Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 12	No. 3	pp. 449-454	2013

Original Research Paper

Resource Utilization of Returned Rapeseed Straw and Its Effect on Soil Fertility and Crop Yields

Hu Hong-xiang, Ma You-hua, Wang Yu-fang and Di Yun-fei
School of Resources and Environment, Anhui Agricultural University, 230036, Hefei, China

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 15-5-2013
Accepted: 4-7-2013

Key Words:
Rapeseed straw
Decomposition
Resource utilization
Crop yield
Soil fertility

ABSTRACT

In order to study the decomposition characteristics of returned rapeseed straw in the process of resource utilization and the effect on soil fertility and crop yields, different treatments of soil with returned rapeseed straw were conducted using the nylon net bag method of field trials. Different treatments include varied amounts of straw, depths to be buried in soil, and addition of straw decomposing bacteria. The results showed that the decomposition ratio of rapeseed straw increased with time and the decomposition rate of rapeseed straw was faster in the first 30 days and then slowed down until the end of 120 days. Straw decomposition rate was negatively correlated with the amounts of returned rapeseed straw. The decomposition rate of rapeseed straw on the soil surface was faster than that buried 20cm below the soil surface, which is also faster than that 10cm below the soil surface. Decomposition ratio of rapeseed straw with addition of decomposing bacteria was higher than without decomposing bacteria. The returned straw improved the physical and chemical properties of soil and increased the soil nutrient content and rice yields. The study provided the basic parameters for controlling the rapeseed straw decomposition rate, which improved the agricultural eco-environment.

INTRODUCTION

China produces about 7×10^{11} kg of straw annually, which accounts for 30% of the production of the entire world (Zhang 2008). About 97% of the straw is burned, stacked or abandoned, which is a waste of resource and may bring negative impacts on many levels including environment and social economy (Michael 2008, Stewart 2005, Li 2008). Returning straw to the field is an effective measure to prevent such wasteful disposal of straw, however, the inefficient straw decomposition has been a constraining factor for straw-returning. Therefore, various studies have investigated how to improve the efficiency of straw-returning and decomposition (Devevre 2000, Pal & Jat 2004, Curtin 2008, Bastian & Bouziri 2009, Yao et al. 2011).

Rape of Crucifereae is an important oil crop in China. It is widely planted across China, especially concentrating along Yangtze River. The rapeseed area is about 7×106 ha in China, accounting for more than 25% of the world's total output (Song et al. 2009, NBSC 2010). Such annual output of 2×1010 kg of rapeseed straw containing rich nutrients of N, P_2O_5, K_2O (Zhang et al. 2006) and effective local reuse of the rapeseed straw has huge potential to solve agricultural problems. However, the very slow straw decomposition rate is an important constraint of local reuse of the rapeseed straw, because most places in China in the year are more than two quarters or two quarters crop rotation; the time between the before and after season crops is short, small proportion of decomposition of the previous crop straw will affect the normal sowing or growth of the next crop. So far, a few studies have investigated the process of straw decomposition. The study by Li et al. (2009) revealed that the decomposing rate of the rapeseed straw was fast in the beginning, and then slowed down over time. The cumulative decomposing ratio was 55.62% during the rice growth season, which lasts about 100 days. The study by Wu et al. (2011) also showed that the decomposition rate of rapeseed straw was faster within the first 30 days and then slowed down until the end of the experiment. The cumulative decomposition ratio of rapeseed straw was 50.88-61.06% after 90 days. However, there is no report about the decomposition characteristics of returned rapeseed straw in rice and rape rotation system.

We conducted different treatments of returned rapeseed straw, such as various amounts of straw, different soil burial depths, and addition of straw-decomposing bacteria, using nylon bags method of field trials in rice and rape rotation system. The objective of this research was to determine the decomposition characteristics of returned rapeseed straw and its effect on soil fertility and rice yield, and to provide the basic parameters for controlling rapeseed straw decomposition rate that could improve the agricultural eco-environment.

MATERIALS AND METHODS

Field experiment

A field experiment was conducted at agricultural test site of

Anhui Agricultural University during January 2010-November 2011. The site of wavy plain terrain is located at 35°22 N and 117°152 E, at an altitude of 20m above the sea level. The climate of the site is northern subtropical monsoon climate. The area receives an annual rainfall of 998 mm, about 42% of which occurs from June to August. The annual mean temperature is 15.7°C. The mean minimum temperature in January is 2.1°C, while the mean maximum temperature in July is 28.9°C. The zonal soil type is yellow cinnamon soil. The soil of experimental site has the characteristics of pH 6.35, clay loam in texture, bulk density 1.42 $g.cm^{-3}$, organic matter 17.05 $g.kg^{-1}$, total nitrogen 1.22 $g.kg^{-1}$, total phosphorus 0.39 $g.kg^{-1}$, total potassium 16.45 $g.kg^{-1}$, hydrolysable nitrogen 99.19 $mg.kg^{-1}$, effective phosphorus 7.50 $mg.kg^{-1}$, rapidly potassium 92.05 $g.kg^{-1}$.

Rapeseed Straw Treatments

The experiment of different amounts of straw returned to field: The experiment included four treatments of the returned rapeseed straw with the whole amount, 2/3 amount, 1/2 amount and 1/3 amount under rice cultivation condition. Rapeseed straw was crushed into 1cm long and was put into nylon bags of 30cm long and 20cm wide. The nylon bags were buried in the paddy field of 10cm depth. Every treatment had three replications. Rapeseed straw yield is 7200 kg per hectare (10000 m^2), so the whole amount, 2/3 amount, 1/2 amount and 1/3 amount of per 10000 m^2 are respectively 7200 kg, 4800kg, 3600kg and 2400kg, and the whole amount, 2/3 amount, 1/2 amount and 1/3 amount of each nylon bag (60 cm^2) are respectively 43.2 g, 28.8 g, 21.6 g and 14.4 g.

The experiment of straw returned to field in different depths and straw with decomposing bacteria and without decomposing bacteria: There were six treatment groups of returned rapeseed straw with different depths and addition of decomposing bacteria, (1) 0cm depth without decomposing bacteria, (2) 0cm depth with decomposing bacteria, (3) 10cm depth without decomposing bacteria, (4) 10cm depth with decomposing bacteria, (5) 20cm depth without decomposing bacteria and (6) 20cm depth with decomposing bacteria under rice cultivation condition. Rapeseed straw was crushed into 1cm long and 1/2 amount of straw (21.6 g) was put into nylon bags of 30cm long and 20cm wide. The nylon bags were buried in the paddy field. Decomposing bacteria were produced by a company in Shanghai. Every treatment had three replications.

The experiment of the effects of different amounts returned straw on soil fertility and crop yield: Five treatments groups of returned rapeseed straw of different amounts were setup with (1) the whole amount (buried 10cm depth), (2) 2/3 amount (buried 10cm depth), (3) 1/2 amount (buried 10cm depth), (4) 1/3 amount (buried 10cm depth) and (5) comparison (without straw-returning) under rice cultivation condition. Rapeseed straw was crushed into 10cm long and was buried in the paddy field. Every treatment had three replication plots of 10 m^2. The whole amount, 2/3 amount, 1/2 amount, 1/3 amount and comparison of each treatment (10 cm^2) were respectively 7.2 kg, 4.8 kg, 3.6 kg , 2.4 kg and 0 kg.

The experiment of the effects of straw returned in different depths on soil fertility and crop yield: Four treatments groups of straw returned in different depths were setup with (1) 0cm depth (1/2 amount), (2) 10cm depth (1/2 amount), (3) 20cm depth (1/2 amount) and (4) comparison (without straw-returning) under rice cultivation condition. Rapeseed straw was crushed into 10cm long and was buried in the paddy field. Every treatment had three replication plots of 10 m^2. The 1/2 amount and comparison of each treatment (10 cm^2) were respectively 3.6 kg and 0 kg.

Rapeseed straw was returned to field two days before transplant of rice seedling. Rice was planted in May and harvested in September. As the field can receive natural rainfall and irrigation water, paddy fields remain saturated and there was always a layer of surface water.

Sampling and Analyses

Rapeseed straw samples from the field were collected for dry weight measurement at 15d, 30d, 60d, 90d and 120d after straw-returning. Soil samples from the 0-20cm soil layer in five locations in each plot were collected for determining soil physical-chemical properties before the experiment and after the experiment. Mature rice in each plot was harvested to determine various rice productions.

Soil samples were analysed using conventional standard methods (Bao 2000, FERCSP 2010) with soil bulk density using ring sampler method, pH using glass-electrode method, organic matter using elemental analyser method, water content using oven method, total nitrogen using semi-micro Kjeldahl method, total phosphorus using sodium hydroxide alkali fusion-molybdenum antimony colorimetric resistance method, total potassium using sodium hydroxide alkali fusion-flame photometry method, hydrolysable nitrogen using alkaline hydrolysis diffusion method, effective phosphorus using $NaHCO_3$ extraction-molybdenum antimony colorimetric resistance method, and rapidly potassium using NH_4OAc extraction-flame photometry method.

Calculation and Data Analysis

The amount of decomposition refers to the relative ratio of decomposition, expressed as percentage of the straw decomposition, calculated as follows.

$$S = 100 \times (A - B)/A$$

In the formula, S represents rapeseed straw decomposition ratio (%); A represents initial straw weight at some stage (g); B represents end straw weight at some stage (g). Decomposition rate was calculated as follows:

$$V = Y \times (A - B)/(A \times T)$$

In the formula, V represents rapeseed straw decomposition rate ($mg.g^{-1}.d^{-1}$); Y represents 1000 ($mg.g^{-1}$); A represents initial straw quantity at certain stage (g); B represents end straw quality at certain stage (g); T represents decomposition time (d).

Statistical analyses of the data were performed using SPSS 13.0 and Microsoft Excel 2003.

RESULTS

Decomposition with different amounts of returned rapeseed straw: Rapeseed straw with different treatments had various decomposition rates while the decomposition ratios had a cumulative increasing trend with time. The decomposition amount increased fast in the early stage, and then slowed down (Fig. 1). The decomposition ratio was about 30% at 30d and 50% at 90d after straw-returning. The decomposition ratio of different amount of returned straw was slightly different. The decomposition ratio was negatively correlated with the amount of returned straw (Fig. 1). The decomposition ratios from Fig. 1 showed that the whole amount < 2/3 amount < 1/2 amount < 1/3 amount.

Regarding the decomposition rate of different amounts of returned rapeseed straw, we found that the decomposition ratio of the rapeseed straw was increasing, but the rate of decomposition was constantly decreasing over time (Fig. 2). Generally, the maximal decomposition rate occurred in the first half of the months with all the treatments of more than 1.16%, of which decomposition rate of 1/3 amount even reached 1.56%. The mean decomposition rate was more than 1.08% between 15-30 days, while the mean decomposition rate was less than 0.35%. It is consistent with the general observation of rape straw decomposition that straw in the field decomposes faster in the early stage and then gradually slowed down.

The straw decomposition rates with different amounts of returned straw were different. The decomposition rate was negatively correlated with the amount of returned straw. The rate of the whole amount was < the rate of 2/3 amount < the rate of 1/2 amount < the rate of 1/3 amount (Fig. 2). For the large amount of returned straw, the change of straw decomposition rate is relatively small over time. For example, the decomposition rate of the whole amount of straw only changed 8.54 ($mg.g^{-1}.d^{-1}$), from 11.57 ($mg.g^{-1}.d^{-1}$) in the first half month to 3.03 ($mg.g^{-1}.d^{-1}$) in the fourth month. For the smaller amount of returned straw, the change of straw decomposition rate is relatively high over the time. For example, the decomposition rate of the 1/3 amount straw changed 12.13 ($mg \cdot g^{-1} \cdot d^{-1}$) from 15.60 ($mg.g^{-1}.d^{-1}$) in the first half month to 3.47 ($mg.g^{-1}.d^{-1}$) in the fourth month (Fig. 2).

Decomposition under different straw burial depths: Regarding the decomposition ratio of returned rapeseed straw under different burial depths, we found that depth influenced the decomposition rate, and the decomposition ratios had a cumulative increasing trend over time (Fig. 3). Rapeseed straw decomposition rate of 0cm depths was the highest, followed by 20cm depth and 10cm depth for the first half month. The decomposition ratios of the 0cm depth, 10cm depth and 20cm depth were respectively 46.30%, 36.76% and 45.37% at 30d, while 72.69%, 60.28% and 68.53% at 120d (Fig. 3). This observation suggested that decomposition ratio can be related to soil, water and heat conditions.

Although the straw decomposition rates gradually reduced over time, the decomposition rates of returned straw at different depths were slightly different (Fig. 4). Rapeseed straw decomposition rate at 0cm depth was the highest, followed by 20cm depth, and then 10cm depth. The decomposition rates at the 0cm depths, 10cm depths and 20cm depths were respectively 18.93 ($mg.g^{-1}.d^{-1}$), 11.81 ($mg.g^{-1}.d^{-1}$) and 13.15 ($mg.g^{-1}.d^{-1}$) between 15d and 30d, while 4.41 ($mg.g^{1}.d^{-1}$), 3.39 ($mg.g^{-1}.d^{-1}$) and 4.27 ($mg.g^{-1}.d^{-1}$) at the fourth month (Fig. 4). It shows that the surface of the straw decomposes easily because of high temperature and the fluid water layer. Therefore, considering the regulation of soil water and thermal conditions is an important aspect to control the rate of straw decomposition. The change of straw decomposition rate at 10cm depths was relatively small over the time, while that of 20cm was higher. They decreased from 15.43 ($mg.g^{-1}.d^{-1}$) and 21.30($mg.g^{-1}.d^{-1}$) in the first half month to 3.39 ($mg.g^{-1}.d^{-1}$) and 4.34 ($mg.g^{-1}.d^{-1}$) in the fourth month, respectively (Fig. 4).

The effect of decomposing bacteria on straw decomposition: Regarding the influence of bacteria on straw decomposition ratio, we found that the decomposition ratios were increased when decomposing bacteria were added into the returned rapeseed straw under rice cultivation conditions (Fig. 5). Decomposition ratios of rapeseed straw at the 0cm, 10cm and 20cm depths with decomposing bacteria were all higher than without decomposing bacteria. The results also showed that with the greater burial depth, the greater impact of the decomposition bacteria was. Decomposition ratios of rapeseed straw with bacteria at the 0cm depths, 10cm depths and 20cm depths were 1.85%, 4.63% and 5.09% higher than without bacteria at 120d (Fig. 5). The differences between with bacteria and without bacteria in ratios were gradually increasing over time.

Regarding the influence of bacteria on straw decomposition rate, we found that the rapeseed straw under different treatments (0cm, 10 cm, 20cm depths without bacteria and with bacteria), all decomposed faster in the early stage and slower later (Fig. 6). The decomposition rate reached even more than 23.15 ($mg.g^{-1}.d^{-1}$) in the early stage, while it decreased to below 4.98 ($mg.g^{-1}.d^{-1}$) in the fourth month. The decomposition rates with decomposing bacteria were always higher than without decomposing bacteria. The effects of decomposing bacteria were more obvious at 20cm depth than other depths (Fig. 6). Therefore, adding decomposing bacteria to straw is recommended in order to increase the straw decomposition rate and to promote the formation of humus, and also to reduce negative impacts on farmland because of the slow straw decomposition.

The effect of straw-returning on soil properties: Regarding the effects of different amount of returned rapeseed straw on soil properties, Table 1 showed that the returned rapeseed straw changed several soil basic properties at 120d after straw-returning. The more returned rapeseed straw, the more obvious soil bulk density was reduced. Soil organic matter showed similar results. Soil organic matter content of the whole amount of returned straw was 20.13 $g.kg^{-1}$, while the control treatment was only 17.31 $g.kg^{-1}$. The changes of total nitrogen, total phosphorus and total potassium content increased with the amount of returned straw. The contents of hydrolysable nitrogen, effective phosphorus, rapidly potassium were all increased, but the correlation was weak between the degree of increase and the amount of returned straw. The more returned rapeseed straw, the more soil pH was reduced. The pH of control treatment, 1/3 amount, 1/2 amount, 2/3 amount and the whole amount was respectively 6.35, 6.30, 6.27, 6.25 and 6.15 at 120d after straw-returning (Table 1).

Regarding the effects of different straw burial depths on soil properties, we found that the soil bulk density of straw-returning at surface of field reduced more obviously than that of the other two depths. Although the contents of soil organic matter, N, P and K were all increased, the returned straw at different depths showed different effects. The contents of soil organic matter, N, P and K with returned straw at 10cm depth increased most obviously (Table 2). Presumably because the surface water of field flows freely and the nutrients at field surface can be lost easily, the soil nutrient contents with returned straw at surface was improved only slightly. Because the soil nutrients at 20cm depth can diffuse into the deeper soil more easily, the soil nutrient content with returned straw at 20cm depth was also improved slightly. Although the soil nutrients in 10cm depth can also be dissolved into deeper soil, most of it was still kept in soil between 10cm and 20cm depths. At the same time, the soil nutrient output by straw-returning at 10cm depths was less than that of surface, and the contents of soil organic matter, N, P and K by straw-returning in 10cm depth increased most significantly.

The effect of straw-returning on rice yield: The returned rapeseed straw can increase rice yield (Table 3). Yields of rice ranged from 7725 $kg.ha^{-1}$ in control group to 9320 $kg.ha^{-1}$ in 1/2 amount + 10cm depth treatment group. The yields increased between 180 $kg.ha^{-1}$ to 1635 $kg.ha^{-1}$ under different straw-returning treatments. The yield in 10cm depth straw-returning treatment was lower than that of 20cm depth and surface of field. The yield had positive correlation with the amount of returned straw. The yields of the whole amount, 2/3 amount, 1/2 amount, 1/3 amount and control groups were respectively 8490 $kg.ha^{-1}$, 8340 $kg.ha^{-1}$, 8190 $kg.ha^{-1}$, 7905 $kg.ha^{-1}$ and 7725 $kg.ha^{-1}$ (Table 3).

DISCUSSION

The decomposition amount increased fast in the early stage, and then slowed down. This is consistent with another study by Li (2009) which found that straw decomposed fast in the early stage, then slowed down towards the end. However, the decomposition difference of varied amounts of straw is also discussed in the paper.

Rapeseed straw decomposition rate of 0cm depths was the highest followed by 20cm depth and 10cm depth. This is because water and heat conditions are different at different depths of soil. In the water saturation surface of paddy field, rapeseed straw decomposition ratio was the highest because of the high temperature in the summer, and the abundant microorganisms needed for decomposition. In 20cm depths, the straw is close to rice roots which may have strong microbial activity, but the ventilation conditions are relatively poor and soil temperature is lower, which may explain the lower decomposition ratio at 10cm depth. In 10cm depth, the combination of water and heat is not as ideal and the microbial activity is weak, so decomposition ratio is the lowest.

The returned rapeseed straw changed several soil basic properties. Similar to the results by Nie (2007) and Yang et al. (2008) who also found that straw-returning improved soil physical and chemical properties, the soil bulk density was reduced and soil nutrient was increased relative to the control treatment. The paper also found that the more returned rapeseed straw, the more change of soil physical and chemical properties.

CONCLUSIONS

In summary, we found that returned rapeseed straw

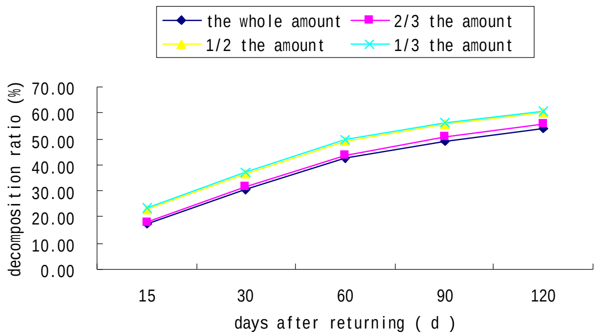

Fig. 1: Decomposition ratios of different amounts of retuned rapeseed straw.

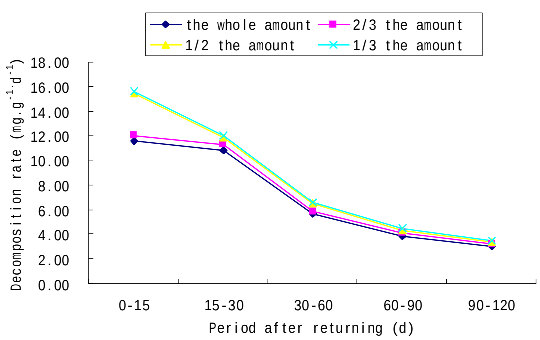

Fig. 2: Decomposition rates of different amounts of returned rapeseed straw.

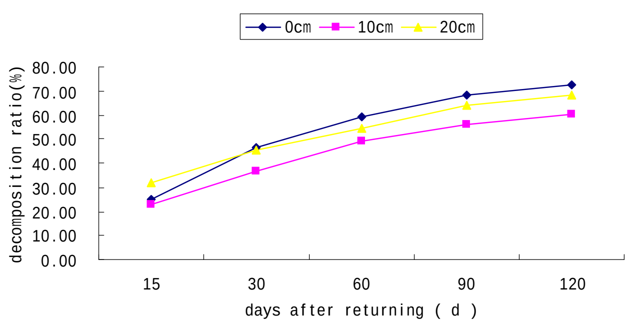

Fig. 3: Decomposition ratios under different straw burial depths.

decomposed faster in the early stage, and then slowed down towards the end stage after straw-returning. Generally, the decomposition ratio was about 50% at 90d. Rapeseed straw decomposition rate is related to the amount of returned straw, the depths of returned straw and decomposing bacteria. Straw decomposition rate was negatively correlated with the amount of returned rapeseed straw. Rapeseed straw decomposition rate at 0cm depth was greater than that at 20cm depth, and at 20cm depth was greater than at 10cm depth. Decomposition ratio of rapeseed straw with decomposing bacteria was higher than without decomposing bacteria. Moreover, returned rapeseed straw improved soil physical and chemical properties at 120d after straw-returning, compared to the control. The soil bulk density was

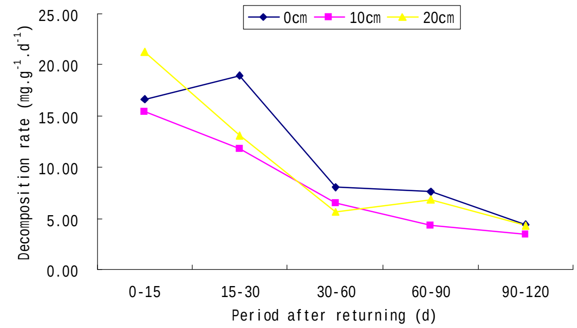

Fig. 4: Decomposition rates under different straw burial depths.

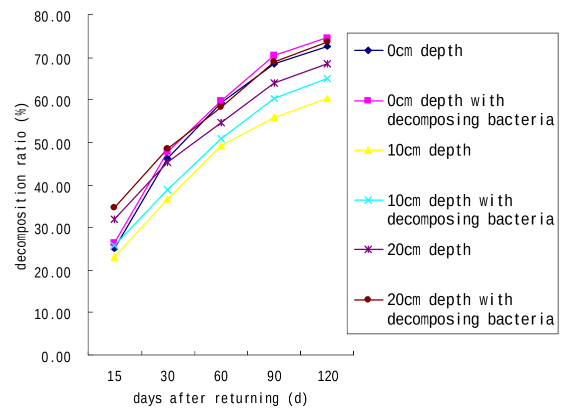

Fig. 5: Decomposition ratios of returned rapeseed straw under different treatments.

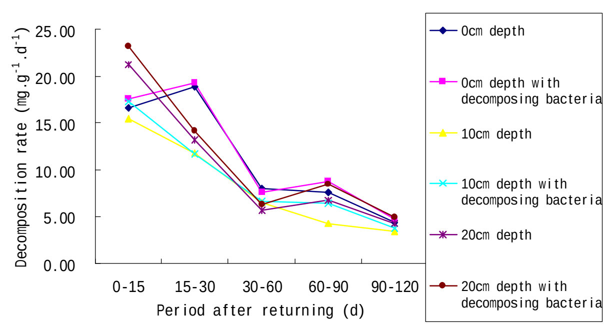

Fig. 6: Decomposition rates of returned rapeseed straw under different treatments.

reduced, and the soil nutrient content was increased. The rapeseed straw-returning can increase rice yield. In this study, the rice yield increased between 180 $kg.ha^{-1}$ to 1635 $kg.ha^{-1}$ in straw-returning groups.

ACKNOWLEDGEMENT

The authors acknowledge Anhui Educational Committee of China. This study was funded by the 12th five-year water special project, Foundation of Anhui Educational Committee and the National 12th Five-Year Science and Technology Support Project of China. We thank YU Xuesheng, XIANG

Table 1: Effects of different amounts of returned rapeseed straw on soil properties.

Treatment	pH	Bulk density ($g.cm^{-3}$)	Organic matter ($g.kg^{-1}$)	Total N ($g.kg^{-1}$)	Total P ($g.kg^{-1}$)	Total K ($g.kg^{-1}$)	Hydro. N ($mg.kg^{-1}$)	Effective P ($mg.kg^{-1}$)	Rapidly K ($mg.kg^{-1}$)
Control	6.35±0.02a	1.42±0.01a	17.31±0.20d	1.23±0.02d	0.40±0.02c	17.15±0.62c	115.65±0.34c	7.87±0.60c	102.43±4.55d
1/3 amount	6.30±0.02b	1.41±0.02ab	18.06±0.23c	1.31±0.03c	0.42±0.02b	17.87±0.21b	116.36±0.23c	7.91±0.25c	113.34±6.70c
1/2 amount	6.27±0.01c	1.39±0.01b	18.38±0.18c	1.42±0.05b	0.44±0.01b	18.12±0.40b	118.65±0.33b	8.54±0.57b	123.32±3.92b
2/3 amount	6.25±0.01c	1.39±0.01b	19.21±0.68b	1.47±0.03b	0.47±0.02a	18.97±0.21a	109.95±2.51ab	8.65±0.04ab	124.54±7.09b
Wholeamount	6.15±0.02d	1.37±0.01c	20.13±0.25a	1.53±0.05a	0.48±0.02a	19.21±0.22a	121.34±1.26a	9.21±0.19a	135.76±5.69a

Different small letters in the same column show significant difference at P=0.05 level according to Duncan test. The same form below.

Table 2: Effects of different depths of returned rapeseed straw on soil properties.

Treatment	pH	Bulk density ($g.cm^{-3}$)	Organic matter ($g.kg^{-1}$)	Total N ($g.kg^{-1}$)	Total P ($g.kg^{-1}$)	Total K ($g.kg^{-1}$)	Hydro. N ($mg.kg^{-1}$)	Effective P ($mg.kg^{-1}$)	Rapidly K ($mg.kg^{-1}$)
Control	6.35±0.02a	1.42±0.01a	17.31±0.20b	1.23±0.02b	0.40±0.02b	17.15±0.62b	115.65±0.34b	7.87±0.60b	102.43±4.55b
0cm depth	6.25±0.03b	1.35±0.02c	18.32±0.58a	1.45±0.03a	0.41±0.02b	17.98±0.33a	114.35±0.58c	7.91±0.11ab	120.21±3.05a
10cm depth	6.27±0.01b	1.39±0.01b	18.38±0.18a	1.42±0.05a	0.44±0.01a	18.12±0.40a	118.65±0.33a	8.54±0.57a	123.32±3.92a
20cm depth	6.35±0.02a	1.42±0.02a	17.52±0.44b	1.24±0.03b	0.41±0.02b	17.16±0.09b	114.73±0.52c	7.88±0.33b	103.54±4.30b

Table 3: Effects of returned rape straw on rice yield.

The amount of returning	Depths of returning(cm)	Yield ($kg.ha^{-1}$)
1/2 amount	0	9210±33Bb
1/2 amount	10	8190±33Ee
1/2 amount	20	9360±46Aa
The whole amount	10	8490±17Cc
2/3 amount	10	8340±26Dd
1/2 amount	10	8190±23Ee
1/3 amount	10	7905±38Ff
Control (without straw)	-	7725±75Gg

Different capital and small letters show significant difference at P < 0.01 and P < 0.05 levels respectively.

Jingxia and DI Yunfei for the field experiment management and sampling.

REFERENCES

Bao, S.D. 2000. Analytical Methods of Soil and Agro-chemistry. China Agriculture Press, Beijing, pp. 25-95.

Bastian, F., Bouziri Lamia and Nicolardot Bernard 2009. Impact of wheat straw decomposition on successional patterns of soil microbial community structure. Soil Biology & Biochemistry, 41(2): 262-275.

Curtin, D., Francis G.S. and McCallum, F.M. 2008. Decomposition rate of cereal straw was affected by soil placement. Australian Journal of Soil Research, 46(2): 152-160.

Devevre, O.C. and Horwath, W.R. 2000. Decomposition of rice straw and microbial carbon use efficiency under different soil temperatures and moistures. Soil Biology & Biochemistry, 32(11): 1773-1785.

First Editing Room of China Standards Press 2010. Chinese Agricultural Standard Collection-Volume of Soil and Fertilizer. China Standard Press, Beijing, pp. 501-540.

Li, L.J., Wang, Y. and Zhang, Q. 2008. Wheat straw burning and its associated impacts on Beijing air quality. Science in China Series D: Earth Sciences, 51(3): 403-414.

Li, P.Y., Sun, X.F. and Hong, W.X. 2009. Nutrient release patterns and decomposing rates of wheat and rapeseed straw. Plant Nutrition and Fertilizer Science, 15(2): 374-380.

Michael, A.B., William, B. Patterson and Steven, L. Hotard 2008. Straw harvesting, fertilization and fertilizer type alter soil microbiological and physical properties in a loblolly pine plantation in the mid-south USA. Biology and Fertility of Soils, 45(2): 145-153.

National Bureau of Statistics of China 2010. China Statistical Yearbook. China Statistics Press, Beijing, pp. 290-320.

Nie, J., Zhou, J. M. and Wang, H.Y. 2007. Effect of long-term rice straw return on soil glomalin, carbon and nitrogen. Pedosphere, 17(3): 295-302.

Pal, S.S. and Jat, M.L. 2004. Enhanced decomposition of rice (*Oryza sativa*) straw and its effect on soil health and crop yield in rice-wheat (*Triticum aestivum*) cropping system in an Ustochrept of Indo-Gangetic plain. Indian Journal of Agricultural Sciences, 74(8): 409-414.

Song, X.N., Fang, R.J. and Wang, X.Z. 2009. Research on utilization techniques of rape straw as resources. Journal of Natural Resources, 24(6): 984-991.

Stewart, B., Wuest, Caesar-Ton, That, T. C., Sara, F. and Wright 2005. Organic matter addition, N and residue burning effects on infiltration, biological and physical properties of an intensively tilled silt-loam soil. Soil & Tillage Research, 84: 154-167.

Wu, J., Guo, X.S. and Wang, Y.Q. 2011. Decomposition characteristics of rapeseed and wheat straw under different water regimes and straw incorporating models. Joural of Food Agriculture & Environment, 9(2): 572-577.

Yang, Z.C., Lv, Y. Z. and Zhang, F.R. 2008. Comparative analysis of the effects of straw-returning and decomposed manure on paddy soil fertility betterment. Transactions of the CSAE, 24(3): 214-218.

Yao, S.H., Zhang, B. and Hu, F. 2011. Soil biophysical controls over rice straw decomposition and sequestration in soil: The effects of drying intensity and frequency of drying and wetting cycles. Soil Biology & Biochemistry, 43(3): 590-599.

Zhang, F. S. 2008. China's Fertilizer Industry and the Scientific Application of Fertilizers Strategic Research. China Agricultural University Press, Beijing, pp. 50-54.

Zhang, J., Chen, J.C. and Tang, Z.L. 2006. Relationship between physical and chemical properties of stem and lodging. Journal of Southwest Agricultural University (Natural science edition), 28(5): 763-76.