS	6.55 ± 0.30 ^{b}	2.88 ± 0.27 ^{a}	3.51 ± 0.24 ^{a,b}	2.78 ± 0.40 ^{a,b}	12.79 ± 0.29 ^{b}
	WP	10.32 ± 0.27 ^{a}	3.25 ± 0.20 ^{a}	3.64 ± 0.22 ^{a}	3.42 ± 0.35 ^{a}	13.78 ± 0.20 ^{a}
	CK	5.88 ± 0.22 ^{c}	2.37 ± 0.35 ^{b}	3.35 ± 0.27 ^{a}	2.21 ± 0.21 ^{a}	10.03 ± 0.90 ^{c}
2018	CS	7.32 ± 0.56 ^{b}	2.63 ± 0.51 ^{b}	3.52 ± 0.22 ^{a}	2.34 ± 0.22 ^{a}	11.60 ± 0.35 ^{b}
	WP	9.15 ± 0.41 ^{a}	3.74 ± 0.16 ^{a}	3.92 ± 0.06 ^{a}	2.80 ± 0.18 ^{a}	13.63 ± 0.19 ^{a}

Note: CK represents ^{15}N labeled urea alone; WP represents mixing pulverized woody peat with 0~20 cm soil layer +^{15}N labeled urea; CS represents mixing pulverized corn straw with 0~20 cm soil layer +^{15}N labeled urea. Different letters in the same column indicate significant difference at 0.05.

3.3. Proportion of ^{15}N from Urea in Total Nitrogen of Maize Plant

In 2017 and 2018, the proportion of ^{15}N from urea (Ndff%) in total nitrogen content of maize plant by applying corn straw and peat is shown in Table 2 ($p < 0.05$). All treatments showed that Ndff% followed the order of CK > CS > WP. In the aboveground parts of maize plant, the contribution of ^{15}N fertilizer was up to 12.48–18.14% and 0.21–1.26% of the total absorbed nitrogen, while soil contributed by 81.86 to 87.52% from the total absorbed N. In 2018, for the aboveground parts, fertilizer contributed of the total absorbed nitrogen while soil contributed 98.74–99.79%.

Table 2. Effect of application of corn straw and peat on nitrogen derived from fertilizer (%) in each organ of maize plant.

Year	Treatment	Leaves	Stems	Bracts	Corncobs	Grains
2017	CK	18.14 ± 0.27 [a]	18.38 ± 0.26 [a]	17.51 ± 0.49 [a]	18.00 ± 0.21 [a]	17.81 ± 0.09 [a]
	CS	16.07 ± 0.31 [b]	14.24 ± 0.54 [b]	13.59 ± 0.29 [b]	14.95 ± 0.24 [b]	15.99 ± 0.71 [b]
	WP	16.69 ± 0.66 [b]	13.80 ± 3.25 [b]	12.48 ± 0.88 [b]	14.41 ± 1.06 [b]	15.65 ± 0.88 [b]
2018	CK	0.50 ± 0.05 [a]	0.49 ± 0.02 [a]	0.33 ± 0.02 [a]	0.23 ± 0.05 [a]	1.26 ± 0.03 [a]
	CS	0.42 ± 0.02 [b]	0.40 ± 0.01 [b]	0.21 ± 0.04 [b]	0.21 ± 0.02 [a]	1.08 ± 0.09 [b]
	WP	0.40 ± 0.02 [b]	0.34 ± 0.03 [c]	0.21 ± 0.01 [b]	0.16 ± 0.01 [b]	0.93 ± 0.02 [c]

Note: CK represents ^{15}N labeled urea alone; WP represents mixing pulverized woody peat with 0~20 cm soil layer +^{15}N labeled urea; CS represents mixing pulverized corn stover with 0~20 cm soil layer +^{15}N labeled urea. Different letters in the same column indicate significant difference at 0.05.

3.4. Effects of Application of Corn Straw and Woody Peat on the Relative Distribution of ^{15}N in Maize

The relative distribution (as a percentage) of recovered ^{15}N urea in maize plant's parts in the different treatments is shown in Figure 3. The distribution ratio of recovered ^{15}N urea in maize among different organs of each treatment is as follows: corn grains > leaves > bracts > cobs > stems. Among different treatments, the distribution ratio of ^{15}N in the leaves of WP treatment was higher than those in other treatments, while the grains of WP had the lowest distribution of ^{15}N. The CS treatment had the highest proportion of ^{15}N distribution in corn kernels and the lowest with CK.

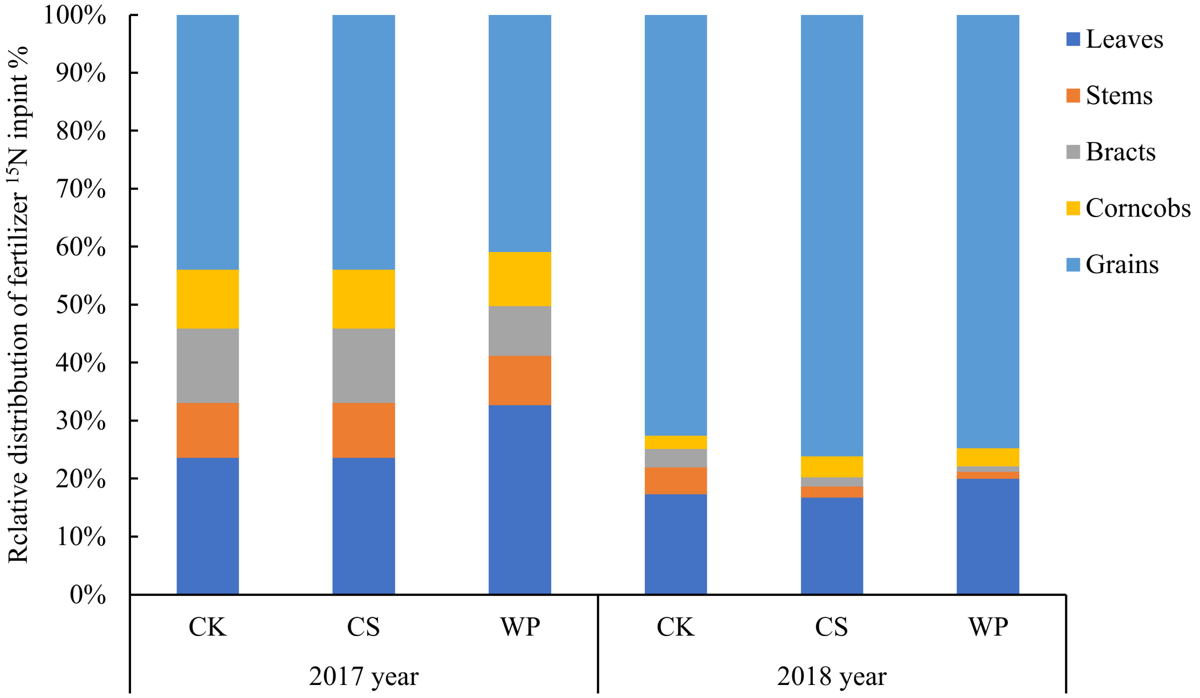

Figure 3. Relative distribution percentage of applied corn straw and peat recovery ^{15}N urea. Note: CK represents ^{15}N labeled urea alone; WP represents mixing pulverized woody peat with 0–20 cm soil layer +^{15}N labeled urea; CS represents mixing pulverized corn straw with 0–20 cm soil layer +^{15}N labeled urea.

3.5. Effects of Application of Corn Straw and Woody Peat on ^{15}N Urea Utilization "By Maize

Application of straw and woody peat improved the utilization rate of ^{15}N urea in maize ($p < 0.05$) Figure 4. The total ^{15}N utilization rate for the different treatments throughout 2017 and 2018 was ranged from 18.90 to 30.05%. The WP treatment had the highest ^{15}N

utilization rate, while CK treatment was the lowest one. The proportion of ^{15}N utilization rate by grains and leaves was ranged from 14.32–22.62% and 2.49–4.88%, respectively.

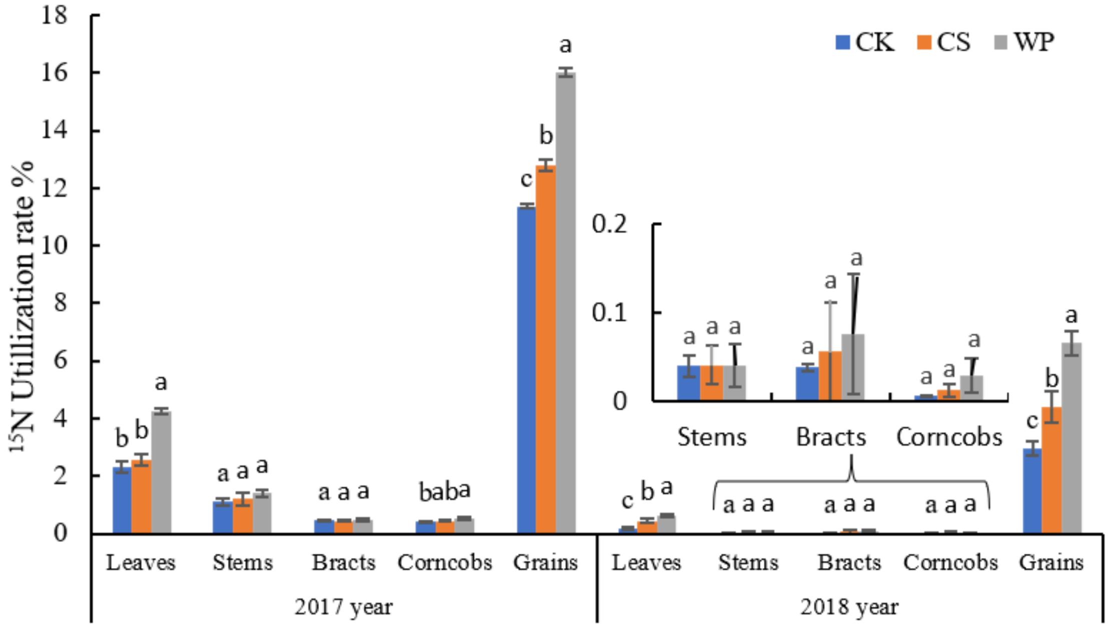

Figure 4. The ^{15}N urea utilization of each organ of maize under application of corn straw and peat Treatment (2017~2018). Note: CK represents ^{15}N labeled urea alone; WP represents mixing pulverized woody peat with 0–20 cm soil layer +^{15}N labeled urea; CS represents mixing pulverized corn straw with 0–20 cm soil layer +^{15}N labeled urea. Different letters in the same column indicate significant difference at 0.05.

In 2017, compared with CK, the ^{15}N utilization rate of maize grains and leaves treated with WP and CS increased from 11.39% and 2.31% to 16.00% and 2.57%, 12.80% and 4.25%, respectively, and the total utilization rate increased from 15.67% to 22.66% and 17.46%, respectively ($p < 0.05$). In 2018, compared with CK, the utilization rate of ^{15}N in maize grains and leaves treated with WP and CS increased from 2.96% and 0.19% to 6.26% and 0.63%, 4.40% and 0.44%, respectively, and the total utilization rate increased from 3.23% to 7.39% and 4.95%, respectively ($p < 0.05$). The total utilization rate of ^{15}N in 2017 and 2018 increased from 18.90% to 30.05% and 22.42%, respectively. Among different treatments, the total nitrogen content of maize organs follow the order of WP > CS > CK.

3.6. Effects of Corn Straw and Woody Peat Application on ^{15}N Soil Residue

Application of corn straw and woody peat significantly increased the residual rate of ^{15}N urea in the 0–30 cm soil layer ($p < 0.05$) (Figure 5), especially in the 0–20 cm soil layer. In 2017, 32.28%~51.41% of the applied ^{15}N urea remained in the soil, which represents 67% of the residual total ^{15}N in the top 20 cm of soil. In general, the residual ^{15}N recovered in the surface 0–40 cm soil layer was significantly higher with WP than in CK and CS treatments. The residual ^{15}N recovered in the 10–20 cm soil layer with WP and CS treatments was higher than CK by 58.11% and 58.88%, respectively ($p < 0.05$). In the 20~30 cm soil layer, WP was significantly ($p < 0.05$) higher than CK treatment by 146.09%, while CS was non-significantly lower than CK treatment by 5.41%. In 2018, the WP treatment also had the highest soil residue of ^{15}N in 0–10, 10–20, 20–30, and 30–40 cm soil layers. In addition, the remained ^{15}N in the soil layers in the studied treatments was ranged from 3.28 to 5.23% from the applied ^{15}N-urea, and the 0–30 cm soil layer occupied more than 70% of the total ^{15}N soil residue in 2018. In general, the 0–40 cm soil layer of WP and CS treatments had higher amount of soil residual ^{15}N (163.73 and 118.26%) than CK ($p < 0.05$).

3.7. Effects of Straw and Peat Application on the Whereabouts of ^{15}N

The fate of the nitrogen fertilizer mainly includes plant absorption, retention in soil, and loss through various mechanisms. In the first year (2017), the utilization rate of ^{15}N urea with the application of CS, and WP was higher by 11.49 and 44.6%, respectively treatments in compared with the CK treatment. Meanwhile, the soil retention rate (%) of ^{15}N urea was 32.39, 37.32, and 51.41% for CK, CS and WP treatments. In the next year (2018) and compared with the control treatment, the utilization rate of ^{15}N urea with the application of CS, and WP was higher by 53 and 128.80%, respectively. The soil retention rate (%) of ^{15}N urea in CS and WP treatments was higher (4.65 and 5.23%) than with CK treatment (3.23%). While, WP treatment had the highest one. During the whole time of the experiment, the total ^{15}N loss of each treatment varies from 64.72 to 77.82%, with a following order of CK > CS > WP (Table 3). Therefore, the application of corn straw and peat increased ^{15}N urea utilization rate, and the retention of ^{15}N urea remained in soil by 18.62 and 59%, and 41.77 and 59.45%, respectively. While, the CS and WP reduced the loss of N fertilizer by 4.83 and 13.10%, respectively, higher than the control (CK). The application of woody peat showed more significant effects on the absorption and utilization of nitrogen fertilizer. Moreover it increase the retention of nitrogen fertilizer in the soil and reduce the loss more than the application of corn straw.

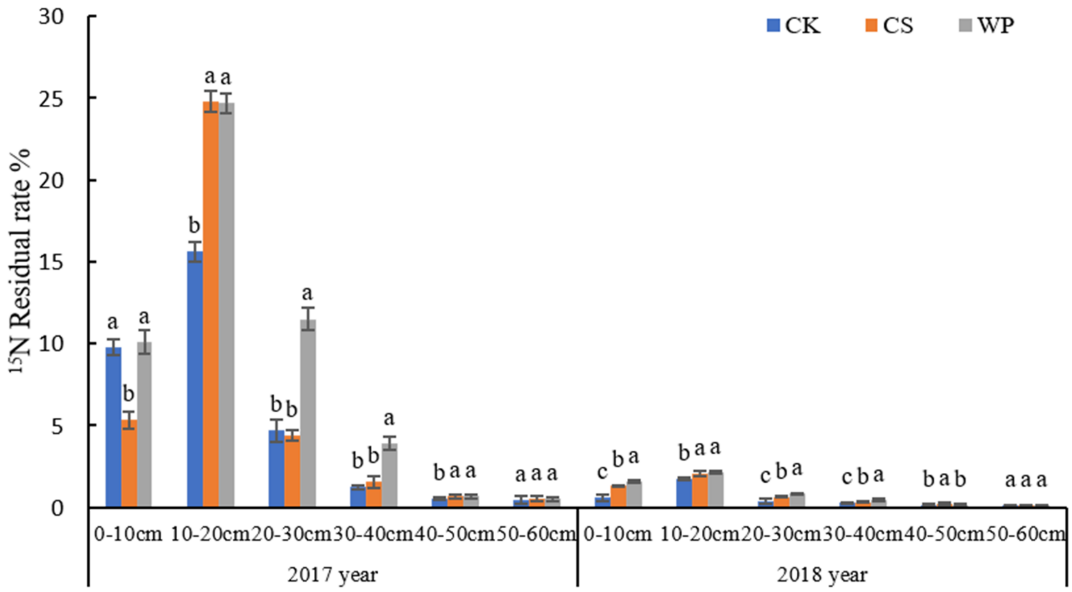

Figure 5. Distribution of ^{15}N residue rate in each soil layer under application of corn straw (CS) and woody peat (WP), and control (CK) treatments (in 2017–2018). Note: CK = ^{15}N labeled urea alone; WP = mixing pulverized woody peat with 0–20 cm soil layer +^{15}N labeled urea; CS = mixing pulverized corn stover with 0–20 cm soil layer +^{15}N labeled urea. Different letters in the same column indicate significant difference at 0.05.

Table 3. Fate of ^{15}N urea under application of corn straw and peat treatments.

Treatments	2017 Year		2018 Year		Total Utilization%	Total Loss Rate %
	Utilization %	Retention Rate %	Utilization%	Retention Rate%		
CK	15.67 ± 0.74 ^{c}	32.29 ± 0.85 ^{c}	3.23 ± 0.07 ^{c}	3.28 ± 0.03 ^{c}	18.90 ± 1.68 ^{c}	77.82 ± 1.85 ^{a}
CS	17.47 ± 1.21 ^{b}	37.32 ± 0.45 ^{b}	4.95 ± 0.61 ^{b}	4.65 ± 0.12 ^{b}	22.42 ± 0.89 ^{b}	72.99 ± 1.71 ^{b}
WP	22.66 ± 1.22 ^{a}	51.41 ± 1.76 ^{b}	7.39 ± 1.15 ^{a}	5.23 ± 0.21 ^{a}	30.05 ± 0.28 ^{a}	64.72 ± 0.93 ^{c}

Note: CK represents ^{15}N labeled urea alone;WP represents mixing pulverized woody peat with 0~20 cm soil layer+^{15}N labeled urea;CS represents mixing pulverized corn stover with 0~20 cm soil layer+^{15}N labeled urea. Different letters in the same column indicate significant difference at 0.05.

4. Discussion

4.1. Application of Straw and Peat Increased Corn Production

In this study, the dry matter production of maize with corn stalk and woody peat treatments was significantly higher than that with CK treatment ($p < 0.05$) (Figure 2), which is consistent with the findings of [12] and [20]. This may be attributed to the fact that the application of corn straw can improve the physical and chemical properties of soil, increase the contents of soil nutrients (N, P, K, Ca, Mg) and micronutrients (S, Cu, B, Zn, Mo, etc.), improve the availability of soil nutrients [24], and promote nutrient uptake [12,25]. Peat has a high content of humic acid [8], and its acidic functional groups such as carboxyl and phenolic hydroxyl groups can interact with amide groups of urea to form humic acid-urea complex [26], which can hamper the hydrolysis process of urea. Urea release and continuous nitrogen supply can be controlled [27,28]. Therefore, the presence of more carboxyl functional groups ensures the continuous supply of nitrogen, thus increasing the accumulation of maize biomass [29]. Application of corn straw or woody peat significantly increased leaves dry matter weight and grains yield (Figure 2). This indirectly indicates that straw and peat can promote the growth and development of maize leaves and improve the photocooperation to achieve the purpose of increasing yield. Whereas, application of woody peat showed significant higher yield as compared to the application of corn straw. Pamela [30] pointed out in their relevant review that numerous studies have shown that humic acid can promote the absorption of nitrogen by plants, as such, we speculated that the difference in the improvement effect of straw and peat on soil organic matter was the main reason for the difference in maize yield. Application of straw and woody peat significantly increased soil organic matter content [20,31], straw with a high C/N ratio can only be converted into humus under the action of microorganisms, while peat itself has a large amount of humus, which can rapidly improve soil humus composition after its application in soil [8,32]. This directly leads to increase the yield [20]. Other studies conducted on the effects of humic acid application in different soils, showed that excessive humic acid application inhibited the growth of maize seedlings [33], which may related to the molecular weight of humic acid application [34].

4.2. Application of Straw and Peat Promoted the Absorption of ^{15}N Urea

The application of straw and peat promoted the absorption and utilization of ^{15}N urea (Figure 4). Straw returning to the soil can promote urease activity, urea hydrolysis and NH_4^+ accumulation [7], thus it can increase soil nitrogen availability and nitrogen supply capacity [35,36]. Studies have shown that up to 75% of nitrogen in maize is absorbed by arbuscular mycorrhizal fungi [37]. Arbuscular mycorrhizal fungi not only directly participate in straw decomposition, but also absorb and transport part of small-molecule organic nitrogen or ammonium nitrogen to host plants for absorption and utilization [38]. In addition, the exocyst can extend to the area around the root, expanding the absorption range of nitrogen [39–41]. Peat can effectively regulate nitrogen conversion in soil [27]. Adding humic acid when urea is used can inhibit urease in a short time. Humic acid with large molecular weight can stabilize urease activity in a long time, thus stabilizing the conversion rate of urea into ammonia in a certain period of time, and providing ammonia that can be directly absorbed and utilized by plants in a lasting and effective way [42]. Adding humic acid to soil can improve the effectiveness of nitrogen fertilizer, but too much will have adverse effects. A study by [43] showed that application of humic acid at level of 60 mg kg^{-1} soil can promote the wheat growth and nitrogen absorption, while the addition amount of 90 mg kg^{-1} was not conducive to wheat growth and nitrogen absorption. This may be attributed to the fact that there are many functional groups such as carboxyl, phenolic hydroxyl, carbonyl and quinone in the higher level of humic acid, which may lead to complex reactions with urea and ammonium ions [26] and inhibit the action of urease, thus affecting the utilization of urea.

Soil nitrogen is the main source for plant growth. Even with the application of large amounts of chemical fertilizer, soil still contribute 50% to 70% of nitrogen absorbed by crops [44]. In the process of maize growth, regardless of the nitrogen brought in by precipitation and irrigation, there are two main sources of nitrogen absorbed by the plant: soil nitrogen and fertilizer nitrogen. According to the analysis of nitrogen sources absorbed by maize in this experiment (Table 2), it was found that the maize absorbed fertilizer nitrogen of WP, CS and CK accounted for 12.48 to 18.14, (2017) and 0.21% to 1.26% (2018) of their total nitrogen uptake, respectively, while the absorbed soil nitrogen accounted for more than 80% of the total nitrogen uptake. This result showed that the application of straw and peat promoted the absorption and utilization of soil nitrogen by maize. This may be related to the fact that humified material promotes organic nitrogen mineralization, but at the same time, the degree of soil humification directly affects the rate of nitrogen mineralization [45]. A research study has shown that the higher the aromatization degree of organic matter, the lower the ratio of mineralized nitrogen, and vice versa [46], so we speculated that straw and peat application reduced the aromatization degree of organic matter in soil. The research shows that the structure of a large number of lignin phenolic compounds in young humic acid is not conducive to nitrogen mineralization [47], while corn straw contains a large amount of lignin [48], which also explains the reason why woody peat is significantly higher than corn straw ($p < 0.05$). However, the mechanism of how humification of humic acid affects nitrogen mineralization remains unclear. Although the degree of humus aromatization in soil was not analyzed in this paper, the promoting effect of woody application on the absorption and utilization of soil nitrogen by maize was significant.

4.3. The Application of Straw and Peat Increased the Residue of ^{15}N Urea in the Soil and Reduced the Loss

In this study, the residual nitrogen fertilizer was mainly concentrated in the active soil layer (0–30 cm), and the residual amount in the lower layers gradually decreased, but there were still residues of nitrogen fertilizer in the 40–60 cm soil layer (Figure 5). Therefore, it can be inferred that there may be residual fertilizer nitrogen in the soil layer below 60cm, and the actual residual nitrogen fertilizer may be slightly higher than the measured value. During the two years, the total amount of residual ^{15}N in soil and in different soil layers followed the order of WP > CS > CK. This is consistent with the studies of [49] and [27]. We speculated that it might be caused by the different effect of straw and peat on soil humus. After application of urea to the soil, it transformed into ammonium and then nitrate via ammonification and nitrification processes. The humic acid molecules have more carboxyl groups, hydroxyl groups and other functional groups with high adsorption capacity. These properties lead to increase the adsorption of ammonium and nitrate nitrogen in soil [50,51]. Therefore, reducing the leaching of the soil nitrogen through the application of OM, increase the soil nitrogen residue and effectively reduces nitrogen migration to the deep soil. In addition, the accumulation of nitrogen fertilizer in the 0–30 cm soil layer is higher with less downward leaching, which can meet the characteristics of plant root and is more conducive to crop growth, which also explains the reason why corn straw and woody peat can promote maize growth and increase maize yield to a certain extent. Peat has a high humic acid content [8], which can rapidly increase the humic acid content after entering the soil [32], while straw needs to be gradually transformed into organic matter under the action of microorganisms [52], which takes a long time and consumes a lot of energy. Therefore, peat has a better fixation effect on ^{15}N urea, and as such, the application of woody peat might bring more benefits for crop growth.

Steiner [53] reported that the combined application of corn stalk and nitrogen fertilizer could improve nitrogen retention and reduce nitrogen loss in nitrogen-applying soil. Humic acid can affect the release rate of ammonia by inhibiting soil urease activity, thus affecting the community structure of ammonia oxidizing microorganisms, inhibiting the increase in the number of ammonia oxidizing bacteria and ammonia oxidizing archaea caused by the addition of urea, reducing the competition between ammonia oxidizing bacteria and plants and reducing the loss of ammonia [27].

5. Conclusions

Application of fresh or humified organic materials could improve the efficiency of nitrogen fertilizer. From the obtained results, the growth of the aboveground organs, dry matter yield and the distribution proportion of ^{15}N in organs were significantly increased during two years application of CS and WP. Compared to the control treatment (CK), the treatments of WP and CS were increased the yield of maize (19.40 and 11.20%), ^{15}N urea utilization rate (58.99% and 18.62%), and residual ^{15}N urea remained in soil (59.45% and 41.77%, respectively). In addition, there was a decrease in the total N loss rate by 19.83% in WP and 6.21% in CS treatment over the two seasons. So, application of woody peat is beneficial to increase the nitrogen use efficiency and the yield of maize compared to CS and CK. Therefore, the application of humified organic material play a crucial role in N utilization efficiency enhancement. More research is required to investigate the effect of the different levels of woody peat on utilization of ^{15}N-urea by maize.

Author Contributions: Conceptualization, S.D.; methodology, C.L. and D.W.; validation, R.M. and S.X.; formal analysis, C.T. and X.Y.; resources, M.G.M.A.E.-R.; data curation, C.L.; investigation, Y.Z.; writing-original draft preparation, M.G.M.A.E.-R.; writing-review and editing, X.L.; supervision, M.G.M.A.E.-R.; funding acquisition, S.D. All authors have read and agreed to the published version of the manuscript.

Funding: The study was supported by the National Natural Science Foundation of China (No. 42077022) and the Key Research and Development Program of Jilin Province (No. 20200402098NC).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ju, X.; Gu, B. Problem and trend of nitrogen fertilization in China. *Plant Nutr. Fertil. Sci.* **2014**, *20*, 783–795. (In Chinese) [CrossRef]
2. Yu, G.; Fang, H.; Gao, L.; Zhang, W. Soil organic carbon budget and fertility variation of black soils in Northeast China. *Ecol. Res.* **2006**, *21*, 855–867. [CrossRef]
3. David, F.; Mhairi, C.; Ute, S.; Mark, A.S.; Stefan, R.; Lucy, J.S.; Alan, J.; Bruna, G.; James, N.G.; Peter, V.; et al. The global nitrogen cycle in the twenty-first century. *Philos. Trans. R. Soc. B Biol. Sci.* **2013**, *368*, 20130164. [CrossRef]
4. Lutes, K.; Oelbermann, M.; Thevathasan, N.V.; Gordon, A.M. Effect of nitrogen fertilizer on greenhouse gas emissions in two willow clones (Salix miyabeana and S.dasyclados) in southern Ontario, Canada. *Agrofor. Syst.* **2016**, *90*, 785–796. [CrossRef]
5. De, V.W.; Kros, J.; Kroeze, C.; Seitzinger, S.P. Assessing planetary and regional nitrogen boundaries related to food security and adverse environmental impacts. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 392–402. [CrossRef]
6. Tang, Y.; Wang, X.Z.; Zhao, H.T.; Ke, F. Effect of potassium and C/N ratios on conversion of NH+4 in soils. *Pedosphere* **2008**, *18*, 539–544. [CrossRef]
7. Pan, B.; Lam, S.K.; Mosier, A.; Luo, Y.; Chen, D. Ammonia volatilization from synthetic fertilizers and its mitigation strategies: A global synthesis. *Agric. Ecosyst. Environ.* **2016**, *232*, 283–289. [CrossRef]
8. Zheng, Y.Y.; Zhang, J.B.; Tan, J.; Zhang, Z.C.; Yu, Z.H. Chemical composition and structure of humus relative to sources. *Acta Pedol. Sin.* **2019**, *56*, 386–397. [CrossRef]
9. Lal, R. The role of residues management in sustainable agricultural systems. *J. Sustain. Agric.* **1995**, *5*, 51–78. [CrossRef]
10. Duiker, S.W.; Lal, R. Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. *Soil Till. Res.* **1999**, *52*, 73–81. [CrossRef]
11. Liu, B.; Wu, Q.; Wang, F.; Zhang, B. Is straw return-to-field always beneficial? Evidence from an integrated cost-benefit analysis. *Energy* **2019**, *171*, 393–402. [CrossRef]
12. Yu, C.; Wang, X.; Hu, B.; Yang, C.; Sui, N.; Liu, R.; Zhou, Z. Effects of wheat straw incorporation in cotton-wheat double cropping system on nutrient status and growth in cotton. *Field Crops Res.* **2016**, *197*, 39–51. [CrossRef]
13. Nieder, R.; Benbi, D.K.; Scherer, H.W. Fixation and defixation of ammonium in soils: A review. *Biol. Fertil. Soils* **2011**, *47*, 1–14. [CrossRef]
14. Zhao, H.; Sun, B.; Lu, F.; Zhang, G.; Wang, X.; Ouyang, Z. Straw incorporation strategy on cereal crop yield in China. *Crop Sci.* **2015**, *55*, 1773–1781. [CrossRef]
15. Gorham, E. Northern peatlands: Role in the carbon cycle and probable responses to climatic warming. *Ecol. Appl.* **1991**, *1*, 182–195. [CrossRef] [PubMed]

16. Limpens, J.; Berendse, F.; Blodau, C.J.; Canadell, G.; Freeman, C.; Holden, J.; Roulet, N.; Rydin, H.; Schaepman-Strub, G. Peatlands and the carbon cycle: From local processes to global implications—A synthesis. *Biogeosciences* **2008**, *5*, 1475–1491. [CrossRef]
17. Laiho, R. Decomposition in peatlands: Reconciling seemingly contrasting results on the impacts of lowered water levels. *Soil Biol. Biochem.* **2006**, *38*, 2011–2024. [CrossRef]
18. Abdel-Salam, A.E. Stabilization of peat soil using locally admixture. *HBRC J.* **2018**, *14*, 294–299. [CrossRef]
19. Liu, M.; Wang, C.; Wang, F.; Xie, Y. Maize (*Zea mays*) growth and nutrient uptake following integrated improvement of vermicompost and humic acid fertilizer on coastal saline soil. *App. Soil Ecol.* **2019**, *142*, 147–154. [CrossRef]
20. Fu, W.; Yong, C.X.; Ma, D.H.; Fan, J.; Zhang, J.B.; Wei, H.; Feng, X.L.; Wei, R.Z.; Liu, X.F.; Wang, G.D.; et al. Rapid fertilization effect in soils after gully control and land reclamation in loess hilly and gully region of China. *Trans. Chin. Soc. Agric. Eng.* **2019**, *35*, 252–261, (In Chinese with English abstract).
21. Qu, C.C.; Chen, X.M.; Zhang, J.B.; Fan, S.Y.; Tan, J.; Ruan, Y.M.; Zhang, Y.F.; Wu, D.H.; Han, Z.Q.; Zhang, S.L. Technique and effects of quickly constructing high-quality tillage layer newly-cultivated arable land in red soil and paddy field based on woody peat and organic materials. *Soil Water Conserv.* **2018**, *32*, 136–142, (In Chinese with English abstract). [CrossRef]
22. Lai, S.; Johansson, M.A.; Yin, W.; Yin, W.; Wardrop, N.A.; Panhuis, W.G.; Wesolowski, A.; Kraemer, M.U.G.; Bogoch, I.I.; Kain, D.; et al. Seasonal and interannual risks of dengue introduction from South-East Asia into China, 2005–2015. *PLoS Negl. Trop Dis.* **2018**, *12*, e0006743. [CrossRef] [PubMed]
23. Ma, R.; Guan, S.; Dou, S.; Wu, D.; Xie, S.; Ndzelu, B.S. Different rates of biochar application change 15N retention in soil and ^{15}N utilization by maize. *Soil Use Manag.* **2020**, *36*, 773–782. [CrossRef]
24. Beare, M.H.; Wilson, P.E.; Fraser, P.M.; Fraser, P.M.; Butler, R.C. Management effects on barley straw decomposition, nitrogen release, and crop production. *Soil Sci. Soc. Am. J.* **2002**, *66*, 848–856. [CrossRef]
25. Yan, F.; Sun, Y.; Xu, H.; Jiang, M.; Xiang, K.; Wu, Y.; Jun, M. The effect of straw mulchon nitrogen, phosphorus and potassium uptake and use in hybrid rice. *Paddy Water Environ.* **2019**, *17*, 23–33. [CrossRef]
26. Liang, Z.; Cheng, S.; Wu, L. Study on mechanism of interaction between coal humic acid and urea. *J. Fuel Chem. Technol.* **1999**, *27*, 176–181. (In Chinese) [CrossRef]
27. Dong, L.H.; Córdova-Kreylos, A.L.; Yang, J.; Yuan, H.; Scow, K.M. Humic acids buffer the effects of urea on soil ammonia oxidizers and potential nitrification. *Soil Biol. Biochem.* **2009**, *41*, 1612–1621. [CrossRef]
28. Reeza, A.A.; Ahmed, O.H.; Majid, N.; Jalloh, M.B. Reducing ammonia loss from urea by mixing with humic and fulvic acids isolated from coal. *Am. J. Environ. Sci.* **2009**, *5*, 420–426. [CrossRef]
29. Li, Z.; Ma, G.; Wang, S.; Lu, X. Transformation of long-lasting UHA in soil and its effect on maize yield. *Chin. J. Eco-Agric.* **2005**, *13*, 121–123. (In Chinese)
30. Pamela, C.; Louise, N.; Joseph, W.K. Agricultural uses of plant biostimulants. *Plant Soil* **2014**, *383*, 3–41. [CrossRef]
31. Thomsen, I.K.; Christensen, B.T. Yields of wheat and soil carbon and nitrogen contents following long-term incorporation of barley straw and ryegrass catch crops. *Soil Use Manag.* **2010**, *20*, 432–438. [CrossRef]
32. Zhao, W.H.; Ma, L.; Xu, J.S.; Tan, J.; Zhang, J.B.; Zhao, B.X. Effects of short-term application of straw and woody peat on composition and function of organic matter and microbial community in aquic soil. *J. Soil* **2019**, *57*, 153–164. (In Chinese) [CrossRef]
33. Asli, S.; Neumann, P.M. Rhizosphere humic acid interacts with root cell walls to reduce hydraulic conductivity and plant development. *Plant Soil* **2010**, *336*, 313–322. [CrossRef]
34. Marzadori, C.; Francioso, O.; Ciavatta, C.; Gessa, C. Activity and stability of jack bean urease in the presence of peat humic acids obtained using different extractants. *Biol. Fertil. Soils* **2000**, *32*, 415–420. [CrossRef]
35. Dolan, M.S.; Clapp, C.E.; Allmaras, R.R.; Baker, J.M.; Molina, J.A. Soil organic carbon and nitrogen in a Minnesota soil as related to tillage, residue and nitrogen management. *Soil Till. Res.* **2006**, *89*, 221–231. [CrossRef]
36. Tong, X.; Xu, M.; Wang, X.; Bhattacharyya, R.; Zhang, W.; Cong, R. Long-term fertilization effects on organic carbon fractions in a red soil of China. *Catena* **2014**, *113*, 251–259. [CrossRef]
37. Tanaka, Y.; Yano, K. Nitrogen delivery to maize via mycorrhizal hyphae depends on the form of N supplied. *Plant Cell Environ.* **2010**, *28*, 1247–1254. [CrossRef]
38. Wang, D.; Xu, C.; Yan, J.; Zhang, X.; Chen, S.; Chauhan, B.S.; Zhang, X. 15N tracer-based analysis of genotypic differences in the uptake and partitioning of N applied at different growth stages in transplanted rice. *Field Crops Res.* **2017**, *211*, 27–36. [CrossRef]
39. Walder, F.; Niemann, H.; Natarajan, M.; Lehmann, M.F.; Boller, T.; Wiemken, A. Mycorrhizal networks: Common goods of plants shared under unequal terms of trade. *Plant Physiol.* **2012**, *159*, 789–797. [CrossRef]
40. Miransari, M. Arbuscular mycorrhizal fungi and nitrogen uptake. *Arch. Microbiol.* **2011**, *193*, 77–81. [CrossRef]
41. Cavagnaro, T.R.; Barrios-Masias, F.H.; Jackson, L.E. Arbuscular mycorrhizas and their role in plant growth, nitrogen interception and soil gas efflux in an organic production system. *Plant Soil* **2012**, *353*, 181–194. [CrossRef]
42. Dong, L.H.; Yang, J.S.; Wang, E.T.; Chen, W.X. Chemical characteristic and influences of two fractions of Chinese lignite humic acids on urease. *Eur. J. Soil Biol.* **2008**, *44*, 166–171. [CrossRef]
43. Tahir, M.M.; Khurshid, M.; Khan, M.Z.; Abbasi, M.K.; Kazmi, M.H. Lignite-derived humic acid effect on growth of wheat plants in different soils. *Pedosphere* **2011**, *21*, 124–131. [CrossRef]
44. Zhu, Z.L. Research on soil nitrogen in China. *Acta Pedol. Sin.* **2008**, *5*, 778–783. (In Chinese)
45. Ve, N.B.; Olk, D.C.; Cassman, K.G. Nitrogen mineralization from humic acid fractions in rice soils depends on degree of humification. *Soil Sci. Soc. Am. J.* **2004**, *68*, 1278–1284. [CrossRef]

46. Ve, N.B.; Olk, D.C.; Cassman, K.G. Characterization of humic acid fractions improves estimates of nitrogen mineralization kinetics for lowland rice soils. *Soil Sci. Soc. Am. J.* **2004**, *68*, 1266–1277. [CrossRef]
47. Olk, D.C.; Samson, M.I.; Gapas, P. Inhibition of nitrogen mineralization in young humic fractions by anaerobic decomposition of rice crop residues. *Eur. J. Soil Sci.* **2007**, *58*, 270–281. [CrossRef]
48. Koullas, D.P.; Christakopoulos, P.; Kekos, D.; Macris, B.J.; Koukios, E.G. Correlating the effect of pretreatment on the enzymatic hydrolysis of straw. *Biotechnol. Bioeng.* **1992**, *39*, 113–116. [CrossRef]
49. Corbeels, M.; Hofman, G.; Van Cleemput, O. Nitrogen cycling associated with the decomposition of sunflower stalks and wheat straw in a Vertisol. *Plant Soil* **2000**, *218*, 71–82. [CrossRef]
50. Burge, W.D.; Broadbent, F.E. Fixation of ammonia by organic soils. *Soil Sci. Soc. Am. J.* **1961**, *25*, 199–204. [CrossRef]
51. Susilawati, K.; Osumanu, H.A.; Nik, M.; Ab, M.; Mohd, K.Y.; Mohamadu, B.J. Effect of organic based N fertilizer on dry matter (*Zea mays* L.), ammonium and nitrate recovery in an acid soil of Sarawak, Malaysia. *Am. J. Appl. Sci.* **2009**, *6*, 1289–1294. [CrossRef]
52. Joshua, S.; Teri, C.B.; Matthew, W. Microbial stress-response physiology and its implications for ecosystem function. *Ecology* **2007**, *88*, 1386–1394. [CrossRef]
53. Christoph, S.; Bruno, G.; Wenceslau, G.T.; Johannes, L.; Winfried, E.H.B.; Wolfgang, Z. Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. *J. Plant Nutr. Soil Sci.* **2008**, *171*, 893–899. [CrossRef]