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Balancing the use of maize residues for soil amendment and forage

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ABSTRACT

Balancing the use of maize (*Zea mays* L.) residues for soil amendment and forage is an important strategy for agricultural sustainability. Therefore, the study assessed the impacts of four proportions of maize residues to soil retention (S) and forage (F) on soil total organic carbon (TOC); total nitrogen (TN); carbon/nitrogen ratio (C/N); grain yield, economic benefits and nutritional contents of removed residues. The concentrations of TOC and TN increased when more residue returned, while the C/N ratios were $S_{100} + F_0 > S_{34} + F_{66} > S_{66} + F_{34}$. Also, crude protein, crude fat, and crude starch in the removed residues were $F_{34} > F_{66} > F_{100}$, while the crude fiber and ash contents exhibited the opposite trend. The crop yield improved with residue retention increased, but there were no differences on the economic benefits of the four residue-use systems. The $S_{34} + F_{66}$ system maintained a TOC ranging from 11.51 to 13.37 g/kg, a TN from 1.12 to 1.16 g/kg, 92.93% of the annual yields of the $S_{100} + F_0$ system, and 6.2 t/ha/year of forage. Therefore, the $S_{34} + F_{66}$ system can balance the use of maize residues for soil amendments and forage to sustainably develop a household crop-livestock system.

Keywords: no-tillage; long-term experiment; wheat-maize rotation system; nutritive contents; spider plot

Crop residues are an important agricultural resource that improves soil fertility and crop productivity when returned to the field as an amendment (Malhi et al. 2011); they can also be used as an important feedstock for household livestock breeding (Houx et al. 2013). The highly efficient management and use of residues play key roles in increasing soil fertility and crop yields, protecting the environment, and facilitating a household-level crop-livestock system (Blanco-Canqui and Lal 2007, Valbuena et al. 2012).

However, residues have been managed inefficiently in many developing countries (Huang et al. 2012, Zheng et al. 2012, Johnson et al. 2013). Maize is arguably the most productive grain crop in the world (Gustafson et al. 2014). Excessive retention of maize residues can reduce seed bed quality, inhibit seedling emergence, and delay soil

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warming in spring, all of which may reduce grain yields in direct-seeding or no-till systems (Huang et al. 2012). In contrast, the complete removal of residues may result in low or no surface cover, exacerbating the potential risks of water erosion (Nelson 2002), reducing soil organic carbon (SOC) levels (Clapp et al. 2000), and decreasing future crop yields (Huang et al. 2012). After adequate retention to field for soil erosion control and for sustaining SOC reserves (Hoskinson et al. 2006), the surplus residues can be used as forage for livestock (Valbuena et al. 2012, Zhao et al. 2013). However, information on the proportions of maize residue that should be retained in the field and removed for livestock forage on SOC, total nitrogen (TN) concentrations, forage nutritive contents, and economic benefits under a winter wheat/maize cropping system is limited.

Therefore, the objectives of this study were to evaluate the effects of four systems utilizing residue on the SOC, TN, yields, economic benefits and forage nutritive contents; and to determine the optimal proportion of residues for amendment and forage in a winter wheat/maize cropping system in North China.

MATERIAL AND METHODS

Experimental sites. The study site was located in Tai'an 36°09'N, 117°09'E), Shandong province, China. The average annual precipitation is 697 mm, and the average annual temperature is 13.0°C. Duration of the annual frost-free period is approximately 170–196 days, and the annual sunlight duration is 2627 h. The soil is classified as Cambisols (FAO). The important properties of initial values in the 0–20 cm depth (2010) are presented as follows: 7.09 pH, SOC 10.87 g/kg, alkali-hydrolyzable N 110 mg/kg, Polsen, 38.44 mg/kg, and NH_4Ac-K 41.32 mg/kg.

Experimental design. The study was based on a 10-year no-till (NT) and residue management experiment, which began in 2002 and the data used in this study were collected from 2010–2012. The area was cultivated with a crop rotation of winter wheat (*Triticum aestivum* L.) and summer maize (*Zea mays* L.). All of the winter wheat residues during the experiment were returned to the field after harvesting and the input amounts was 11.02 t/ha/year in residue retention-use systems; the maize residues were returned to the soil (S) according to three cutting heights (0, 0.5, and 1 m), and the surplus residues were used as forage (F). The dry matter weight was 0.16 kg/plant, and the residue-use proportions and biomasses are shown in Table 1. These four residue-use systems were arranged in a randomized block design with three replications: 100% of residues removed for forage ($S_0 + F_{100}$); 34% residue retention and 66% removed for forage ($S_{34} + F_{66}$); 66% residue retention and 34% removed for forage ($S_{66} + F_{34}$); and 100% residue retention ($S_{100} + F_0$). Each plot was 35-m long and 4-m wide.

Winter wheat (cv. Jimai-22) was seeded at a rate of 90 kg/ha on 10 Oct. 2010 and 12 Oct. 2011 and was harvested on 6 June 2011 and 10 June 2012, respectively. A basal fertilizer containing 225 kg N, 78 kg P, and 87 kg K per ha was applied prior to sowing wheat, and 100 kg of N/ha was top-dressed at the jointing stage with 160 mm irrigation. Summer maize (cv. Zhengdan-958) was sown on 15 June 2011 and 20 June 2012 at the rate of 66 600 plants/ha and was harvested on 8 Oct. 2011

Table 1. Residue-use proportions and biomasses under four residue-use systems

	Treatment			
	$S_0 + F_{100}$	$S_{34} + F_{66}$	$S_{66} + F_{34}$	$S_{100} + F_0$
Cutting height (m)	0	0.5	1	–
Proportion used for retention (%)	0	34	66	100
Total biomass for retention (t/ha/year)	0	3.58	6.82	10.05
Proportion used for forage (%)	100	66	34	0
Total biomass for forage (t/ha/year)	10.05	6.20	3.23	0

$S_0 + F_{100}$ – 100% residues for forage; $S_{34} + F_{66}$ – 34% residues for soil amendment and 66% for forage; $S_{66} + F_{34}$ – 66% residues for soil amendment and 34% for forage; $S_{100} + F_0$ – 100% residues for soil amendment

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and 10 Oct 2012, respectively. For maize, 120 kg N, 52 kg P, and 83 kg K per ha were used as a basal fertilizer, and 120 kg N/ha was top-dressed at the jointing stage.

Soil sampling and measurements. Soil samples (0–20 cm and 20–40 cm depths) were obtained at five random positions in each plot at three sampling times during each crop season. The soil samples were air-dried, ground and passed through a 0.25-mm sieve after thorough mixing. The soil TOC and TN concentrations were determined using a TOC/TN analyzer (Multi N/C 3000, Analytik Jena AG, Germany).

Grain yield and economic benefit analysis. The grain yield samples of winter wheat and maize were harvested from a 9-m^2 area in the centre of each plot to exclude edge effects. Grains were separated from plants and oven-dried at 65°C for 48 h to determine the water content. The grain yield is reported at a water content of 14%. The economic benefit analysis of grain and forage calculated the market value of averaged grain yields and residue biomass yields in two years.

Maize residue samples and analysis. Residue samples were cut at 0-, 0.5-, and 1-m heights from the soil surface at five random positions in each plot after maturity. The residues samples were air-dried for determining the dry matter (DM). Then the samples were ground, and passed through a 0.25-mm sieve, and determined crude protein (CP); crude fat (EE); crude starch (CS); crude fiber (CF); and ash contents (AOAC 1990).

Analysis of the four residue-use systems. A spider plot of equivalent ratios was used to compare the four residue-use systems according to the method of Ning et al. (2012). The relative values for the soil and grain yield parameters were based on the $S_{100} + F_0$ system, while the forage nutritive parameters (CP, EE, CS, CF and ash) were based on the $S_0 + F_{100}$ system.

Statistical analysis. The data were analysed using ANOVA via the general linear model procedure in SPSS (Ver. 11, SPSS, Chicago, USA). The differences between the treatments were considered significant if $P < 0.05$. A spider plot was created in Microsoft Office Excel (2007).

RESULTS AND DISCUSSION

Soil TOC, TN and C/N ratio. TOC and TN concentrations at the 0–20 cm and 20–40 cm layers were significantly related to the proportion of residue-retention in four residue-use systems (Figure 1, $P < 0.01$). A linear relationship was also reported between residue-retention proportions and TOC concentration (Surekha et al. 2003, Johnson et al. 2013). Averaged soil TOC concentrations at $S_{100} + F_0$ treatment in the 0–20 cm soil layers were by 20.3, 28.8 and 43.6% higher than those of $S_{66} + F_{34}$, $S_{34} + F_{66}$ and $S_0 + F_{100}$ treatments (Table 2), respectively. Soil TN concentration of the 0–20 cm layer under the $S_{100} + F_0$ treatment was by 7.0, 19.4 and 25.3% higher than those of $S_{66} + F_{34}$, $S_{34} + F_{66}$ and $S_0 + F_{100}$ treatments, respectively. Increasing the quantity of crop residues is an effective method to improve the SOC level and soil quality (Benbi and Senapati 2010, Lenka and Lal 2013). Chen et al. (2010) reported that 30–60% residue returning under no-till could generally maintain the soil TOC and TN concentrations.

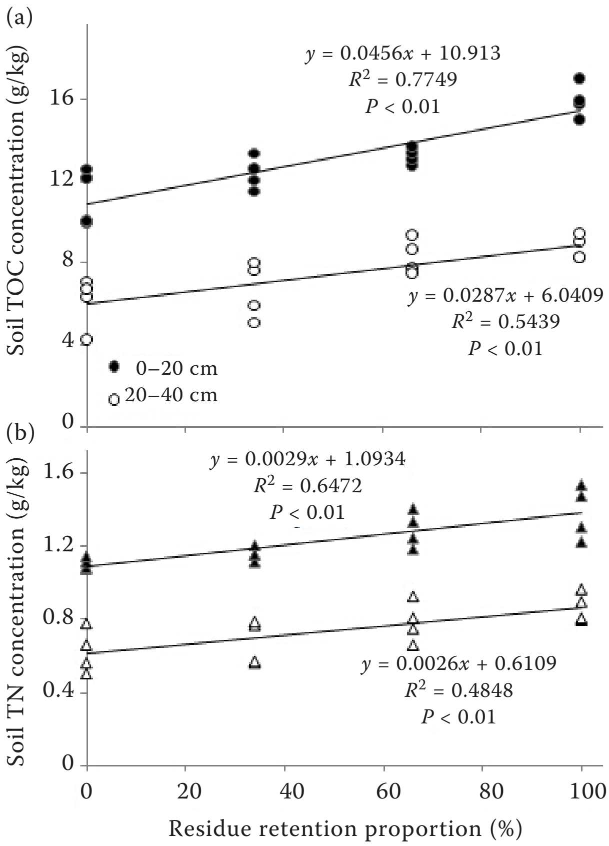

Figure 1. Regression analysis between soil total organic carbon (TOC) and total nitrogen (TN) concentrations and residue retention proportion. (a) and (b) indicated linear relationships between soil TOC and TN with retention proportions of maize residues in different soil layers, respectively

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Table 2. Concentrations of soil total organic carbon (TOC); total nitrogen (TN) and the carbon nitrogen ratio (C/N) ratio under four residue-use systems

Crop growth period	Treatment	TOC 0–20 cm	TOC 20–40 cm	TN 0–20 cm	TN 20–40 cm	C/N ratio 0–20 cm	C/N ratio 20–40 cm
		(g/kg)					
Wheat period (10/2010~06/2011)	$S_0 + F_{100}$	9.95^d	4.26^{dc}	1.08^d	0.50^d	9.22^d	8.49^d
	$S_{34} + F_{66}$	11.51^c	5.09^c	1.16^c	0.56^c	9.92^b	9.09^c
	$S_{66} + F_{34}$	12.78^b	7.74^b	1.34^b	0.81^b	9.53^c	9.59^a
	$S_{100} + F_0$	15.00^a	8.26^a	1.48^a	0.90^a	10.11^a	9.24^b
Maize period (06/2011~10/2011)	$S_0 + F_{100}$	12.16^d	6.39^c	1.09^d	0.56^c	11.15^c	11.32^b
	$S_{34} + F_{66}$	12.63^c	5.94^d	1.12^c	0.57^c	11.27^b	10.43^c
	$S_{66} + F_{34}$	13.08^b	7.52^b	1.19^b	0.66^b	10.99^d	11.43^a
	$S_{100} + F_0$	15.75^a	9.06^a	1.23^a	0.80^a	12.81^a	11.33^b
Wheat period (10/2011~06/2012)	$S_0 + F_{100}$	10.06^d	7.10^b	1.12^d	0.78^b	8.98^d	9.14^d
	$S_{34} + F_{66}$	12.05^c	7.65^b	1.21^c	0.77^b	9.95^b	9.94^b
	$S_{66} + F_{34}$	13.41^b	8.71^a	1.41^b	0.93^a	9.55^c	9.36^c
	$S_{100} + F_0$	15.96^a	8.29^a	1.54^a	0.97^a	10.36^a	11.22^a
Maize period (06/2012~10/2012)	$S_0 + F_{100}$	12.59^c	6.76^c	1.15^c	0.66^b	10.95^d	10.31^c
	$S_{34} + F_{66}$	13.37^b	8.04^b	1.16^c	0.79^a	11.53^b	10.19^d
	$S_{66} + F_{34}$	13.73^b	9.37^a	1.25^b	0.75^a	11.04^c	12.50^a
	$S_{100} + F_0$	17.06^a	9.44^a	1.31^a	0.81^a	13.02^a	11.74^b

The lowercase letters indicate significant differences at the 0.05 levels according to the *LSD* multiple range test. $S_0 + F_{100}$ – 100% residues for forage; $S_{34} + F_{66}$ – 34% residues for soil amendment and 66% for forage; $S_{66} + F_{34}$ – 66% residues for soil amendment and 34% for forage; $S_{100} + F_0$ – 100% residues for soil amendment

The C/N ratios in 0–20 cm soil layers for the two-year period under $S_{100} + F_0$ system were by 12.2, 8.1 and 14.6% higher than those of $S_{66} + F_{34}$, $S_{34} + F_{66}$ and $S_0 + F_{100}$ systems, respectively. Maintenance of an optimal C/N ratio can be achieved with sufficient retention of residues (Six et al. 1999, Puget and Lal 2005, Maia et al. 2010). Specifically, crop residue retention can increase the proportion of active SOC (Xu et al. 2011) with a lower degree of decomposition and a higher C/N ratio (Yamashita et al. 2006).

Grain yields and economic benefit. The annual yield of $S_{100} + F_0$ treatment was by 2.7, 7.6 and 11.0% higher than those under $S_{66} + F_{34}$, $S_{34} + F_{66}$ and $S_0 + F_{100}$ treatments, respectively. The benefits from grains of $S_{100} + F_0$, $S_{66} + F_{34}$ and $S_{34} + F_{66}$ systems were by 11.0, 8.0, and 3.1% higher than that under $S_0 + F_{100}$ treatment, respectively. Some studies indicated that a positive correlation exists between the succeeding grain yield and the proportion of returned residues (Gebrekidan et al. 1999, Surekha et al. 2003). However, the total economic benefits in four residue-use systems revealed no statistical differences. The economic benefit might be affected by the market prices of grain and forage. In this study, the low price of forage maybe the reason. With the larger scale use of the S + F system, the economic benefits will increase. Further, if special-purpose ensiling maize with higher quality was used, as Song (2001) recommend, the total benefits of $S_{66} + F_{34}$ and $S_{34} + F_{66}$ would be increased.

Nutritive contents of residues for forage. The highest contents of CP, EE, CS were measured at the forage portion of $S_{66} + F_{34}$ treatment, while there were no differences on EE and CS contents between the F_{34} and F_{66} portions of $S_{34} + F_{66}$ and $S_{66} + F_{34}$ treatments (Table 4). The higher contents

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Table 3. Grain yields and economic benefit analysis of four residue-use systems

Treatment	Grain yields 2010~2011 wheat	Grain yields 2010~2011 maize	Grain yields 2011~2012 wheat	Grain yields 2011~2012 maize	Annual grain yields	Economic benefit analysis[§] grain	Economic benefit analysis[§] forage	Total economic benefit
	(t/ha)					(US$/ha)		
$S_0 + F_{100}$	5.68^d	6.49^{cd}	5.80^d	6.41^d	12.2^b	4372.2^b	359.9	4767.8^a
$S_{34} + F_{66}$	5.78^c	6.54^c	6.06^c	6.76^c	12.5^b	4508.5^b	222.0	4767.4^a
$S_{66} + F_{34}$	6.04^b	6.85^b	6.36^b	7.08^b	13.1^a	4721.9^a	115.7	4876.2^a
$S_{100} + F_0$	6.15^a	7.08^a	6.50^a	7.33^a	13.4^a	4851.2^a	0	4890.6^a

The lowercase letters in the same column indicate significant differences at the 0.05 levels according to the *LSD* multiple range test (n = 3). The grain benefits of wheat and maize at 26/8/2015 were 383.0 and 341.5 US$/t, and forage benefit of maize residue forages was 35.8 US$/t. $S_0 + F_{100}$ – 100% residues for forage; $S_{34} + F_{66}$ – 34% residues for soil amendment and 66% for forage; $S_{66} + F_{34}$ – 66% residues for soil amendment and 34% for forage; $S_{100} + F_0$ – 100% residues for soil amendment

of CF and ash were observed at the returned portions of $S_{34} + F_{66}$ and $S_{66} + F_{34}$ treatments. The contents of CP, EE and CS in residue under the $S_{66} + F_{34}$ system were significantly higher than those in the other treatments because the F_{34} treatment had higher nutritive residues for forage. The CP in residue under F_{34} was by 7.5% and 11.8% higher than those of F_{66} and F_{100}, respectively. The EE in residue under F_{34} was by 4.3% and 7.4% higher than those of F_{66} and F_{100}, respectively. Several studies have reported that leaf possesses a higher forage nutritive value than stem (Gustafson et al. 2010) and that harvesting residues at a height of approximately 40 cm are the best for farmers (Hoskinson et al. 2006).

Comparison of four residue-use systems. Although the $S_{100} + F_0$ treatment resulted in the highest grain yield and soil C/N ratio (because all of the residues were returned to the field), this treatment did not balance the use of residues for both soil quality and forage as no residues were used for forage (Figure 2). Similarly, the $S_0 + F_{100}$ treatment resulted in the high nutritive value for forage but produced the lowest yield and soil C/N

Table 4. Forage nutritive contents of four residue-use systems

Treatment		CP	EE	CS	CF	Ash
		(g/kg)				
$S_0 + F_{100}$	S_0	–	–	–	–	–
	F_{100}	0.51^c	0.68^b	0.12^{ab}	3.83^c	0.62^c
$S_{34} + F_{66}$	S_{34}	0.43^e	0.49^d	0.10^c	5.16^a	0.65^a
	F_{66}	0.53^b	0.70^{ab}	0.12^{ab}	3.51^c	0.59^d
$S_{66} + F_{34}$	S_{66}	0.47^d	0.56^c	0.11^{bc}	4.49^b	0.63^b
	F_{34}	0.57^a	0.73^a	0.13^a	3.43^c	0.58^e
$S_{100} + F_0$	S_{100}	0.51^c	0.68^b	0.12^{ab}	3.83^c	0.62^c
	F_0	–	–	–	–	–

The lowercase letters indicate significant differences at the 0.01 level according to the *LSD* multiple range test (n = 3). $S_0 + F_{100}$ – 100% residues for forage; $S_{34} + F_{66}$ – 34% residues for soil amendment and 66% for forage; $S_{66} + F_{34}$ – 66% residues for soil amendment and 34% for forage; $S_{100} + F_0$ – 100% residues for soil amendment; CP – crude protein; EE – crude fat; CS – crude starch; CF – crude fiber

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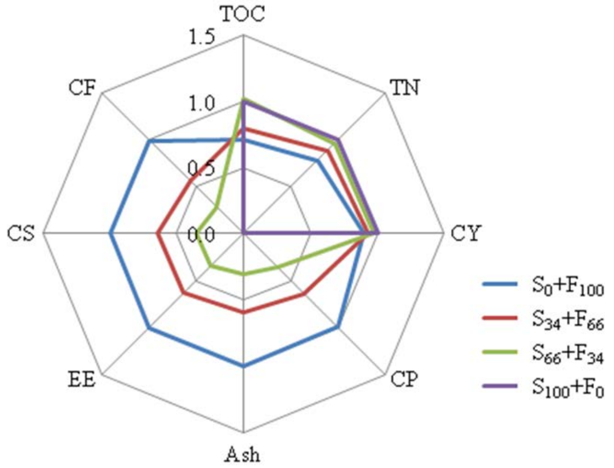

Figure 2. A spider plot of the equivalent ratios for the soil, yield and forage nutritive composition parameters under four residue-use systems. TOC – total organic carbon; TN – total nitrogen; CY – crop yield; CP – crude protein; EE – crude fat; CS – crude starch; CF – crude fiber. $S_0 + F_{100}$ – 100% residues for forage; $S_{34} + F_{66}$ – 34% residues for soil amendment and 66% for forage; $S_{66} + F_{34}$ – 66% residues for soil amendment and 34% for forage; $S_{100} + F_0$ – 100% residues for soil amendment

ratio. When comparing the proportions of residue retention and feeding potential of the $S_{66} + F_{34}$ system with those of the $S_{34} + F_{66}$ system, the latter system was balanced as to the levels of soil C and N and offered more residues for forage. Many problems are associated with the process of retention (Vadas and Digman 2013), which may delay a broader use of residue retention and removal. Moreover, farmers typically burn the residues or use all of the residues for forage or bioenergy production (Zheng et al. 2012), which may decrease soil quality and productivity. Thus, Hoskinson et al. (2006) suggested collecting the fraction of maize residues with the greatest glucose potential (i.e., cobs, leaves, and husks) and leaving the remaining residues in the field for soil erosion control and for sustaining SOC reserves.

In conclusions, the four residue-use systems had significant effects on improving the soil C and N and economic benefits through the retention of residues and/or meeting nutritive feedstock needs for forage. The $S_{34} + F_{66}$ system (with a cutting height of 0.5 m) was the optimal choice for providing a sustainable amount of high-quality forage without strongly affecting the soil C and N levels and economic benefits.

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