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Estimation of Organic Nutrient Sources and Availability for Land Application in China

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Knowledge of the status and characteristics of organic nutrient resources in China *is essential for their efficient management in agricultural production.*

Provincial and regional level estimates are provided *for the amount of organic wastes, their nutrient supply capacity, as well as their availability to cropland.*

Great increases in Chinese crop production and livestock farming have in turn produced large amounts of nutrient-laden animal wastes and crop residues. Organic wastes from human activities, and of green legume manures are also viewed as valuable organic resources. The recent government policy of "zero growth by 2020" for fertilizer sources is increasing the focus on how all available nutrient sources can be used best. Part of this focus is placed on an increased interest in using organic nutrient sources, like livestock manure, to offset inorganic fertilizer use. Estimation of the nutrient supply capacity and availability from these organic resources is important for understanding nutrient input/output balances in the Chinese agricultural system, and will have a great effect on nutrient management and fertilizer application in China.

Estimating Nutrients from Animal Sources

The annual amount of animal manure and urine for specific livestock or poultry was estimated based on the amount of animals (stock) at the end of the year (Q1), the amount of off-take within the year (Q2), off-take rate (R, %), feeding period (T), and daily manure quantity (q, kg/d):

The amount of manure/urine (mt) = $[Q_1 \times (T/R) + Q_2 \times T] \times q/1000$

The term off-take refers to livestock or poultry that come to market when they are at slaughter weight. The off-take rate represents the percentage of off-take from the total stock for a specific livestock or poultry type. Data on numbers of livestock/poultry and off-take were taken from the China Agriculture Yearbook (Ministry of Agriculture, 2013). Data on feeding period, daily excrement/urine and their nutrient contents, proportion of various manure types returned to agricultural land, and nutrient losses during storage/composting were from literature listed in **Table 1**.

Table 1. Nutrient contents of animal manure (fresh weight basis).

Livestock	Average feeding period[1], d	Average returned to cropland[2], %	Excrement and nutrient content[3]				Urine and nutrient content[3]				Nutrient loss rate[4]		
				N	P_2O_5	K_2O		N	P_2O_5	K_2O	N	P_2O_5	K_2O
			kg/d	%			kg/d	%					
Cattle	194	66	18	0.38	0.22	0.28	9	0.50	0.04	1.10	60	15	19
Horse	77	61	10	0.44	0.31	0.46	5	0.69	0.14	0.82	38	18	28
Donkey	100	74	10	0.49	0.43	0.64	5	0.17	0.03	0.28	38	18	28
Mule	64	74	10	0.31	0.36	0.28	5	0.17	0.05	0.34	38	18	28
Sheep	193	61	1.5	1.01	0.50	0.64	0.5	0.59	0.05	0.84	15	18	28
Pig	134	75	2	0.54	0.56	0.35	3	0.17	0.05	0.19	75	15	36
Poultry	210	61	0.13	0.76	0.76	0.72	0	-	-	-	40	15	15

[1] Values for cattle, sheep, pig, and poultry (NDRC, 2014); Values for horse, donkey, and mule (Li and Jin, 2011).

[2] Values for the listed livestock wastes (Yang et al., 2014; Qiu et al., 2012; Zhao et al., 2010; Xu et al. 2012; Li, 2013; Yang and Dong, 2015; Qian et al., 2014; Zhang et al., 2012; Wang and Shen, 2013; Lin et al., 2012; Shang, 2011; Wang et al., 2011; Xu et al., 2009; Lei et al., 2014; Yang et al., 2010).

[3] Values from Li and Jin, 2011.

[4] Values of N and P loss rate for cattle, pig, and poultry wastes (Kellogg et al., 2000). Average K loss rate for cattle wastes (Sommer, 2001; Michel Jr. et al., 2004; Eghball et al., 1997; Chadwick, 2005). K loss rate for pig wastes (Tiquial et al., 2002). K loss rate for poultry (Wei et al., 2012). Horse, donkey, and mule wastes: N loss rate (Wang and Zhao, 1979), P loss rate (Sun et al., 2013; Jia et al., 2014; Tiquial et al., 2002), and K loss rate (Jia et al., 2014; Tiquial et al., 2002). Sheep wastes: N loss rate (Velasco et al., 2011), P loss rate (Sun et al., 2013; Jia et al., 2014; Tiquial et al., 2002), and K loss rate (Jia et al., 2014; Tiquial et al., 2002).

The total amount of animal manure including manure and urine was more than 3.1 billion t (Bt), theoretically providing about 15.1, 8.8, 16.2 million t (Mt) of N, P_2O_5, and K_2O, respectively. There were 18 provinces/cities that produced more than 1 Mt of total N, P_2O_5, and K_2O of animal manure.

The top three provinces (Sichuan, Henan, and Shandong), produced a total of 4.22, 2.98, and 2.55 Mt of $N+P_2O_5+K_2O$, respectively (**Table 2**). As a whole in China, the total amount of NPK from animal manure was 68% of the total fertilizer NPK consumption of 59.12 Mt in 2013. However, after considering the amount of livestock manure that is actually returned to agricultural land, and nutrient losses that occur during storage and processing, the estimate of organic nutrients flowing to cropland were adjusted to 4.83, 4.95, and 8.33 Mt of N, P_2O_5, and K_2O—a total of 18.11 Mt. This amount accounts for 31% of the total fertilizer consumed in 2013. After accounting for these losses, the proportion of N, P_2O_5, and K_2O originating from animal manures and returned to cropland was 32%, 56%, and 51% of the total excreted.

Estimating Nutrients from Human Sources

The amount of human excreta was estimated based on average human excreta of 5.4 kg N/year/capita (Sun et al., 2008). The average N, P_2O_5, and K_2O in human excreta was (fresh weight basis) 0.64%, 0.11%, and 0.19% (CNATES, 1999), and the recoverable portion for application to cropland was calculated based on the values of 1-0.25-0.25 kg N-P_2O_5-K_2O/year/capita (Sheldrick et al., 2003).

Table 2. Total amounts of NPK nutrients ($N+P_2O_5+K_2O$) from organic sources in different provinces.

Region	Provinces	Animal manure, Mt	Crop residues, Mt	Legume green manure, Mt	Human excreta, Mt	Total
NE[1]	Liaoning	1.45	0.84	0.03	0.40	2.72
	Jilin	1.07	1.22	0.03	0.26	2.58
	Heilongjiang	1.37	1.89	0.04	0.36	3.66
NC	Beijing	0.12	0.05	0.00	0.16	0.33
	Tianjin	0.12	0.09	0.00	0.11	0.32
	Hebei	1.48	1.64	0.02	0.65	3.79
	Shanxi	0.49	0.47	0.02	0.32	1.30
	Shandong	2.55	1.99	0.00	0.88	5.42
	Henan	2.98	2.19	0.03	0.88	6.08
MYL	Shanghai	0.27	0.06	0.00	0.18	0.51
	Jiangsu	0.91	1.53	0.03	0.72	3.18
	Zhejiang	0.36	0.40	0.05	0.48	1.29
	Anhui	0.98	1.36	0.03	0.57	2.94
	Hubei	1.39	1.28	0.04	0.53	3.25
	Hunan	1.94	1.34	0.03	0.60	3.90
	Jiangxi	1.05	0.85	0.06	0.41	2.37
SE	Fujian	0.53	0.29	0.04	0.34	1.20
	Guangdong	1.57	0.68	0.03	0.89	3.17
	Guangxi	1.89	1.19	0.06	0.45	3.59
	Hainan	0.34	0.12	0.03	0.08	0.57
SW	Chongqing	0.59	0.43	0.02	0.26	1.30
	Sichuan	4.22	1.42	0.03	0.76	6.43
	Guizhou	1.57	0.47	0.11	0.35	2.51
	Yunnan	2.17	0.89	0.08	0.42	3.57
	Tibet	2.11	0.05	0.00	0.03	2.19
NW	IMAR	1.99	1.17	0.09	0.23	3.47
	Shaanxi	0.60	0.50	0.08	0.35	1.53
	Gansu	1.38	0.47	0.03	0.25	2.13
	Qinghai	1.45	0.06	0.00	0.05	1.56
	Ningxia	0.22	0.14	0.00	0.06	0.42
	Xinjiang	0.84	1.35	0.04	0.20	2.43
	China	40.00	26.45	1.06	12.21	79.71

[1] NE: northeast, NC: north central, MYL: middle/lower reaches of the Yangtze River, SE: southeast, SW: southwest, NW: northwest.

The amount of organic material derived from human activities was related to population in various provinces. By estimation, the total amount of total human excreta in China was nearly 1.1 billion tons (B t) that had NPK supply of 12.21 M t, with 7.07, 2.67 and 2.48 M t of N, P_2O_5 and K_2O. However, only 1.31, 0.75 and 0.39 M t of N, P_2O_5 and K_2O were recoverable for agricultural land calculated based on Sheldrick et al., 2003, accounting for 18%, 28% and 16% of the respective total excreted. Most of this human organic nutrient supply was in the high population areas of north central and the middle/lower reaches of Yangtze River regions. Guangdong, Henan, Shandong, Sichuan and Jiangsu were the five provinces that supply the most nutrients from human excreta (**Table 2**).

Estimating Nutrients from Crop Residues

Straw for a specific crop (S) was estimated by harvest production (P) and straw-to-product ratio (R):

S (mt) = P (mt) × R

Data on crop production were from the China Agriculture Yearbook (Ministry of Agriculture, 2013). The average straw-to-product ratio, percent of straw returned, and percent nutrient contents in straw are listed in **Table 3**.

Table 3. Nutrient contents in different crop residues (dry matter basis).

Crops	Residue/ Product ratio[1]	Directly returned to crop land[2], %	Returned to crop land after burning[2], %	Nutrient content in residue[3], %		
				N	P_2O_5	K_2O
Rice	0.8-1.5	1.4-56	1.0-29	0.83	0.27	2.06
Wheat	1.1-1.4	1.4-88	0.9-48	0.62	0.16	1.22
Maize	1.0-2.0	0.0-69	1.2-35	0.87	0.30	1.34
Sorghum	1.7-2.3	1.4-56	1.2-29	1.20	0.35	1.65
Millet	1.1-2.3	1.4-56	1.2-29	0.77	0.22	1.96
Barley	1.5-2.3	1.4-56	1.2-29	0.51	0.17	1.58
Other cereals	1.6-2.3	1.4-56	1.2-29	1.05	0.31	1.78
Soybeans	1.1-1.7	1.4-60	1.2-29	1.63	0.39	1.27
Potatoes	0.4-1.0	1.4-56	0.7-45	0.31	0.07	0.56
Peanut	0.8-1.7	0.0-86	1.2-29	1.66	0.34	1.19
Rapeseed	1.5-3.0	0.0-59	1.2-45	0.82	0.32	2.24
Sunflower	2.0-3.0	1.4-56	1.2-32	0.73	0.24	1.98
Cotton	2.6-3.4	1.4-56	3.5-40	0.94	0.33	1.10
Lint	1.4-6.6	1.4-56	1.2-29	1.25	0.13	0.58
Sugarcane	0.1-0.9	1.4-56	1.2-29	1.00	0.29	1.21
Sugar beet	0.1-0.4	1.4-80	3.5-29	1.00	0.29	1.21
Tobacco	0.7-1.1	1.4-56	1.2-29	1.30	0.35	2.00
Vegetables	0.1	1.4-80	2.9-29	2.37	0.64	2.10
Melons	0.1	1.4-80	2.9-29	2.35	0.48	2.16

[1] Zhang et al., 2010a; Zhao, 2015; Gao et al., 2009a; Wei and Lv, 2013; Li et al., 2011; Wang et al., 2013b; Hu et al., 2011; Yao et al., 2009; Pan et al., 2014; Liu et al., 2010; Wang et al., 2013c; Xie and Zhou, 2013; Shi et al., 2012; Xu and Zhang, 2011; Li, 2012; Ma, 2010; Sun, 2011; Yang and Zhang, 2011; Zhang et al., 2012; Li, 2009; Hou et al., 2013; Zhu et al., 2011; Gao et al., 2009b; Bi et al., 2009.

[2] Chen, 2014; Chang et al., 2012; Wang et al., 2009; Liu et al., 2010; An et al., 2012; Sun and Yu, 2011; Pan et al, 2014; Yao et al., 2009; Zhao, 2015; Zhang et al., 2010a; Gao et al., 2009a, b; Guan and Shi, 2009; Yang, 2011; Zheng and Shi, 2012; Xu et al., 2012; Cui and Guo, 2012; Zhang et al., 2014; Wen et al., 2011; Xie and Zhou, 2013; Wang, 2010; Wang et al., 2013a; Zhang et al., 2010b; Wan and Wan, 2014; Shen et al., 2011; Fan, 2012; Zou et al., 2004; Huang et al., 2009; Mo et al., 2009; Lv and Wang, 2009; Li, 2009; Zhang, 2010; Wang, 2008; Hu et al., 2011; Yang et al., 2012; Xu et al., 2009; Li, 2012; Xu and Zhang, 2011; Zhu et al., 2011; Zhang, 2011; Guo and Zhang, 2007; Cao et al., 2011; Peng, 2007; Yang et al., 2010; Hou et al., 2013.

[3] CNATES, 1999.

The total amount of crop residue in China was estimated at more than 925 Mt, which is mainly distributed in north central China and the middle/lower reaches of the Yangtze River. The total nutrient NPK from crop residues was 26.45 Mt, which is divided into 9.16 Mt N, 2.81 Mt P_2O_5, and 14.48 Mt K_2O. There were 13 provinces/cities that had access to more than 1 Mt of total N, P_2O_5, and K_2O nutrients in crop residue. These regions were mainly in northeastern and north central China, and in the middle/lower reaches of the Yangtze River (**Table 2**).

Nowadays, more and more crop residues are being returned to cropland, especially in north central and southern China. Less re-use of straw occurs in the northeast and northwest regions due to colder temperatures and water shortages, which prevents straw from decomposing fast enough.

Recycling of crop residues to cropland can alleviate high K removal at harvest. However, no official statistics on the straw recycling exist at the regional level. Published data indicates about 3.11 Mt N, 1.37 Mt P_2O_5, and 7.24 Mt K_2O is applied to cropland through either the direct return of straw or through the return of burned straw ash. This represents 34%, 49%, and 50% of the total N, P_2O_5, and K_2O supply capacity of these straws. It is interesting to note that this amount of K_2O represents nearly 77% of China's potash fertilizer consumption in 2013. Data indicates that 12 provinces/cities had over 50% straw NPK nutrients returning to cropland, mainly in the north central and southern regions of China.

Estimating Nutrients from Green Legume Manure

Green manures in China mainly consist of leguminous crops such as milk vetch, hairy vetch, pea, sesban, sunhemp, etc. They are usually grown during the fallow period in winter and are either used for livestock forage or incorporated mid season as a soil improvement practice. Green manures are usually planted in southwest China, in provinces like Guizhou and Yunnan, and northwest China like the Inner Mongolia Autonomous Region (IMAR) and Shaanxi province. The total amount of leguminous crops in China produced about 93.4 Mt of fresh weight. Based on the average N, P_2O_5, and K_2O concentration of 0.50%, 0.13%, and 0.50% (CNATES, 1999), the total NPK from green manure was 1.06 Mt (0.47-0.12-0.47 Mt of N, P_2O_5, and K_2O), much less than quantities determined for animal manure and crop residues (**Table 3**). Yang et al., 2010 estimates about 49% of green manures are returned directly back to cropland.

Characteristics of Total Organic Nutrients and Their Availability in Different Regions

There are great differences for organic N sources in the various regions in China (**Figure 1**). In the northeast region, organic N was mainly from animal manure (42%) and crop residues (39%). In the northwest and southwest regions, animal manure was the main N source, accounting for an average of 55% and 64% of total organic N sources, respectively. In north central and southeast China, and the middle/lower reaches of the Yangtze River, crop residues and human excreta were the main N sources in addition to animal manure, accounting for 58%, 61%, and 53% of the total organic N, respectively.

Animal wastes were the main organic source of P in all provinces (**Figure 2**). In the northeast, north central, middle/lower reaches of the Yangtze River, southeast, southwest, and northwest regions, 57%, 58%, 55%, 62%, 72%, and 62% of P originated from animal manure.

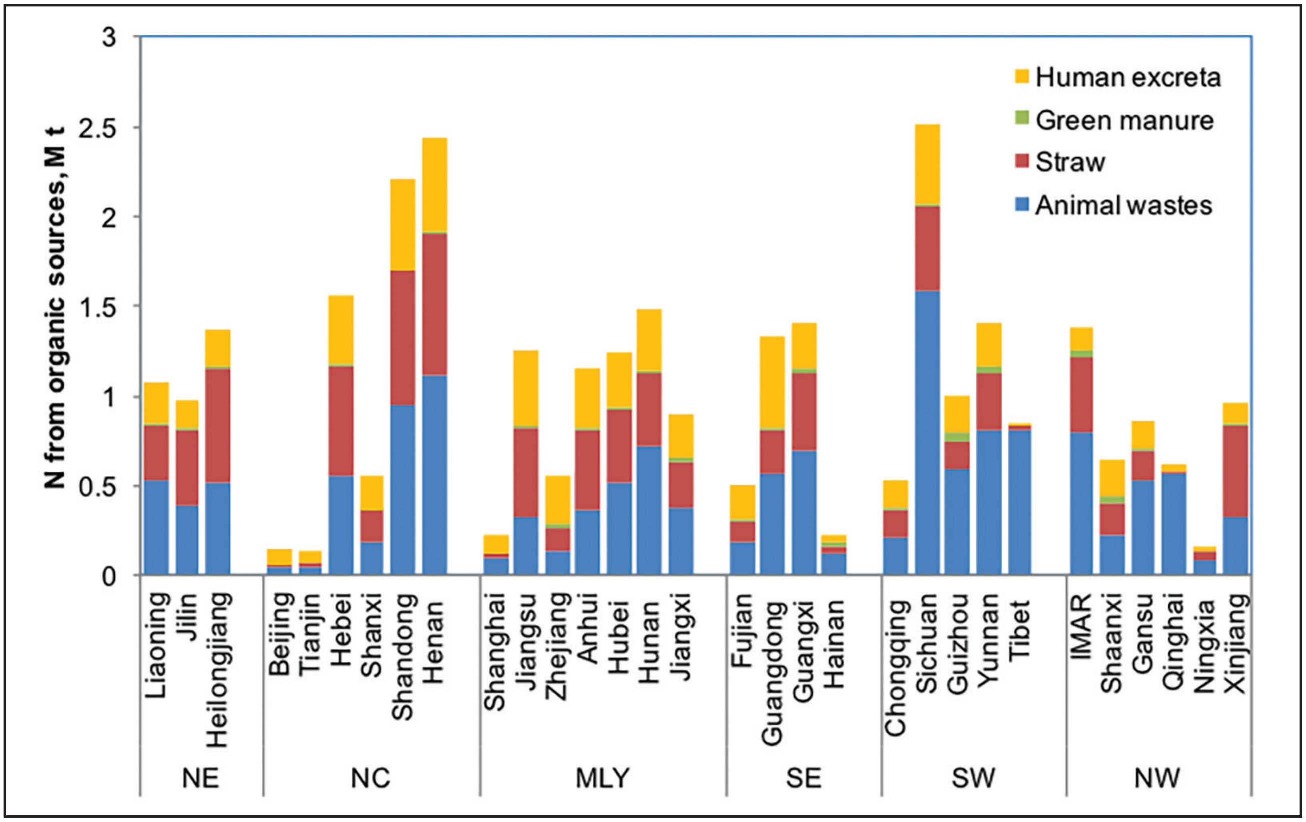

Figure 1. Total amount of nitrogen from different organic sources when totally recovered in 2013.

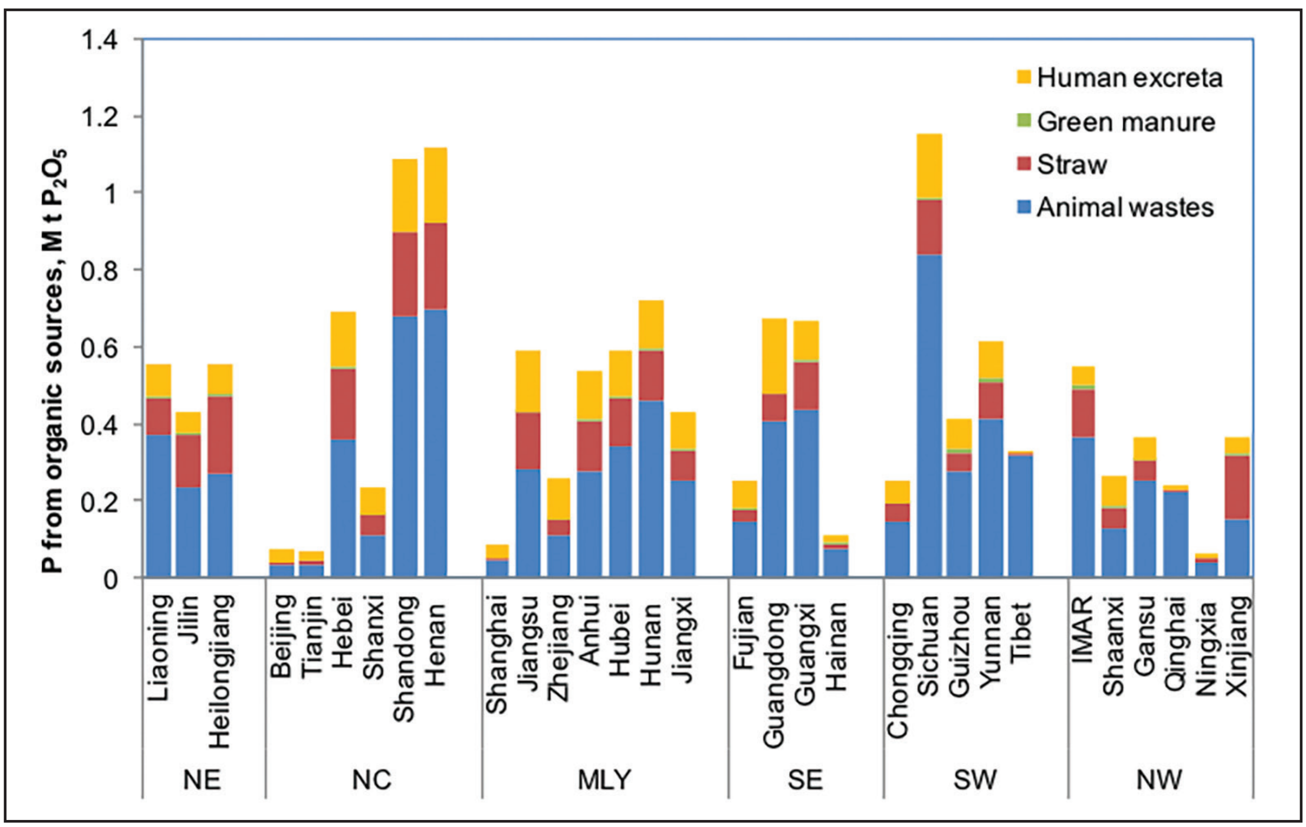

Figure 2. Total amount of phosphorus from different organic sources in 2013.

The most significant nutrient contained within organic nutrient sources, mainly animal manure and crop residues, was K (**Figure 3**). In the northeast, north central, and the middle/lower reaches of the Yangtze River regions, straw K represented 54%, 48%, and 54% of the total organic K resource, more than from animal wastes. While in the southeast, southwest, and northwest regions, animal wastes were the main organic K source, accounting for 51%, 67%, and 55% of the total.

As a whole, the total organic resources in China represent more than 5.0 Bt in fresh weight. This total product has the potential to supply 79.7 Mt of NPK nutrients including 31.7, 14.4, and 33.6 Mt of N, P_2O_5 and K_2O, respectively. This represents a similar amount of N and P_2O_5 to that which was applied via fertilizers in 2013, while the K_2O from organic sources was almost four times more than that applied as fertilizer that year.

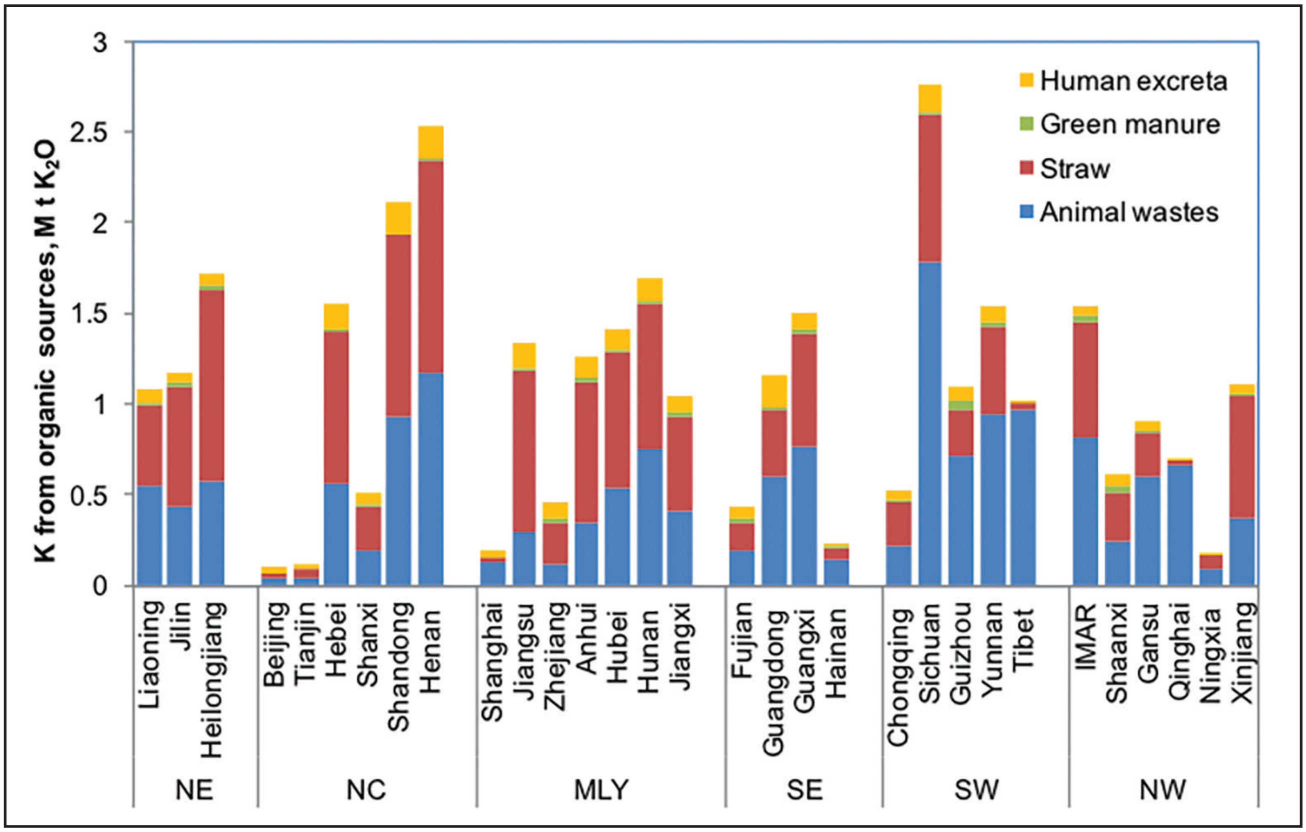

Figure 3. Total amount of potassium from different organic sources in 2013.

Sichuan, Henan, and Shandong were the top three provinces in terms of organic nutrient supply capacity—each with more than 5 Mt (**Figure 4**). The contribution of the various organic sources, relative to the total organic resources, varied greatly among provinces. Animal waste accounted for 28% to 96% (mean of 50%) of the total organic nutrient resources, straw was 2.3% to 56% (mean of 31%), human excreta was 1.2% to 48% (mean of 18%), and legume green manure was less than 5% (mean of 1.5%) (**Figure 5**).

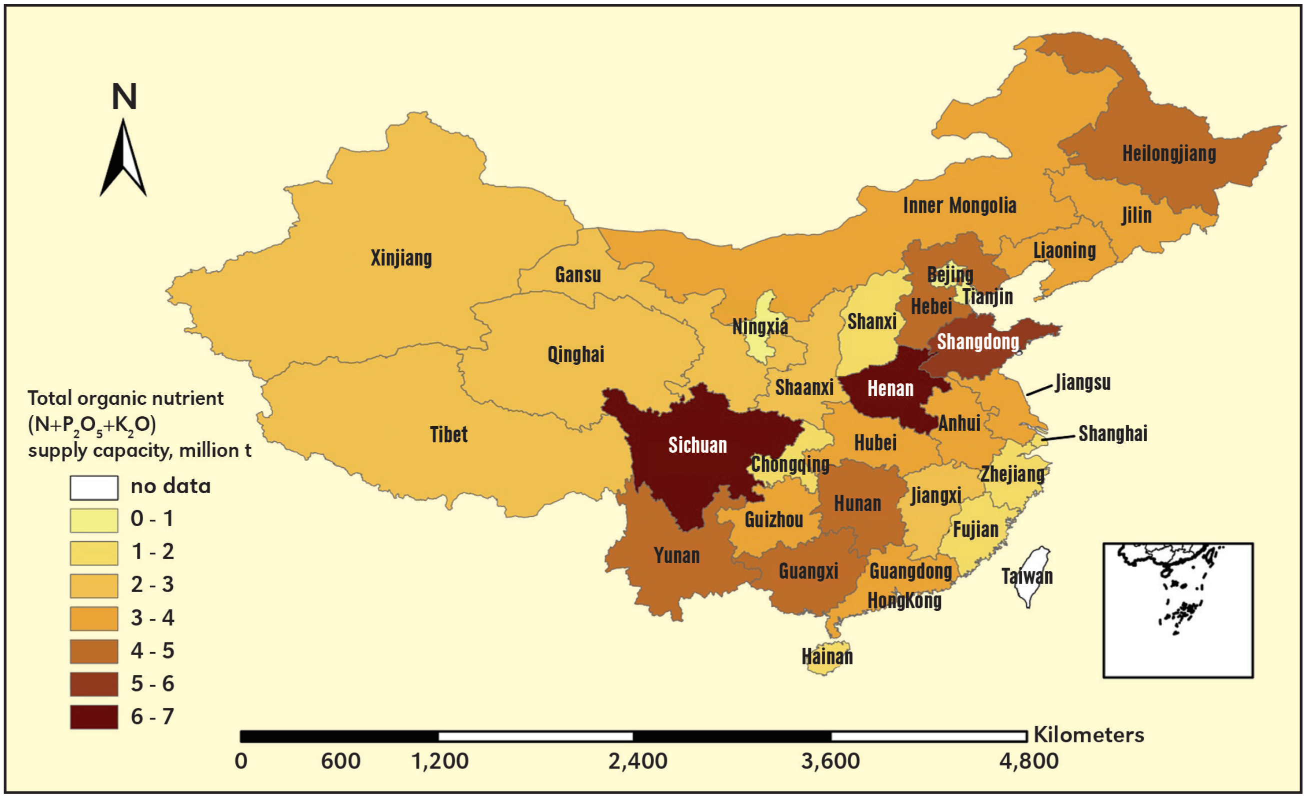

Figure 4. Total organic nutrient supply capacity by province in China. Nine provinces show capacities above 3 Mt of $N+P_2O_5+K_2O$.

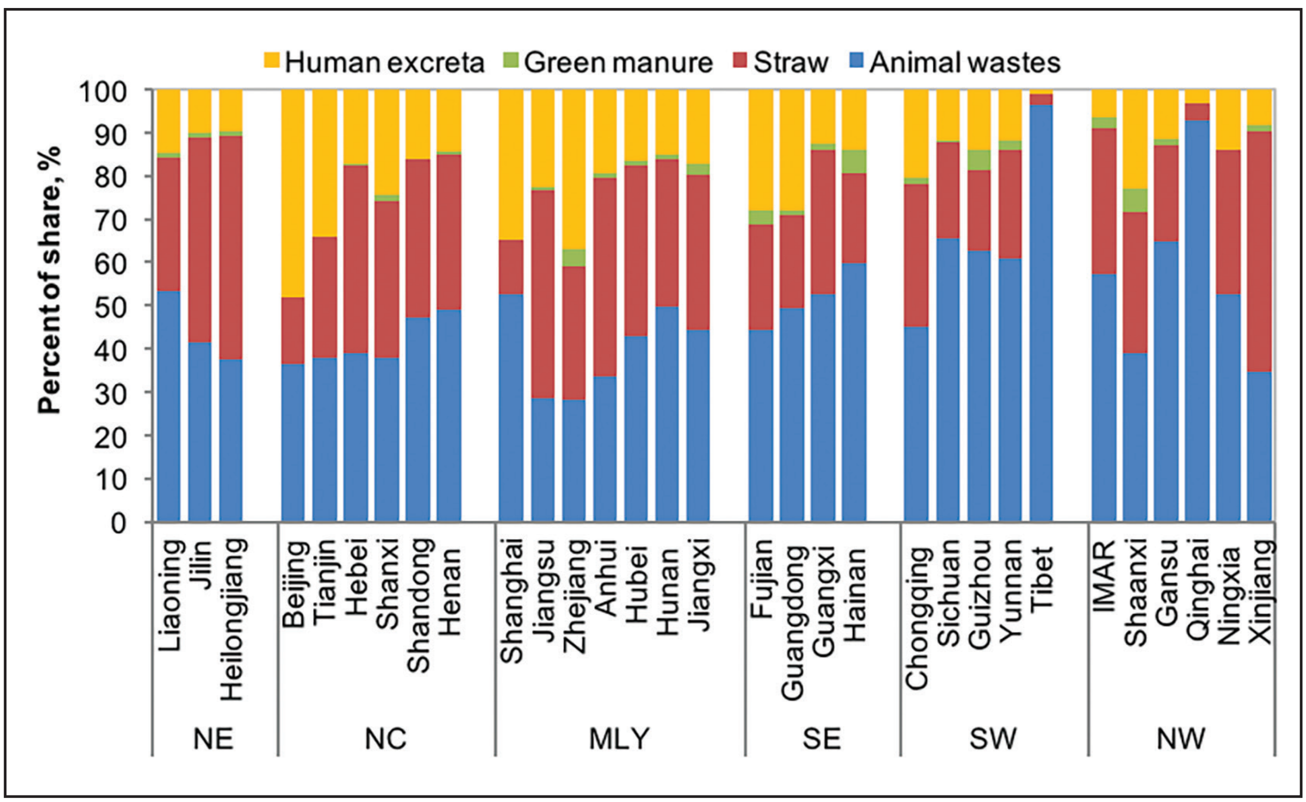

Figure 5. Total organic nutrients capacity represented by the relative share of each nutrient source in 2013.

If properly used, these organic nutrient resources would be appropriate substitutions for fertilizers, especially in the case of potash. However, the potential for mismanagement of these organic sources is high and there are significant risks towards serious environmental issues for China's surface and shallow water sources.

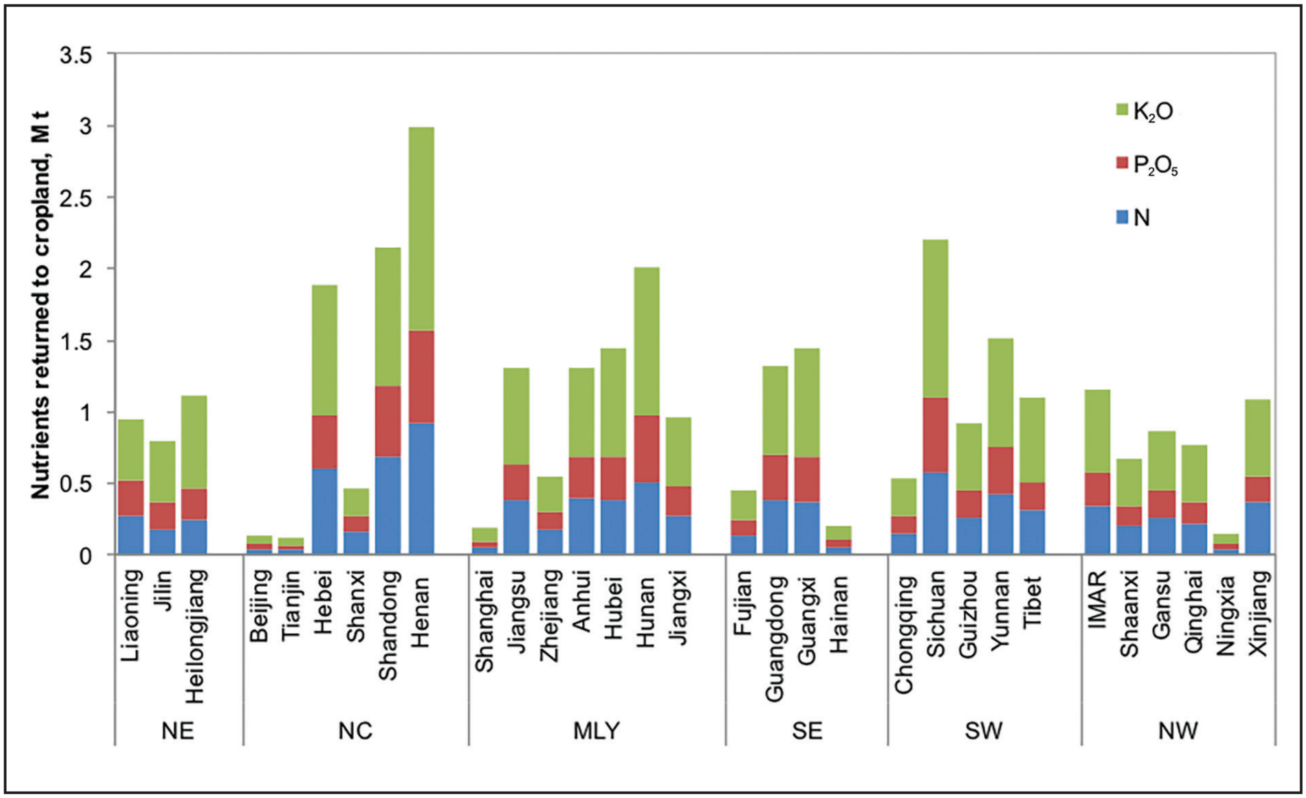

Figure 6. The amount of organic nutrient N, P_2O_5, and K_2O returned to cropland in 2013.

Although there are large organic nutrient resources available, nutrient losses during storage and processing is also large and seemingly unavoidable, especially for manure N. The amount of recoverable organic nutrient that is available to be returned to cropland varied greatly among provinces (**Figure 6**). Amounts ranged from 0.04 to 0.92 Mt N, 0.03 to 0.66 Mt P_2O_5, and 0.05 to 1.41 Mt K_2O for individual provinces, with a total of 9.48, 7.13, and 16.19 Mt in China. The percentage of organic nutrient N, P_2O_5, and K_2O returned to cropland was 18 to 38%, 39 to 64%, and 37 to 62% of the total supply capacity for individual provinces, with an average of 30%, 49%, and 48% in China. These data suggest that more than half of the total organic nutrients are not recycled to agricultural land. A concerted effort is needed to increase the use of organic nutrients and balance their use with fertilizers, but this will require both scientific and policy support.

The proportion of various organic nutrient sources in the total returned to cropland varied greatly among provinces. For animal wastes it was 28% to 99% (mean of 56%) of the total, straw was 0.4% to 60% (mean of 33%), human excreta was 0.5% to 23% (mean of 9%), and legume green manure was 0% to 9% (mean of 2%) (**Figure 7**).

These estimates of the amount of organic sources and nutrient capacity/availability can vary considerably based on parameters such as daily excrement of livestock animals, nutrient content of manures, and the proportion of manure/crop residues that can be returned to land. This review of the current literature was performed to obtain the best estimate for application rates and nutrient loss. Organic wastes are mainly applied to land directly, or as composts, in the region where these wastes originate because of transportation cost. Only a small portion of these organic wastes was used to produce commercial organic-inorganic fertilizer that can be economically transported across regions.

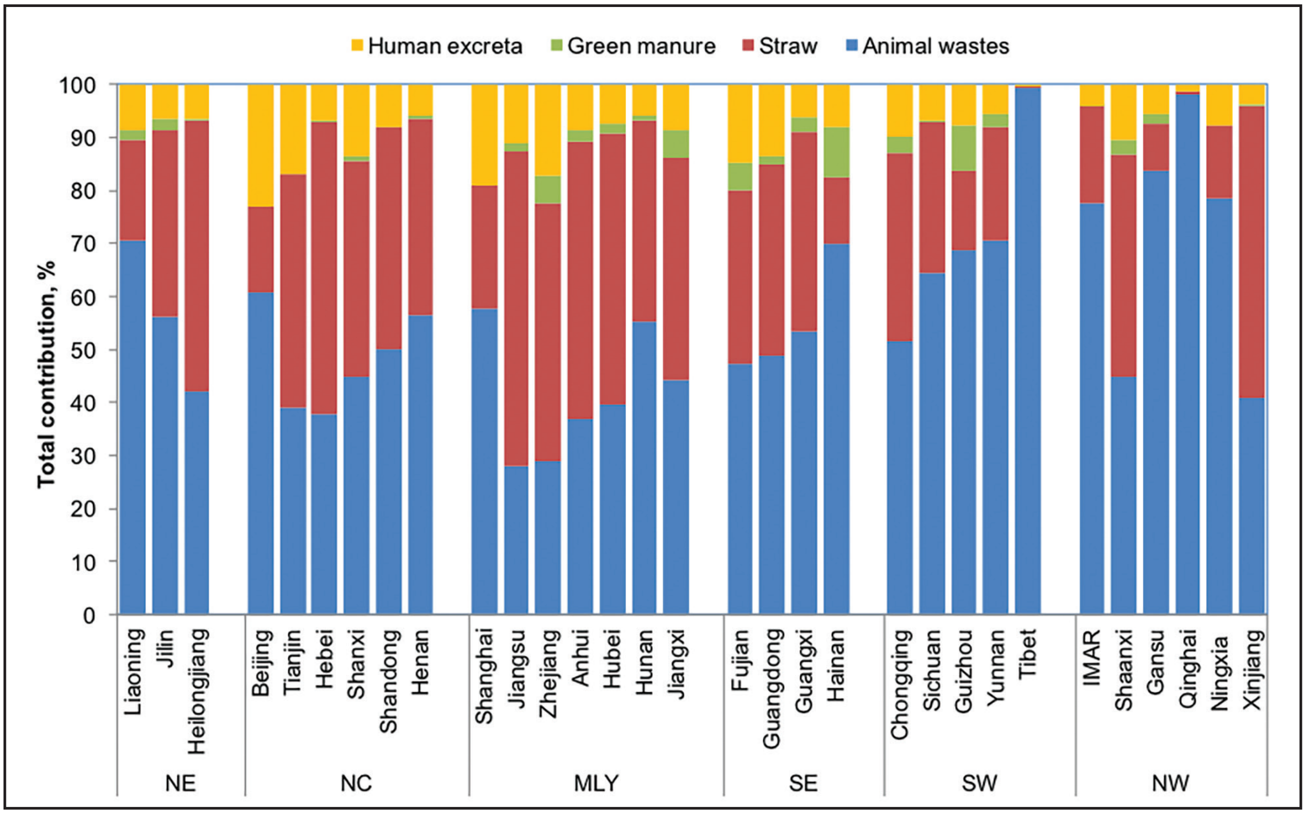

Figure 7. The share of returned nutrients from various organic sources in the total returned organic nutrients in 2013.

Summary

China has an abundant resource of organic residues with a nutrient-supplying capacity that exceeds the total fertilizer consumption in 2013. The challenge of recovering, transporting, and applying these nutrients uniformly across agricultural lands remains. Regardless, these organic nutrients could make a great contribution to the current policy promoting a zero increase in fertilizer consumption by 2020. Efforts should be made to capture the 50% or more of these organic nutrients that are currently not being returned to croplands.

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