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Original Research Paper

Effects of Different Ways to Return Biomass on Soil and Crop Nutrient Contents

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ABSTRACT

Using wheat and corn as the selected crops, this study aims to explore the effects of different ways to return biomass, on soil and crop yield with wheat and corn straw, and the biochar made by them as the material. The results exhibited that the different ways of returning biomass could significantly improve the soil cation exchange capacity (CEC) and the content of organic matter after the harvesting of two annual crops. The soil nutrient content showed a rising trend in general, and the effect was most significant when the biochar consumption was the most. The soil total nitrogen content in wheat and corn season significantly increased by 100% and 16.2% respectively compared with the control. The soil mineral nitrogen content and available P content in wheat season significantly increased by 0.9% and 217% respectively compared with the control. And the soil mineral nitrogen content, available P content and available K content in corn season significantly increased by 21.2%, 30% and 90% respectively compared with the control. The effects of direct straw application to soil was a bit poor, and it had no significant effect on crops yield, but it can promote plants to absorb nutrients, and the effect increased with the increase of biomass usage. The effect of sole biochar application is better than that of direct straw application.

INTRODUCTION

China has been bestowed with abundant biomass resources, which account for about a quarter of the world's total biomass (Li et al. 2013), but unfortunately this huge amount of biomass has not been exploited effectively for a long time, and some even has been abandoned and burned, which not only wasted the resources but also increased pollution in the environment. However, different researches revealed that the biomass in cracking furnace generated carbon-rich solid matter through thermal cracking under the condition of limited oxygen, the solid matter called biochar (Antal et al. 2003). Functional importance and possible mechanism of biochar working has also been reported in detail in different studies. Most studies conducted on biochar, represent enhanced soil fertility and crop growth on the weathering soil and typical tropical arid soil (Steiner et al. 2007). Using meta-analysis method, the systematic analysis of previous studies showed that, the average increase rate of crop productivity was about 10% after the soil being improved by biochar, but actually it varied around (-28%-39%) (Jeffery et al. 2011).

In recent years, Chinese scholars have begun to focus on related function of biochar, not only relating the physical and chemical properties and the environmental function of biochar (Liu et al. 2009, Zhang et al. 2009), but also applied it to increasing crop yield (Liu et al. 2009, Zhang 2013). They used pot experiment to study the influence of applying biochar on spinach growth, and found that the use of biochar significantly improved the spinach yield and biomass in the loam, with the growth of 2.5%-57.3% (Zhang et al. 2011). But there are relatively few reports on the comparison of applying biomass as biochar and directly returning way, to study the effect on soil and crop (You 2012, Fengping Wu et al. 2013). Taking winter wheat and summer corn cultivated in loessial soil in Guanzhong Plain of Shaanxi province as the research object, with wheat and corn straw and its biochar material, this study preliminarily explored the influence of different ways of returning biomass on agricultural soil chemical properties, soil nutrient content, crop yield and biomass, as well as the crop nutrient content. Also it tried to explore the difference of effects of two ways of returning biomass (biochar and straw application) on soil properties and crop growth, and to provide the reference for the rational application of living substance in agriculture.

MATERIALS AND METHODS

Materials: This experiment was conducted at the experimental station No. 3 of Northwest A & F University, located at the west of Guanzhong Plain, where the annual average temperature range is 13-15°C, annual average evaporation capacity is around 993mm and average annual precipitation is 550-650mm, concentrating in July to September. The climate of field varies from warm temperate to semi humid and frost-free duration as 184-216 days. The types of soil are brown soil, subclass of loessial soil, red soil and yellow cinnamon soil, which was genealogically classified as Earth-cumuli-Orthic Anthrosols and calcareous soil. The biochar of this study was produced by Shangqiu Sanli New Energy Co., Ltd. Henan, China, and it was sieved through 2mm sieve. The selected tested crops were wheat (Xiaoyan 22) and corn (Zhengshan 958). Basic properties of surface layer (0-20cm) of soil and biochar is mentioned in Table 1.

Field experiment design: Taking the field experiment, corn biochar and straw was applied one-time before planting wheat, and wheat biochar and straw before planting corn. Since five tons straw could produce 1.5 tons of biochar, the exact calculated dosage of biochar and straw are mentioned in Table 2. The area under crop cultivation was 30m^2, using randomized complete block design with six treatments and three replications. Nitrogen (short for N; urea 46.4%), phosphorus (short for P; single superphosphate 46%) and potassium fertilizer (short for K; potassium chloride 60%) were used as base fertilizers. Average dose of NPK was 150:100:50kg in each hectare during wheat season. Similarly, 180:60:75kg of NPK was applied in each hectare during corn season. Biochar and straw had been applied and well mixed with surface soil once before planting, while fertilizer and irrigation was applied as crop schedule.

The test adopted a rotation system of two crops in a year: wheat sowing in winter followed by corn sowing during summer, under similar agricultural and management practices. As the crop reached physiological maturity, spikes were harvested and packed into a clean envelope separately, then placed in an oven for 30 minutes at 105°C, and baking at 65°C to gain a constant weight. After successful digestion of the plant samples with H_2SO_4-H_2O_2, they (plant/gain) were analysed by automatic intermittent chemical analyser (Cleverchem 200) to test the content of total N and total P, and then flame photometer was employed to measure the content of total K. Then serpentine sampling method was used for random distribution of five dots to collect 0-20cm composite soil in the field to test the soil properties.

Index measurement: Fundamental physical and chemical properties of biochar and soil were determined by referring the methods given by Bao (2001). Biochar nature was determined using potentiometer method with water (0.01 mol/L $CaCl_2$)/C as 5-1), and spectrometer was utilized for element content determination.

All the soil indexes were determined by routine method. Among them, the soil pH value used extraction-acidity meter method with water soil ratio as 2.5:1; CEC used sodium acetate-flame photometry; organic matter used sulphuric acid-potassium dichromate outside heating method; mineral N used 1 mol/L KCl extraction-flow analyser to determine NO_3^--N and NH_4^+-N, then get the sum of the two; available P used Olsen method; and available K used 1 mol/L NH_4OAc extraction-flame photometry. After the soil sample observed a constant volume then, it was digested with sulphur-catalyst, and the content of total N was tested by automatic intermittent chemical analyser (Cleverchem 200).

Table 1: Elementary chemical and physical properties of soil and biochar in the experiment.

Soil	pH[1]	Bulk[2]	CEC[3]	OM[4]	N[5]	P[6]	K[7]	NN[8]	AN[9]	P[10]	K[11]
	7.68	1.51	22.58	2.32	0.99	1.03	25.24	33.42	0.21	6.75	193.24
		pH		C%	H%		O%	N%	K%	P%	
Wheat biochar		10.35		72.03	3.23		8.06	0.74	6.98	0.47	
Corn biochar		8.75		61.78	2.82		1.56	0.78	7.01	0.58	

1= pH(1:2.5); 2 = density/g.cm^{-3}; 3 = cmol kg-1; 4 = Organic matter in %; 5, 6, 7 = per g per kg amounts showed in total; 8, 9, 10, 11 = per mg per kg; 8 = Nitrate nitrogen; 9 = Ammonium nitrogen

Table 2: Table of different experimental treatments in this study.

Treatment	Wheat		Corn	
	Corn biochar (t/ha)	Corn straw (t/ha)	Wheat biochar (t/ha)	Wheat straw (t/ha)
DCK	0	0	0	0
D1	1.5	0	15	0
D2	3	0	30	0
D3	0	5	0	5
D4	0	10	0	10
D5	0.75	2.5	7.5	25

Table 3: Effects of different ways to return biomass on soil chemical properties.

Treatment	Wheat			Corn		
	pH (H_2O)	CEC (cmol/kg)	Organic matter(%)	pH(H_2O)	CEC (cmol/kg)	Organic matter (%)
DCK	8.05±0.14a	21.26±1.32d	2.86±0.18bc	8.22±9.94cd	51.93±2.76b	2.10±0.05d
D1	8.02±0.01a	22.58±0.51cd	3.09±0.21ab	8.31±0.06ab	56.65±1.59a	3.26±0.31b
D2	8.02±0.14a	25.82±0.76a	3.35±0.12a	8.32±0.04a	56.73±0.84a	3.94±0.11a
D3	8.00±0.02a	24.79±0.44ab	2.79±0.18c	8.25±0.05abc	53.77±2.14ab	2.29±0.01cd
D4	8.07±0.28a	23.91±0.67bc	3.04±0.19bc	8.15±0.07d	56.21±1.68a	2.43±0.21c
D5	7.94±0.07a	23.61±0.44bc	3.02±0.10bc	8.23±0.02bc	55.60±1.20a	2.50±0.09c

Note: different small letters mean difference in significance level when $P < 0.05$.

Table 4: Effects of different ways to return biomass on soil total chemical nutrients.

Treatment	Wheat			Corn		
	N	P	K	N	P	K
DCK	$1.03±0.13^{cd}$	$1.13±0.04^{ab}$	$31.11±1.78^{ab}$	$1.11±0.08^{bc}$	$0.57±0.02^{ab}$	$14.44±0.75^{a}$
D1	$1.03±0.10^{cd}$	$1.03±0.15^{ab}$	$30.16±1.77^{ab}$	$1.25±0.10^{ab}$	$0.51±0.03^{b}$	$14.48±0.70^{a}$
D2	$2.06±0.17^{a}$	$1.25±0.16^{a}$	$32.22±0.66^{a}$	$1.29±0.17^{a}$	$0.61±0.03^{a}$	$14.60±0.48^{a}$
D3	$1.20±0.20^{c}$	$0.98±0.16^{b}$	$29.51±1.57^{bc}$	$0.98±0.07^{c}$	$0.61±0.03^{a}$	$14.48±0.44^{a}$
D4	$1.72±0.12^{b}$	$1.13±0.07^{ab}$	$29.46±1.74^{bc}$	$1.14±0.04^{abc}$	$0.62±0.07^{a}$	$14.94±0.30^{a}$
D5	$0.83±0.25^{d}$	$0.97±0.19^{b}$	$27.19±1.07^{c}$	$1.15±0.08^{abc}$	$0.53±0.02^{b}$	$13.22±0.82^{b}$

All concentrations of NPK are mentioned here are in g/kg; different small letters mean difference in significance level when $P < 0.05$.

Digested with nitric acid, perchloric acid and hydrofluoric acid, the content of total P was tested by automatic intermittent chemical analyser and consequently total K was measured by flame photometer.

Data processing: All data were processed with Excel and SPSS 18.0 conducting one-way Anova analysis (One-way ANOVA) and the multiple comparisons were employed using Least Significant Difference (LSD) with 0.05% significance level.

RESULTS

Effects of different ways to return biomass chemical properties of the soil: Table 3 shows that there was no significant fluctuation in soil pH value after wheat harvest, however, solely application of biochar after corn harvest considerably increased the soil pH (up to 1.2%) compared with the control, while rest of the treatments exhibited no apparent change. Restoration of organic biomass in different ways could significantly improve soil cation exchange capacity. Hence, after harvesting the two season crops, the effect of biochar application was most significant when its consumption was highest, which respectively increased by 21.4% and 9.2% in wheat and corn season compared with the control.

After biochar application in wheat season, it exhibited increased organic matter (17.1%) in contrast to control and other treatment. In the corn season, apart from the treatment of low dosage of direct straw application, other treatments significantly improved soil organic matter compared with the control, however, the effect of solely application of biochar was still more apparent than direct straw application.

Effects of different ways to return biomass on total chemical nutrients of the soil: The treatment containing a maximum quantity of biochar, significantly enhanced the total soil nitrogen content by 100% and 16.2% respectively when compared with the control after wheat and corn harvest. Unlike this trend, the highest dosage of straw application only increased the total soil nitrogen content by 67% as compared to control after wheat harvest. Meanwhile, other treatments had no effect on soil total nitrogen content. Interestingly, treatments containing combined application of biochar and direct straw had no significant influence on soil total P content. Similarly, sole application of biochar or direct straw had no considerable influence on soil total K content, but applying the two ways together could significantly reduce the soil total K content, the reason needs further research.

Effects of different ways to return biomass on the available nutrients of the soil: Table 5 shows that, the treatment of the highest dosage of biochar alone or in combination with direct straw, significantly increased the soil mineral nitrogen content after wheat and corn harvest when compared with the control. Returning biomass in different ways could significantly increase the soil available P content after wheat harvest, which got the most significant effect when

Table 5: Effects of different ways to return biomass on soil available nutrients.

Treatment	Wheat			Corn		
	Mineral nitrogen (mg/kg)	AP (mg/kg)	AK (mg/kg)	Mineral nitrogen (mg/kg)	AP (mg/kg)	AK (mg/kg)
DCK	25.65±0.37b	10.06±0.39d	237.82±1.16a	17.86±1.33b	13.30±0.93c	297.63±1.43de
D1	26.44±1.58ab	23.14±0.73b	299.12±3.90a	16.33±1.48b	16.50±0.46ab	486.84±1.08b
D2	27.9±0.85a	32.06±0.60a	287.98±4.35a	21.64±0.84a	17.25±1.12a	565.79±1.55a
D3	26.98±1.24ab	18.15±0.86c	247.11±1.47a	20.63±1.03a	14.30±1.48bc	269.04±1.93e
D4	27.34±0.77ab	23.66±0.50b	258.26±4.95a	20.17±1.41a	16.52±2.76ab	307.16±2.94d
D5	27.35±0.12a	18.59±0.33c	293.55±3.36a	18.05±0.78b	11.76±0.99c	339.83±1.23c

Table 6: Effects of different ways to return biomass on crop nutrient contents.

	Treatment	Wheat			Corn		
		N (g/kg)	P (g/kg)	K (g/kg)	N (g/kg)	P (g/kg)	K (g/kg)
Grain	DCK	17.28±1.54a	2.72±0.18a	2.55±0.28a	9.33±0.42d	0.13±0.01b	3.22±0.16a
	D1	17.06±1.33a	2.84±0.29a	2.55±0.28a	9.76±0.43cd	0.13±0.01b	3.32±0.28a
	D2	18.20±1.45a	2.98±0.12a	2.22±0.01a	11.11±0.64a	0.17±0.02a	3.12±0.25a
	D3	16.83±1.28a	2.71±0.13a	2.71±0.49a	9.87±0.26bcd	0.13±0.01b	3.35±0.37a
	D4	16.43±1.15a	2.92±0.13a	2.54±0.28a	10.43±0.33abc	0.13±0.01b	3.08±0.11a
	D5	16.22±2.16a	2.79±0.33a	2.87±0.57a	10.71±0.81ab	0.14±0.01b	3.18±0.17a
Straw	DCK	4.60±0.49d	1.21±0.08b	25.71±0.96a	6.65±0.17c	0.038±0.005a	15.41±1.75d
	D1	6.12±0.42c	1.15±0.02b	21.13±0.73cd	7.05±0.75c	0.045±0.004a	19.11±1.83bc
	D2	7.84±0.32a	1.31±0.17ab	21.61±0.54bc	8.16±0.89ab	0.043±0.006a	21.65±1.35ab
	D3	5.96±0.45c	1.18±0.03b	22.75±0.51b	7.40±0.50abc	0.041±0.005a	18.03±1.37cd
	D4	7.23±0.47ab	1.47±0.16a	20.10±0.97d	7.24±0.62bc	0.042±0.005a	23.62±1.77a
	D5	6.74±0.83bc	1.27±0.03b	18.33±0.49e	8.42±0.31a	0.038±0.003a	19.40±1.33bc

the dosage of biochar was highest, and when the usage of biochar and dosage of straw application was 10 t/ha; it still could significantly increase the soil available P content after the corn harvest. The available K content increased in some degree after wheat harvest, yet there was no significant difference between the treatments, but the biochar application could significantly increase soil available K content after corn harvest, while direct straw application had no significant influence on the soil available K content. The available K content also increased in combined application of biochar and straw, however, it was not as effective as application of biochar alone.

Effects of different ways to return biomass on crop straw and crop yield: It could be seen from Fig. 1 that there was no significant difference among the crop yield, the reason might be due to the fact that only two season crops were planted, and the planting duration was too short, hence, the biomass showed no significant replenishment effect on soil.

Effects of different ways to return biomass on crop nutrient contents: From Table 6, the biomass has no significant effect on the nutrient uptake in wheat grains, but when the dosage of biochar and straw application reached the highest amount, it could significantly improve the nitrogen content in the corn grain compared with the control. Applying the two methods together could also increase the nitrogen uptake of corn grain. When the dosage of biochar was 30 t/ha, it significantly increased the phosphorus content in the corn grain. There was no significant difference in K content in corn grains among the different ways. The data clearly demonstrated that the application of biomass had improved the effect of crop nutrient uptake ability.

Biochar and straw application significantly improved N and P content in the wheat straw, the effect was most significant when the amount of biochar and straw application was intense, however, these methods of biomass replenishment significantly reduced the K content in the wheat straw. In the corn season, the biochar dosage as 30 t/ha or applying the two ways together significantly improved the N content in the straw. Similarly, there was no significant difference in the P content among different treatments, and applying biomass could significantly improve the K content in only the straw containing treatment.

DISCUSSION

In this study, the usage of biochar only significantly improved soil pH in corn season and had no significant effect on soil pH in wheat season. The reason might be that, in both the applications, year and duration of corn season

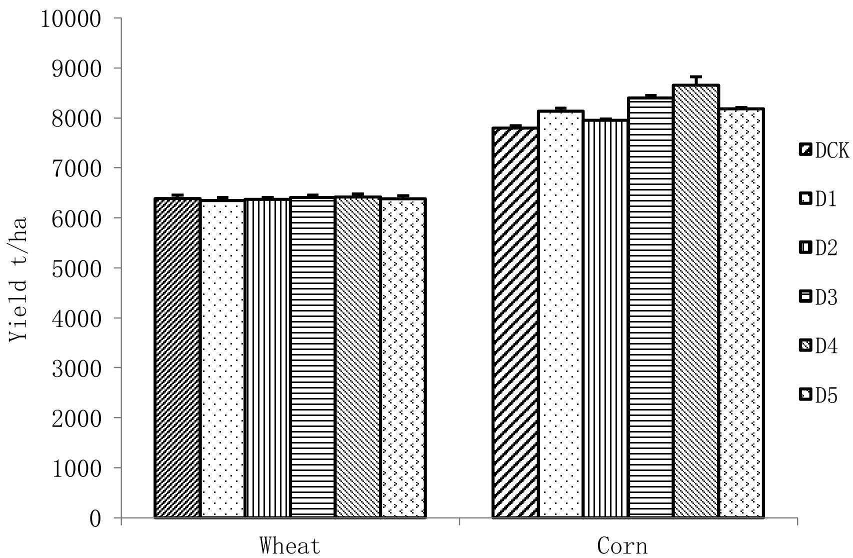

Fig. 1: Effects of different ways to return biomass on crop yield.

increased compared with wheat season. The biomass of biochar is generated by thermal cracking, which lead to higher pH, and with the increased amount and extent of prolonged duration in field area it could significantly improve the soil pH (Van et al. 2010). Returning biomass can increase soil organic matter content, and improve soil physical and chemical properties including permeability (Zhu et al. 2010) allowing aeration. It can restore NPK and various trace nutrient elements with improved water-holding capacity and consequently soil fertility. This study confirms the results of previous studies (Huang et al. 2011, Gou et al. 2014). Since biochar itself is a rich source of organic matter content, it has ability of soil amendment because it increases the soil organic matter content after suitable cultural practices on land. Moreover, molecular structure of biochar is dominated by aromatic carbon skeleton, hence it is much more persistent for a long time due to reduced microbial activity. Its novel structure works as the inevitable source of protection against nutrient loss which can improve the soil fertility and fertilizer usage efficiency as well. The impact of returning biomass on soil chemical properties is poor than that of biochar of the same proportion, the reason may be that pore structure and surface functional groups formed after thermal cracking affected its interaction with soil colloid.

In addition to this, biochar had a larger specific surface area and stronger adsorption performance, but because of its selectivity of NH_4^+ and NO_3^- holding, it could refurbish soil mineral N content after ploughing in the soil (Ding et al. 2010, Chen et al. 2013). The result of this study is consistent with the above researches, biochar did not have significant influence on the available P and available K. But the effect of direct returning biomass on the soil mineral N was not stable, this might be due to the microbial need to consume soil nutrient as mineral N and available K (Xu 2010) in the process of decomposing straw, which was related to the original soil available nutrient content.

Numerous studies have shown that the application of biochar could significantly promote crop growth, increase production and dry matter accumulation of above ground parts of spinach (Zhang et al. 2011), tomatoes (Zhu et al. 2010) and corn (Tang et al. 2011), and straw application could also improve crop yield (Zheng et al. 2009), while different ways of biomass returning in this study had no significant effects on wheat and corn yield. The reason may be that, while returning straw, the microbial activity rose in the process of decomposing straw, it needed to compete with the crop seedling for the N in the soil, which reduced soil nutrient availability. And a high biochar carbon content and low mineral nutrient content increased the soil C/N ratio, and thus reduced the soil nutrients, especially N availability (Zhong et al. 2006). So, the usage of biochar in most of the soil had no significant positive effect on the yield of seasonal crop or several season crops, which could even lead to yield reduction (Khan et al. 2008).

CONCLUSION

1. Different ways of returning biomass could significantly improve soil nutrient content, including cation exchange capacity (CEC) and organic matter content, and this effect was more apparent when the amount of biochar was the highest.

2. But this replenishment does not always enhance crop yield significantly, however, it promotes plant nutrient uptake ability and work as a useful tool for quality production crops and biomass usage.
3. In this study, we found good results using biochar, (alone) however, we are ambiguous about the results of coupled application (biochar and dry straw) i.e., why production was reduced during coupled application of both soil amendments, which needs to be explored further.

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