agronomy

Article

Zero Tillage Improves Soil Properties, Reduces Nitrogen Loss and Increases Productivity in a Rice Farmland in Ghana

Fuseini Issaka [1], Zhen Zhang [1], Yongtao Li [1], Zhongqiu Zhao [1], Evans Asenso [2], Adam Sheka Kanu [3], Wenyan Li [1,*] and Jinjin Wang [1,*]

[1] College of Natural Resources and Environment, South China Agricultural University, Guangzhou 510642, China; fatiabubakar2020@gmail.com (F.I.); zzhangal@scau.edu.cn (Z.Z.); yongtao@scau.edu.cn (Y.L.); zq.zhao1991@foxmail.com (Z.Z.)
[2] College of Water Conservancy and Civil Engineering, South China Agricultural University, Guangzhou 510642, China; asensoevans@stu.scau.edu.cn
[3] College of Agriculture, South China Agricultural University, Guangzhou 510642, China; a.kanu@slari.gov.sl
* Correspondence: lily1984191@scau.edu.cn (W.L.); wangjinjin@scau.edu.cn (J.W.); Tel./Fax: +86-(0)20-38604957 (W.L.); +86-(0)20-8528-1887 (J.W.)

Received: 4 September 2019; Accepted: 12 October 2019; Published: 15 October 2019

Abstract: Soil fertility in Ghana continues to decline due to the overdependency on farm machinery to till the land coupled with the continuous application of mineral fertilizer, which has a resultant effect on agricultural non-point source (AgNPS) pollution. A two-year field experiment was conducted to evaluate the effects of different tillage methods on soil properties, nitrogen loss reduction and rice productivity of a gleysol, developed over granite. Five tillage methods—namely, zero tillage direct seeding (ZTDS), zero tillage transplanting (ZTTS), reduced tillage direct seeding (RTDS), reduced tillage transplanting (RTTS), and conventional tillage (CT)—were studied in a Randomized Complete Block Design (RCBD) with three replicates. After two cropping seasons, soil bulk density was in the order of (ZTTS = ZTDS) > RTDS > RTTS > CT. ZTDS and ZTTS were associated with significantly higher levels of nutrients in the top soil (0–20 cm) as compared with the rest of the treatments. Plant height was in the order of CT > RTTS = ZTTS > RTDS > ZTDS. The highest grain yield was recorded by both CT and ZTTS significantly different from the rest of the treatments. ZTDS recorded the highest stover yield for both years. Subsequently, CT was associated with high release of potential pollutant loads which could lead to AgNPS pollution, as is evident from the high nutrient loss. Considering the high nutrient concentration at 0–20 cm, the reduced nutrient movement and the corresponding yield improvement, ZTDS and ZTTS are recommended for farmers in Ghana to ensure sustainable rice production, reduce AgNPS pollutant movement and ultimately provide an eco-protective and friendly environment for sustainable rice production.

Keywords: conservation tillage; conventional tillage; environmental pollution; soil properties; nitrogen loss; rice yield

1. Introduction

Rice plays a critical role in contributing to food security, income generation, poverty alleviation and socioeconomic growth in Ghana [1]. Between the years of 2000 and 2010, hectares of land under rice cultivation increased from 0.09 to 0.16 million hectares, while productivity fluctuated between 1.7 to 2.7 tons per hectare [2].

The production of rice in Ghana relies on the use of farm machinery and increased usage of inorganic fertilizers [1]. Also, Ghana is an example of a country with land dynamics suitable for mechanization, with the rapidly increasing farm sizes in recent years leading to medium-scale farmers (5–100 ha) cultivating the largest share of national cropland [3]. Results from the 2013 IFPRI/SARI survey of medium-to-large farmers in Northern Ghana, showed that over half of tractor owners cited land expansion as the primary motivation for their investment [4]. From the year 2000 to 2010, the Government of Ghana, under the Japanese Grant Assistance, 2KR-programme, imported several agricultural machines yearly to enable farmers to have access to modernized agriculture [5]. Conventional tillage (CT) involving the use of farm machinery generally involves ploughing and intensive soil disturbance. This type of tillage has been recognized as the major driver of soil degradation through the depletion of soil organic matter and associated nutrient loss [6]. Moreover, continuous soil dilapidation and productivity decline are as a result of unsuitable land use and management practices that caused decline in soil organic matter (SOM), soil erosion by running water and other nutrient losses [7]. Also, extreme use of farm inputs for nutrients from manure and commercial fertilizers serve as the principal pollutants from agricultural activities [8,9].

Improvement in soil value and prolonged crop yield could be attained by ensuring proper soil management practices [10], including conservational tillage. Conservation agriculture (CA) is considered to be a technology that is friendly to the environment due to its positive effect on soil and water conservation, environmental health, and economic viability [11]. The true benefit of CA will, to a great extent, depend on specific practices, regional climatic dynamics and the type of cropping systems in place [12].

Much tillage research work has been carried out in Ghana, but very little work has been done specifically on the effect of conservation tillage, ZTDS rice on soil properties, and nutrient loss, or on the effect of such tillage methods on rice productivity. This study was therefore conducted (i) to characterize the effect of ZTDS rice on soil properties, nutrient movement and distribution along the soil profile, (ii) to investigate the effect of such tillage methods on nitrogen loss, and (iii) to evaluate rice (*Oryza sativa*) growth and yield parameters in order to provide scientific support for emerging and evidence-based rice soil management and productivity support strategies that would help achieve global food security.

2. Materials and methods

2.1. Plant Material and Growing Conditions

An aromatic rice (Jasmine) with a maturity period of 114 days and extensively cultivated in Ghana was planted at the Central Agricultural Station (6°40′25.6″ N, 1°40′40.3″ W) located at Kwadaso in the Ashanti region of Ghana. The study was conducted on an experimental field established five years ago. The area falls under the forest agro-ecological zone, characterized by two growing seasons; a major rainy season and a minor rainy season. The month of August experiences a short dry spell. Temperature varies between 26 °C and 34 °C. The area is also scattered with shrubs and a few trees which normally shed their leaves during the dry season (October–March). The monthly rainfall and average temperature values are shown in Figure 1.

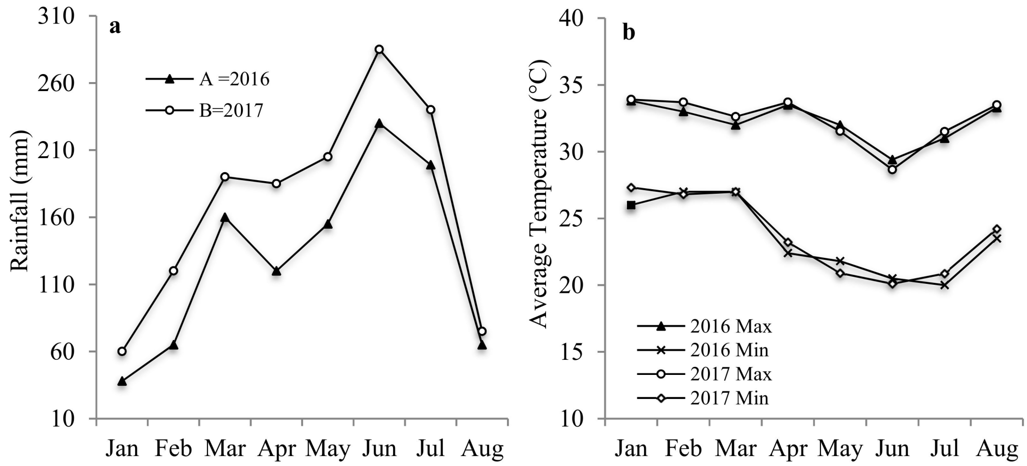

Figure 1. (**a**) Monthly variation of rainfall; and (**b**) monthly variation in temperature.

2.2. Experimental Conditions

Five treatments made up of four conservation tillage methods and one CT method were used for the study. The experimental plots had been under cultivation for the previous five years. The treatment descriptions are: zero tillage direct seeding (ZTDS); zero tillage transplanting (ZTTS); reduced tillage direct seeding (RTDS); reduced tillage transplanting (RTTS) and CT. The treatments were arranged in RCBD in triplicate. The treatment sites were divided into three main blocks using bunds (about 100 cm) to represent three replications. Each block was further divided into five (5) main plots. The dimensions of each plot were 10 × 40 m (length × width) = 400 m^2. ZTDS plots were sprayed with non-selective weedicide (Gylphosate). Dry rice seeds with a density of 55 kg·ha^{-1} were hill-seeded by hand at a spacing of 20 × 20 cm and covered with loose soil. Each hill was planted with 2–4 seeds. ZTTS plots were prepared similar to ZTDS above. Ten (10)-day-old seedlings were hill-transplanted manually at a spacing of 20 × 20 cm. RTDS plots were rotovated once at the depth of 8-10 cm using power tiller. Seeding was done similar to ZTDS on the 28 May, 2016–2017 and immediately covered with loose soil. Each hill was planted with 2–4 seeds. This was followed by flooding and the field kept moist but not saturated to avoid seed rot for about two weeks. RTTS plots were rotovated once at the depth of 8 cm using power tiller. One-time puddling was done before planting. Seeding was also done similar to ZTTS. CT plots were rotovated at the depth of 20 cm with power tiller followed by hill transplanting of 10 days old rice seedlings at two per stand (hill).

In all the conservation tillage treatment plots, organic fertilizer obtained from decomposed rice straw was applied at the rate 15 t·ha^{-1}, in late April each year. After planting, the plots were managed using a typical flooding-drainage water regime throughout the entire rice growing season. Rice fields were submerged under water at a depth of approximately 3–5 cm for about a month, drained dry during mid-season aeration for about one week. Intermittent irrigation was carried out when necessary. Mineral fertilizer was also applied at the rate of 90 kg·N·ha^{-1}, 60 kg·P_2O_5·ha^{-1} and 60 kg·K_2O·ha^{-1} to all treatment plots. All P and K and 50% N were applied three weeks after seeding on the ZTDS plots and immediately after transplanting on the ZTTS, RTTS and the CT plots. The remaining 50% N was applied at panicle initiation stage for all treatments. Direct seeding and transplanting were all done manually by hand. Crop protection (weed and disease control) was carried out when necessary with the use of glyphosate (Isopropylamine salt). After planting, all treatments plots were managed using a typical flooding-drainage water regime throughout the entire rice growing season.

2.3. Soil Sampling and Analysis

A total of 75 sampling points were selected from the five treatment sites, with each plot sampled five times at incremental soil depths of 0–20, 20–40, 40–60, 60–80, 80–100 cm with the help of soil auger. Soil samples were collected after treatment application (January each year), during the rice active growth stage (April, each year) and at harvest (August each year) for the 2016/2017 growing seasons, respectively. Augured soil samples were air dried for 4–5 days, and sieved into various sizes of 2 mm, 1 mm and 0.15 mm for laboratory analysis. The basic physical and chemical properties were determined using standard methods. Undisturbed soil samples were used to determine soil bulk density using the core method [13]. Soil pH was measured using a glass electrode (pH meter) in a soil to water ratio of 1:2.5 [14]. Soil alkaline-nitrogen (AN) was determined using the alkaline hydrolysis diffusion method [15]. Total nitrogen (TN) was determined by the macro-Kjeldahl wet oxidation method [16]. Soil total organic carbon (TOC) was estimated using the potassium dichromate volumetric method [17]. Exchangeable K was determined using flame photometry [18]. Available phosphorous (AP) was determined by the Olsen method [19]. Nitrate (NO_3^--N) and Ammonium (NH_4^+-N) were extracted using KCl [20], and determined by detection using a Skalar flow injection analyzer (SA 5000). Initial soil physical and chemical properties of the experimental site are shown in Table 1.

Table 1. General soil properties of the experimental site (0–20 cm) before initiation of the experiment in 2016.

Bulk Density ($g \cdot cm^{-3}$)	1.56
pH	6.99
TOC ($g \cdot kg^{-1}$)	45.35
TN ($g \cdot kg^{-1}$)	1.73
TP ($g \cdot kg^{-1}$)	1.19
AN ($mg \cdot kg^{-1}$)	10.83
Exchangeable K ($mg \cdot kg^{-1}$)	65.47
NO_3^--N ($mg \cdot kg^{-1}$)	25.56
NH_4^+-N ($mg \cdot kg^{-1}$)	60.10

2.4. Monitoring of Runoff N Loss

Computation of N input losses in runoff water ($mg \cdot kg^{-1}$) and TN runoff loss ($Kg \cdot N \cdot ha^{-1}$) were carried out in 2016–2017. A rain gauge was mounted at the experimental site. A metal plate measuring about 100 mm by 2 mm was driven vertically 30 mm into the soil along the outer limits of each plot parallel to the slope to direct runoff water into a three hundred-liter storage container (see Figure 2). The amount of water from each rainfall event captured by the rain gauge was deducted from the amount of water in the uncovered storage tank. This was done before calculating the volume of runoff generated from each treatment plot. After every rainfall event, runoff water collected in the storage tanks were mix carefully and a 500 mL sample collected, stored at a temperature of 4 °C before filtering within a 24-h period. Filtrates as well as runoff water were analyzed for TN.

Figure 2. Installation of runoff collection system for monitoring N losses.

2.5. Growth and Yield Parameters of Rice

Growth and yield parameters such as plant height, stover yield, and grain yield of rice were measured at maturity by demarcating an area of 2 m^2 on each treatment plot and yield per hectare estimated.

2.6. Data Analysis

In the present study, all experiments were conducted in triplicate. The data presented in figures and tables are the arithmetic mean values of the triplicate measurements. Data on soil physical and chemical properties, as well as N loss, were analyzed using SPSS version 23.

3. Results and Discussion

3.1. Effect of Tillage Methods on Soil Properties

The distribution of bulk density (0–20 cm) at the end of the study is shown in Figure 3a. Bulk density generally decreased under the conservation tillage techniques. The soil bulk density of the different conservation tillage treatments did not differ significantly when soil monitoring was performed in January–April, 2016. Significantly, lower bulk density of 1.32, 1.48 and 1.45 was recorded by CT at the beginning of the experiment in January, April and July 2016. RTDS, RTTS, ZTDS and ZTTS all recorded a bulk density of 1.43, 1.42, 1.47 and 1.48 g.cm^{-3}, respectively. At the end of the study in July, 2017, the average highest soil bulk density was recorded by CT (1.39 g.cm^{-3}). The results of this study reveal that soil bulk densities for all of the conservation tillage techniques were significantly higher than CT (Figure 3a) at the beginning of the experiment. However, at the end of the experiment in July, 2017, CT recorded the highest soil bulk density, which was significantly different from the rest of the treatments. The lower bulk density recorded by conservation tillage methods, especially ZTDS and ZTTS, at the end of the study in 2017 was a result of good interaction between the soil and the decomposed rice straw. This has the potential to enhance microbial growth with the resultant effect on the slow breakdown of organic materials to release soil organic carbon (SOC) within the soil. Similar results have been produced by other researchers. For example, it is widely acknowledged that the physical properties of the soil required for adequate crop improvement are enhanced by the accumulation of OM in the soil [21,22]. Boosting soil organic carbon (SOC) availability in the soil will reduce bulk density, improve water holding capacity and enhance soil aggregate stability (AS) [23]. Results from a two-year study in selected areas in Northern Ghana showed an enhanced biomass accumulation and productivity of soils with adequate N and P fertilization and moisture retention in CA fields compared to non-CA fields [24]. Moreover, conservation measures lasting several years could reduce bulk density and aggregate stability of the soil through increase in SOM and adoption of cover crops [25]. According to [26], soil bulk density in the top soil experiences a decline resulting from the practice of zero tillage cropping. Soil properties are positively enhanced due to the yearly retention of crop residues [27]. Additionally, suitable bulk density (1.2–1.3 g·cm^{-3}) is appropriate for the absorption of water and nutrients for plant growth [20], with bulk density having the propensity to highlight soil compaction. The low bulk density initially recorded by CT was as a result of the destruction caused by the physical breakdown of soil structure by the power tiller. This leads to an increase in soil macropore spaces resulting in lower bulk density and high porosity. However, with time, densification of soil associated with environment factors such as wetting and drying could lead to a high bulk density under CT. This could be the reason for the significant increase in bulk density at the end of the study in July, 2017.

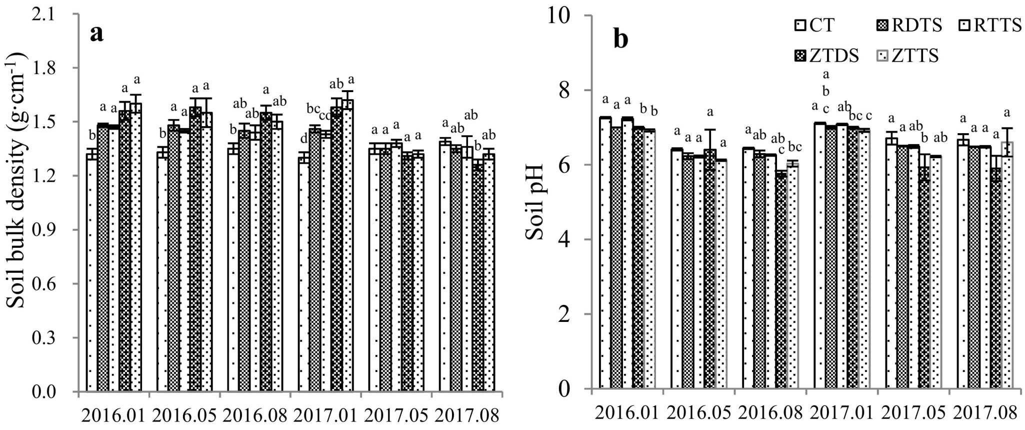

Figure 3. Effect of tillage methods on (**a**) soil bulk density; (**b**) soil pH for 2016 and 2017.

The highest soil pH at the end of the study period was recorded by CT with a two-year average of 6.92 (Neutral). This was significantly ($p \leq 0.05$) different compared to the slightly acidic (pH = 6.50) recorded under all the conservation tillage technologies (Figure 3b). However, the lowest soil pH at the end of the two-year study in the month of July, 2017 was recorded by ZTDS, with pH = 6.33, indicating slight acidity. Results from the experiment showed that all conservation tillage methods recorded a reduction in soil pH (Figure 3b). The reduction in pH was a result of the reduced water movement, which encouraged the retention of nutrients and hydrogen ions from decomposed rice straw and the mineralization of inorganic fertilizer. The high presence of hydrogen ions causes the soil to become acidic. This can be explained by other studies that have also recorded acidification in the soil profile of conservation tillage. [28], asserted that many years of using N-containing fertilizers such as ammonium or related organic forms of N leads to nitrification, releasing H^+ that causes a deficit in basic cations. Additionally, due to the eluviation of rainfall and irrigation, some hydrogen (H^+) substances were leached from the A layer into the subsoil, which subsequently caused the decrease in the pH of soils under conservation tillage. Furthermore, production enhances humus formation with a resultant increase in H^+ ions [29].

Results from the study also show that TOC, AP, TP and AN all increased significantly under ZTDS and ZTTS compared to the rest of the treatments (Figure 4). Only AP and AN showed no significant difference in the first year the study was conducted. However, significant differences among the treatments were recorded in 2017 for TN, AN and $NH_4{}^+$-N, with ZTDS recording the highest values compared to the rest of the treatments. Generally, all the conservation tillage methods performed better in terms of increasing soil nutrients at the 0–20 cm soil depth compared to CT. All soil TOC, AN, AP and TP at the depth of 0–20 cm for all the treatments increased, even though higher concentrations were recorded under conservation tillage technologies. Higher levels of nutrients were recorded under ZTDS and ZTTS, which promoted rice growth and led to higher straw yields in the second year of implementation of conservation tillage (Figure 4). Enhanced SOC accumulation after production has been reported in different areas in China [30]. In the past 20 years, many cultivable soils have revealed an increase in SOC and total nitrogen [27]. Residue retention coupled with their breakdown had a positive effect on SOC content in the soil layer [31]. Moreover, combining retained residue with different tillage methods increased SOC levels, water stable aggregates and microbial biomass, and subsequently enhanced soil fertility and quality [32]. Similarly, our results showed a gradual but consistent increase in TOC accumulation under the conservation tillage methods during the two years of this study. The high nutrients levels among the conservation tillage methods at the soil depth of 0–20 cm could be as a result of the additional nutrients realized from the mineralization of rice straw coupled with the application of inorganic fertilizer. The presence of adequate organic manure also helped retain the inorganic fertilizer for efficient utilization by the crop. The improved amounts of TN, as well as N, P, and K in their available forms could be related to the availability of soil surface residues, creating the right environmental conditions for soil microbial activity and the mineralization of SOM. The changes in the soil properties were mainly attributable to the management of activities such as rice straw incorporation and fertilizer application, a conclusion which was further evidenced from the rice yield.

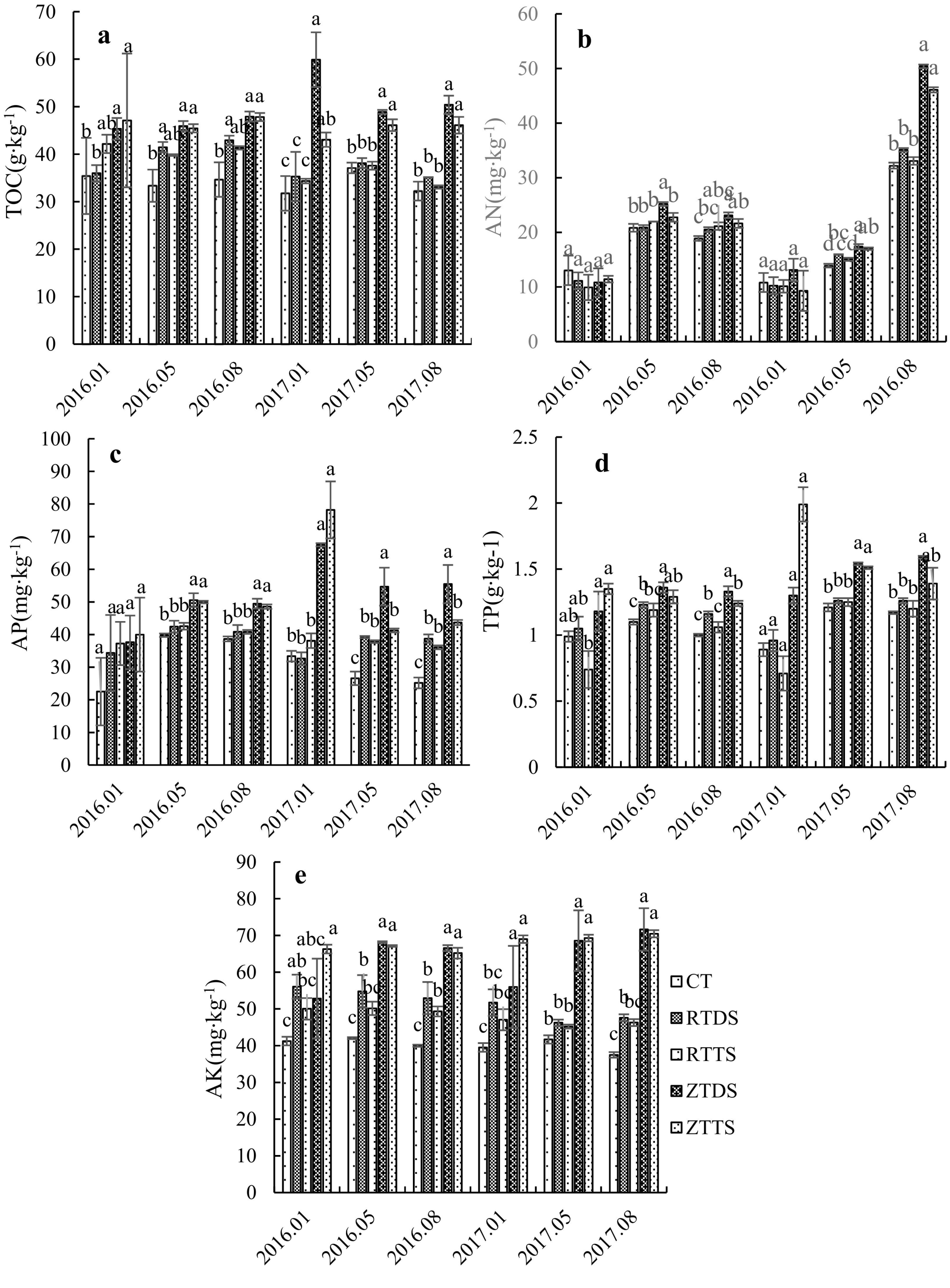

Figure 4. Effect of tillage on selected nutrients in the top soil (0–20 cm). Note: (**a**) TOC; (**b**) AN; (**c**) AP; (**d**) TP and (**e**) AK.

3.2. *Effect of Tillage Methods on Soil Nutrient Movement and TN Loss*

The results showed that there were high concentrations of soil inorganic nitrogen (TN, NO_3^--N and NH_4^+-N) in the top soil at depths of 0–20 cm (Figure 5). Even though, no significant difference in TN was recorded among the treatments, ZTDS and ZTTS recorded values higher than the rest of the treatments (Figure 5). Similarly, all the conservation tillage methods increased in NO_3^--N and NH_4^+-N, with ZTDS and ZTTS recording significant increase over CT. Interestingly, as the soil depth increases, the concentration of these nutrients under the ZTDS and the rest of the conservation tillage methods decreases relative to CT, which showed continuous and persistent increase as the soil depth increases. At the highest soil depth (80–100 cm), CT recorded high levels of TN, NH_4^+-N and NO_3^--N with 1.74 g kg^{-1}, 66.89 g kg^{-1} and 25.12 g kg^{-1}, respectively. The percentage increases in TN, NH_4^+-N and NO_3^--N by CT over the rest of the conservation tillage methods were 19.18, 28.86 and 104.04%, respectively. The distribution of soil nutrients was generally high in the top soil, with high and significant values recorded under the conservation tillage methods, especially ZTDS and ZTTS (Figure 5). This was probably a result of the protective role played by the rice straw to the top soil. This allows for the gradual decomposition of the rice straw, allowing nutrients to incorporate well within the top soil, and also allowing nutrients from the inorganic fertilizer to be retained in the top soil. Also, the rice straw played a significant role in the hydrological dynamics of the ZTDS and ZTTS as a result of the creation of a gradual stable aggregate structure that contributed to the high nutrient levels under the two conservation tillage plots relative to CT. On the other hand, using farm machinery under CT, RTDS and RTTS to break and thoroughly mix rice straw with the soil at the depth of 0–20 cm and 0–8 cm makes the soil vulnerable to agents of erosion, as well as speeding up the mineralization of rice straw when temperature and other environmental factors become favorable. Similarly, other investigators have concluded that soil and nutrient losses could be adequately reduced by practicing cultivation methods that ensure adequate protection of the soil [33]. However, as the soil depth increases, the concentration of these nutrients decreased under the conservation tillage techniques but increased under the CT. Also, the inversion of soil under the CT not only exposed the rice straw to microbial decomposers at the 20 cm soil depth, leading to a high rate of nitrogen mineralization, but also creates aggregate instability that encourages a high rate of infiltration, with a resultant increase in nitrogen leaching. At the relatively deeper soil depth (80–100 cm), highly significant levels of these nutrients were recorded under CT, signifying huge movement down the profile. These results indicate that conservation tillage has the tendency to reduce water movement and erosion. Similarly, previous studies have reported that conservation tillage methods considerably minimized the movement of water and soil erosion [34,35].

The lowest measurements of runoff (mm), concentration of TN in runoff water and TN runoff loss ($kg{\cdot}N{\cdot}ha^{-1}$) recorded under ZTDS ($g{\cdot}kg^{-1}$) were 177.35mm, 0.98 ($mg{\cdot}L^{-1}$) and 2.69, respectively, with all of these being significantly different from the rest of the treatments except for ZTTS (Table 2). Higher values, significantly different from all the conservation tillage methods, were recorded under CT (Table 2). This clearly shows the potential of CT to contribute to AgNPS pollution. At the end of the study, CT recorded the highest runoff (300 mm), high concentration of TN in runoff water (1.68 $mg{\cdot}L^{-1}$) and TN runoff loss (4.09 $Kg{\cdot}N{\cdot}ha^{-1}$), which were significantly different from the rest of the treatments. ZTDS and ZTTS recorded the lowest values. The highest value recorded by CT was likely a result of the breakdown of the soil particles by the tillage implement making the soil loose and susceptible to running water. This makes nutrients from the decomposed rice straw very mobile and easily moved by running water.

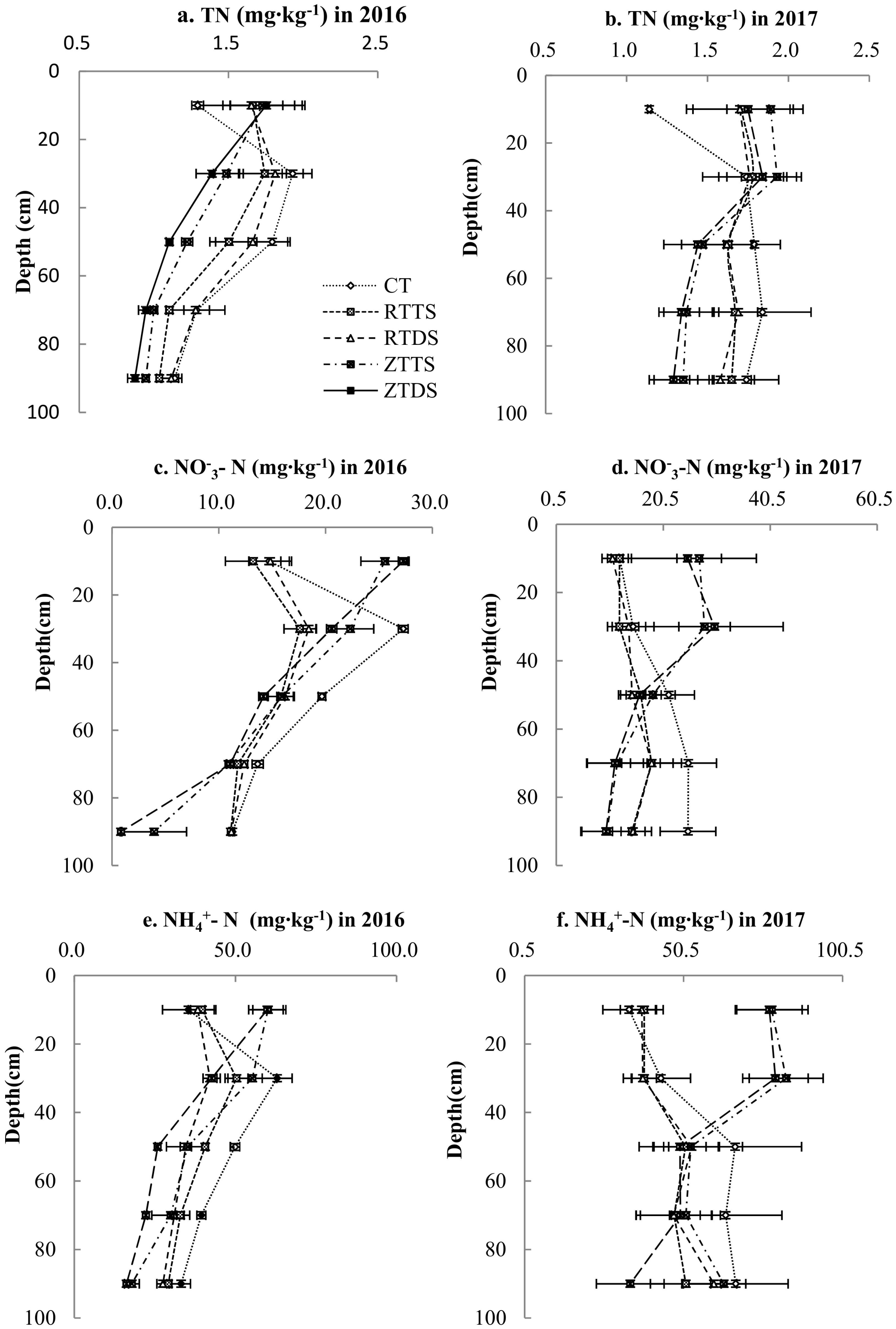

Figure 5. Effects of tillage on soil TN, NO_3^--N, NH_4^+-N distribution along the soil profile. Note: (**a**) TN in 2016; (**b**) TN in 2017; (**c**) NO_3^--N in 2016; (**d**) NO_3^--N in 2017; (**e**) NH_4^+-N in 2016 and; (**f**) NH_4^+-N in 2017.

Table 2. Effect of tillage methods on N loss.

Treatments	Runoff (mm)	Concentration of TN in Runoff Water (mg·L^{-1})	TN Runoff Loss (kg·N·ha^{-1})
CT	300.00 ± 11.56a	1.68 ± 0.02a	4.09 ± 0.04a
RTDS	269.94 ± 3.16b	1.29 ± 0.07b	3.47 ± 0.09b
RTTS	259.27 ± 3.72b	1.26 ± 0.07b	3.45 ± 0.09b
ZTDS	177.35 ± 10.71c	0.98 ± 0.09d	2.69 ± 0.11c
ZTTS	182.53 ± 5.28c	1.11 ± 0.02c	2.73 ± 0.04c

CT: conventional tillage; RTDS: reduced tillage direct seeding; RTTS: reduced tillage transplanting; ZTDS: zero tillage direct seeding; ZTTS: zero tillage transplanting. Different letters within a column represents significant difference at the 5% level of significance (LSD).

3.3. *Effect of Tillage Methods on Rice Productivity*

As for the year of 2016, CT recorded significantly higher plant height, and the trend was similar in 2017 (Table 3). Plant height values ranged from 132.20–135.10 cm in 2016 and 132.10–136.20 cm in 2017, with the highest values recorded under CT in both years (Table 3). However, ZTDS recorded the highest "stover" yield in both years (Table 3). The reason for the high stover yield was probably the good interaction between the decomposed rice straw, the soil and the inorganic fertilizer applied. This interaction provided a good environment, with readily available nutrients for the rice seed to germinate. Even though the same conditions were available under ZTTS, the stress associated with transplanting of seedlings and the time taken for the seedlings to adjust to the field condition probably accounted for the small stem girth recorded under ZTTS compared to ZTDS. However, ZTTS produced grain yield comparable to CT, but significantly different from ZTDS, RTDS, RTTS.

Table 3. Growth and yield parameters of rice.

Treatments	2016			2017		
	Plant Height (cm)	Stover Yield (t·ha^{-1})	Grain Yield (t·ha^{-1})	Plant Height (cm)	Stover Yield (t·ha^{-1})	Grain Yield (t·ha^{-1})
CT	135.10 ± 2.39a	5.70 ± 0.10ab	6.40 ± 0.11a	136.20 ± 2.89a	5.70 ± 0.10b	6.60 ± 0.17a
RTDS	133.15 ± 1.73ab	5.60 ± 0.11b	6.20 ± 0.11ab	133.10 ± 1.73ab	5.53 ± 0.13b	6.16 ± 0.14ab
RTTS	134.15 ± 2.31ab	5.63 ± 0.09b	5.86 ± 0.22b	134.20 ± 2.31ab	5.77±0.09ab	5.90 ± 0.35b
ZTDS	132.20 ± 1.15b	5.93 ± 0.14a	6.30 ± 0.06a	132.10 ± 1.15b	6.03 ± 0.17a	6.50 ± 0.21ab
ZTTS	134.25 ± 1.15ab	5.60 ± 0.18b	6.30 ± 0.17a	134.30 ± 1.15ab	5.53 ± 0.18b	6.60 ± 0.21a

CT: Conventional tillage; RTDS: Reduced tillage direct seeding; RTTS: Reduced tillage transplanting; ZTDS: zero tillage direct seeding; ZTTS: zero tillage transplanting. For the three treatments, means in each row for a given depth followed by same letters are not different at ($p > 0.05$).

Generally, plant height and grain yield of rice increased under CT with no significant difference as compared with ZTTS (Table 3) in 2016 and 2017. This result is in conformity with the work done by [36], who found that rice yields were equal between NT and CT. [37] reported that crop yield was generally higher under no/reduced tillage with straw retention than under CT in dry years, but was lower in wet years. However, the highest stover yield was recorded by ZTDS in both years, which was significantly different from the rest of the treatments. The reason for the high stover yield was due to the good interaction between the decomposed rice straw, the soil, and the inorganic fertilizer applied. This interaction provided a good environment, with readily available nutrients for the rice seed to germinate. Even though the same conditions apply to ZTTS, the stress associated with transplanting seedlings and the time taken for the seedlings to adjust to the field conditions probably accounted for the reduction in stover yield under ZTTS compared to ZTDS. Also, rice seedlings, once transplanted, would have to expend a lot of energy before assuming root growth. However, ZTTS produced grain yield comparable to CT but significantly different from ZTDS, RTDS, RTTS. This was as a result of the early transplanting (10 days) that was carried out. Usually, transplanting seedlings before they are 15 days old and as early as 10 days—when only the first small root and tiller, with two tiny leaves, have emerged from the rice seed—enhances rice yield. Planting older seedlings from 15 days upwards means the seedlings have already lost much of their potential to produce a large number of tillers. Also, early transplantation allows the seedlings to have fast absorption of nutrients after getting use to the field conditions.

Generally, the rice straw increased the retention time of the inorganic fertilizer in the top soil of ZTDS and ZTTS, thereby allowing the rice plant ample time and space to absorb the nutrients. This is at variance with CT, RTDS and RTTS, where the rice straw is ploughed and rotovated at the depth of 20 cm and 8 cm, respectively. Also, the modification of temperature around the base of the rice plant as a result of heat interception by the rice straw ensures continuous and sustained mineralization and gradual release of nutrients for the rice plant usage. This subsequently improved the yields under ZTDS and ZTTS, since productivity is a function of good nutrient retention and absorption under conducive environment. According to [38], a warm-dry climatic environment or well-drained soil can impact positively on the yield of crops. This accounted for the improved yield recorded under ZTDS and ZTTS from an average yield of 6.30 in 2016 to 6.50 and 6.60 in 2017.

From this study, improved and sustained productivity in rice can be achieved by the use of ZTDS and ZTTS (conservation tillage methods) considering their ability to characterize soil nutrients at the top 0–20 cm to sustain plant growth. Moreover, their ability to control runoff losses makes them capable of reducing AgNPS N pollutant movement. Also, their potential benefit to the environment through pollution prevention could be achieved if well designed and managed, leading to sustainable and environmentally friendly food production. This work has provided additional insight about changes in physical and chemical soil properties, as well as N movement resulting from practicing conservation tillage coupled with rice straw retention and inorganic fertilizer application. We observed that variation in soil properties including the movement of N requires many experimental years to be able to realize their full potential. Hence, continuous field experiments over many years (5 or more) is required to determine the time change in N distribution, movement dynamics and loss along the soil profile under ZDTS and ZTTS methods. This will provide researchers with the opportunity to make long-term decisions regarding environmental monitoring of conservation tillage farms in order to forecast accurately, the consequences associated with the introduction of such tillage methods and to recommend appropriately.

4. Conclusions

In summary, there are significant variations in the impact of tillage methods on soil properties, nutrient loss and rice productivity. Conservation tillage methods (ZTDS and ZTTS), were associated with a reduction in soil bulk density, enhanced soil nutrients, a reduction in TN runoff losses, and improved yield of rice. To achieve maximum and sustained food production, management methods that ensure the combined effect of conservation tillage, rice straw retention and inorganic fertilizer incorporation should be followed. Also, the enhanced synergy from such a combination could help in the reduction of AgNPS pollutant load emissions into the environment. Our results therefore suggest that improved soil nutrients, reduction in AgNPS N pollutant load and sustained growth and yield parameters of rice could be attained using conservation tillage technologies especially, ZTDS and ZTTS and are therefore recommended for sustainable and environmentally safe rice production by farmers in Ghana.

Author Contributions: Conceptualization, Y.L. and J.W.; Data curation, Z.Z. (Zhongqiu Zhao); Funding acquisition, Z.Z. (Zhen Zhang); Investigation, F.I., E.A. and A.S.K.; Methodology, Z.Z. (Zhongqiu Zhao); Project administration, Y.L.; Supervision, J.W.; Writing—original draft, F.I.; Writing—review & editing, Z.Z. (Zhen Zhang), W.L. and J.W.

Acknowledgments: This study was supported by the National Key Research and Development Program of China (No. 2017YFD0800102 and 2017YFD0800103), and the National Science and Technology Support Program (No. 2015BAD05B05).

Conflicts of Interest: All authors of this manuscript declare no conflict of interest.

References

1. Coalition for African Rice Development (CARD). *Mapping of Poverty Reduction Strategy Papers (PRSPs), Sector Strategies and Policies Related to Rice Development in Ghana*; Coalition for African Rice Development (CARD): Nairobi, Kenya, 2010.
2. Angelucci, F.; Asante-Poku, A.; Anaadumba, P. *Analysis of Incentives and Disincentives for Rice in Ghana*; Technical notes series, MAFAP; FAO: Rome, Italy, 2013.
3. Jayne, T.S.; Chapoto, A.; Sitko, N.; Nkonde, C.; Muyanga, M.; Chamberlin, J. Is the scramble for land in Africa foreclosing a smallholder agricultural expansion strategy? *J. Int. Aff.* **2014**, *67*, 35–53.
4. Diao, X.; Fang, P.; John, A.; Fang, P.; Justice, S.E.; Doreen, K.; Takeshima, H. *Agricultural Mechanization in Ghana: Insights from a Recent Field Study*; IFPRI Discussion Paper 01729; International Food Policy Research Institute: Washington, DC, USA, 2018.
5. Ministry of Food and Agriculture (MOFA). *Agriculture in Ghana. Facts and Figures 2010*; SRID: Accra, Ghana, 2011.
6. Mutema, M.; Mafongoya, P.L.; Nyagumbo, I.; Chikukura, I. Effects of crop residues and reduced tillage on macrofauna abundance. *J. Org. Syst.* **2013**, *8*, 5–16.
7. Ramos, M.E.; Robles, A.B.; Sanchez-Navarro, A.; Gonzalez-Rebollar, J.L. Soil responses to different management practices in rain fed orchards in semi-arid environments. *Soil Tillage Res.* **2011**, *112*, 85–91. [CrossRef]
8. Fournier, M.L.; Echeverría-Sáenz, S.; Mena, F.; Arias-Andrés, M.; De la Cruz, E.; Ruepert, C. Risk assessment of agriculture impact on the Frío River watershed and Caño Negro Ramsar wetland, Costa Rica. *Environ. Sci. Pollut. Res.* **2017**, *25*, 13347–13359. [CrossRef]
9. Chen, W.; He, B.; Nover, D.; Duan, W.; Luo, C.; Zhao, K.; Chen, W. Spatiotemporal patterns and source attribution of nitrogen pollution in a typical headwater agricultural watershed in southeastern China. *Environ. Sci. Pollut. Res.* **2017**, *25*, 2756–2773. [CrossRef]
10. Aziz, I.; Mahmood, T.; Raut, Y.; Lewis, W.; Islam, R.; Weil, R.R. *Active Organic Matter as a Simple Measure of Field Soil Quality*; ASA International Meetings: Pittsburg, PA, USA, 2009.
11. Lamar, R. Adoption of conservation agriculture in Europe lessons of the KASSA project. *Land Use Policy* **2010**, *27*, 4–10. [CrossRef]
12. Van den Putte, A.; Govers, G.; Diels, J.; Gillijns, K.; Demuzere, M. Assessing the effect of soil tillage on crop growth: A meta-regression analysis on European crop yields under conservation agriculture. *Eur. J. Agron.* **2010**, *33*, 231–241. [CrossRef]
13. Rahman, M.H.; Okubo, A.; Sugiyama, S.; Mayland, H.F. Physical, chemical and microbiological properties of an Andisol as related to land use and tillage practice. *Soil Tillage Res.* **2008**, *101*, 10–19. [CrossRef]
14. Xu, S.; Zhao, Y.; Wang, M.; Shi, X. Comparison of multivariate methods for estimating selected soil properties from intact soil cores of paddy fields by Vis–NIR spectroscopy. *Geoderma* **2016**, *310*, 29–43. [CrossRef]
15. Wang, J.J.; Zeng, X.B.; Zhang, H.; Li, Y.T.; Zhao, S.Z.; Su, S.M.; Bai, L.Y.; Wang, Y.N.; Zhang, T. Effect of exogenous phosphate on the lability and phytoavailability of arsenic in soils. *Chemosphere* **2018**, *196*, 540–547. [CrossRef]
16. Calvo-Fernández, J.A.; Taboada, A.; Fichtner, W.; Härdtle, L.; Calvo, L.; Marcos, E. Time-and age-related effects of experimentally simulated nitrogen deposition on the functioning of montane heath land ecosystems. *Sci. Total Environ.* **2016**, *613–614*, 149–159.
17. He, S.R.; Lu, Q.; Li, W.Y.; Ren, Z.L.; Zhou, Z.; Feng, X.; Zhang, Y.L.; Li, Y.T. Factors controlling cadmium and lead activities in different parent material-derived soils from the Pearl River Basin. *Chemosphere* **2017**, *182*, 509–516. [CrossRef] [PubMed]
18. Ji, W.J.; Shi, Z.; Huang, J.Y.; Li, S. In Situ Measurement of Some Soil Properties in Paddy Soil Using Visible and Near-Infrared Spectroscopy. *PLoS ONE* **2014**, *9*, e105708. [CrossRef] [PubMed]
19. Egan, G.; Crawley, M.J.; Fornara, D.A. Effects of long-term grassland management on the carbon and nitrogen pools of different soil aggregate fractions. *Sci. Total Environ.* **2016**, *613–614*, 810–819. [CrossRef] [PubMed]
20. Zhang, H.H.; Zhang, Y.Q.; Yan, C.R.; Liu, E.K.; Chen, B.Q. Soil nitrogen and its fractions between long-term conventional and no-tillage systems with straw retention in dryland farming in Journal of Agricultural Science. *Geoderma* **2016**, *269*, 138–144. [CrossRef]

21. Bolvin, P.; Schafferr, B.; Sturny, N. Quantifying relationship between soil organic carbon and soil physical properties using shrinkage modelling. *Eur. J. Soil Sci.* **2009**, *60*, 265–275.
22. Ruehlmann, J.; Körschens, M. Calculating the effect of soil organic matter concentration on soil bulk density. *Soil Sci. Soc. Am. J.* **2009**, *73*, 876–885. [CrossRef]
23. Celik, I.; Ortas, I.; Kilic, S. Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil. *Soil Tillage Res.* **2004**, *74*, 59–67. [CrossRef]
24. Kugbe, X.J.; Zakaria, I. Effects of soil conservation technologies in improving soil productivity in northern Ghana. *J. Soil Sci. Environ. Manag.* **2015**, *6*, 158–167.
25. Higashi, T.; Yunghui, M.; Komatsuzaki, M.; Miura, S.; Hirata, T.; Araki, H.; Kaneko, N.; Ohta, H. Tillage and cover crop species affect soil organic carbon in Andosol, Kanto, Japan. *Soil Tillage Res.* **2014**, *138*, 64–72. [CrossRef]
26. He, J.; Li, H.; Rasaily, R.G.; Wang, Q.; Cai, G.; Su, Y.; Qiao, X.; Liu, L. Soil properties and crop yields after 11 years of no tillage farming in wheat-maize cropping system in North China Plain. *Soil Tillage Res.* **2011**, *113*, 48–54. [CrossRef]
27. Zhang, F.; Hao, X.; Wang, R.; Xu, Y.; Kong, X.B. Changes in soil properties in southern Beijing Municipality following land reform. *Soil Tillage Res.* **2004**, *75*, 143–150. [CrossRef]
28. Pierson-Wickmann, A.C.; Aquilina, L.; Weyer, C.; Molenat, J.; Lischeid, G. Acidification processes and soil leaching influenced by agricultural practices revealed by strontium isotopic ratios. *Geochim. Cosmochim. Acta* **2009**, *73*, 4688–4704. [CrossRef]
29. Malo, D.D.; Schumacher, T.E.; Doolittle, J.J. Long-term cultivation impacts on selected soil properties in the northern Great Plains. *Soil Tillage Res.* **2005**, *81*, 277–291. [CrossRef]
30. Zhong, J.H. The cultivated land soil ecology and mechanism in the Pearl River delta. *Environ. Sci.* **2009**, *18*, 1917–1922.
31. Choudhury, S.G.; Srivastava, S.; Singh, R.; Chaudhari, S.K.; Sharma, D.K.; Singh, S.K.; Sarkar, D. Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice–wheat cropping system under reclaimed sodic soil. *Soil Tillage Res.* **2014**, *136*, 76–83. [CrossRef]
32. Abdullah, A.S. Minimum tillage and residue management increase soil water content, soil organic matter and canola seed yield and seed oil content in the semiarid areas of Northern Iraq. *Soil Tillage Res.* **2014**, *144*, 150–155. [CrossRef]
33. Withers, P.J.A.; Hodgkinson, R.A.; Bates, A.; Withers, C.L. Soil cultivation effects on sediment and phosphorus mobilization in surface runoff from three contrasting soil types in England. *Soil Tillage Res.* **2007**, *93*, 438–451. [CrossRef]
34. Jordán, A.; Zavala, L.M.; Gil, J. Effects of mulching on soil physical properties and runoff under semi-arid conditions in Southern Spain. *Catena* **2010**, *81*, 77–85. [CrossRef]
35. Won, C.H.; Choi, Y.H.; Shin, M.H.; Lim, K.J.; Choi, J.D. Effects of rice straw mats on runoff and sediment discharge in a laboratory. *Geoderma* **2012**, *189*, 164–169. [CrossRef]
36. Huang, M.; Zou, Y.B.; Jiang, P.; Xia, B.; Feng, Y.H.; Cheng, Z.W.; Mo, Y.L. Effect of tillage on soil and crop properties of wet-seeded flooded rice. *Field Crop. Res.* **2012**, *129*, 28–38. [CrossRef]
37. Wang, X.B.; Dai, K.A.; Zhang, D.C.; Zhang, X.M.; Wang, Y.; Zhao, Q.S.; Cai, D.X.; Hoogmoed, W.B.; Oenema, O. Dryland maize yields and water use efficiency in response to tillage/crop stubble and nutrient management practices in China. *Field Crop. Res.* **2011**, *120*, 47–57. [CrossRef]
38. Liu, S.; Yang, J.Y.; Zhang, X.Y.; Drury, C.F.; Reynolds, W.D.; Hoogenboom, G. Modeling crop yield, soil water content and soil temperature for a soybean–maize rotation under conventional and conservation tillage systems in North east China. *Agric. Water Manag.* **2013**, *123*, 32–44. [CrossRef]