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Demand-Supply Balance of the Nitrogen Nutrients Converted from Regional Agricultural Organic Wastes for Agricultural Utilization

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ABSTRACT

To promote the recycling of agricultural organic wastes (AOWs), e.g., crop straws, and livestock and poultry (LP) manures, it is very important to analyze the demand-supply balance of the nitrogen nutrients converted from AOWs for agricultural utilization on a regional basis. Focusing on Shangshui County in central China's Henan Province, this paper thoroughly analyzes this demand-supply balance through literature query and field survey. Firstly, the amount of nitrogen nutrients converted from the crop straws, and LP manures were calculated for the study area. Next, the demand for nitrogen nutrients of agricultural planting in the study area was estimated based on the soil properties and agricultural planting area. Based on the calculation results, the demand-supply balance of the nitrogen nutrients converted from AOWs for agricultural utilization in the study area was subject to quantitative analysis. The results show that: In 2017, the agricultural planting in Shangshui County demanded 35.16 kilotons of nitrogen nutrients; the total supply of nitrogen nutrients converted from AOWs stood at 25.86 kilotons, including 12.41 kilotons from crop straws (47.99%) and 13.45 kilotons (52.01%) from LP manures; the demand-supply ratio (amount of demand/supply quantity) of nitrogen nutrients was 1.36, that is, the demand surpassed the supply; therefore, the nitrogen nutrients provided by the AOWs in the study area can be fully utilized by the agricultural soil in the region.

1. INTRODUCTION

In recent years, a growing attention has been paid to circular agriculture. One of the important strategies for the development of circular agriculture is the land reduction of agricultural organic wastes (AOWs) [1, 2]. Despite its importance, the efficient utilization of AOWs has not been realized in many regions [3, 4].

The concept of zero waste, proposed by Paul Palmer in 1973, did not attract widespread attention until the late 1990s. The core of zero waste is to redefine the value of waste, and recognize waste as a potential resource. So far, many countries have laid down policies to reduce the landfill and incineration of waste [5, 6]. The most effective reduction method is source reduction and recycling [7, 8].

Livestock and poultry (LP) manures and crop straws, as major AOWs [9], have been the focal points in recycling. Many scholars have explored the recycling methods [10, 11] and utilization technologies [12-14] of these AOWs. Currently, AOWs are mostly recycled by composting [15, 16] and biogas fermentation [17, 18]. Recycling through composting has the minimum impact on the environment [19, 20].

The rapid growth of China's economy is accompanied by continued increase in the per-capita emissions of AOWs in rural areas, which is higher than that in any other development countries [21]. This severely threatens the sustainability of the rural environment. In the traditional agricultural economy of China, AOWs are usually used as feed (crop straws) or compost (LP manures, and crop straws). Only a small number of AOWs is discharged into the environment.

With the burgeoning social economy in rural areas, the ability to recycle AOWs has declined sharply, and the rural environment has been seriously impacted by the heavy emissions of AOWs [4]. China is a large agricultural country with abundant sources of crop straws [22]. At present, more than 700 million tons of crop straws is produced every year. However, the crop straws have not been utilized comprehensively. Many of them are disposed of in environmentally unfriendly ways, such as random littering and incineration [23].

Meanwhile, the boom of China's animal husbandry has brought lots of LP manures, creating a major source of pollution. Each year, the LP industry produces 2.43×10^8t of manures. Without being decomposed, these manures are directly applied to farmland, which not only harm crops, but also pollute surface water and groundwater. The severity and scope of environmental pollution that ensures far exceed those of industrial pollution and urban sprawl [24].

There are about 4,100 organic fertilizer manufacturers in China, producing about 50 million tons of compost each year. However, the production merely consumes 2.6% of the annual generation of AOWs (http://www.cnfert.com/). Against this backdrop, it is of great significance to recycle AOWs such as crop straws and LP manures [25]. The recycling can efficiently convert materials and circulate energy in the agricultural production system, and promote environment protection and circular agriculture [26].

The early research has greatly contributed to the recycling of AOWs. This paper holds that the success of the recycling strategy for AOWs hinges on the effective utilization of the recycled materials. It is also important to mine the demand for the materials recycled from AOWs, and grasp the possibility of their supply.

This paper mainly discusses the demand-supply balance of the nitrogen nutrients converted from regional AOWs for agricultural utilization. Firstly, the calculation formulas were derived for the supply of nitrogen nutrients converted from regional AOWs, and the demand for nitrogen nutrients of agricultural planting. Next, the said demand-supply balance was modeled for analysis. Finally, an empirical analysis was conducted on Shangshui County in central China's Henan Province. The research findings lay a scientific basis for the recycling of AOWs in the region.

2. METHODOLOGY

This paper mainly studies the demand-supply balance in the nitrogen nutrients converted from AOWs in 9 towns, 11 townships, 1 farm, and 3 subdistrict offices of Shangshui County, namely, Huangzhai Town, Lianji Town, Weiji Town, Guqiang Town, Baisi Town, Bacun Town, Tanzhuang Town, Dengcheng Town, Huji Town, Chengguan Township, Pingdian Township, Yuanlao Township, Huahe Township, Yaoji Township, Shuzhuang Township, Dawu Township, Zhangming Township, Haogang Township, Zhangzhuang Township, Tangzhuang Township, Shangshui County Farm, Xincheng Subdistrict Office, Laocheng Subdistrict Office, and Dongcheng Subdistrict Office.

The amounts of nitrogen nutrients converted from crop straws and LP manures were calculated for each region. Considering the soil properties of the study area, the demand for nitrogen nutrients of agricultural soil in each region. Based on these calculation results, the demand-supply balance of nitrogen nutrients was analyzed quantitatively, providing a scientific reference of the recycling of AOWs in the study area.

3. CALCULATION OF DEMAND AND SUPPLY

3.1 Demand calculation

The demand for nitrogen nutrients P_{ij} in each region was calculated by multiplying the planting area of each crop S_{ij} with the reference demand for nitrogen nutrients D_j of each crop:

$$P_{ij} = S_{ij} \times D_j \tag{1}$$

where, P_{ij} is the demand for nitrogen nutrients (kiloton/year); S_{ij} is the planting area of each crop (thousand hectares/year); D_j is the reference demand for nitrogen nutrients of each crop (kiloton/ thousand hectares); j is the serial number of crops; i is the serial number of regions in the study area.

The planting area of each crop was obtained from relevant statistical yearbooks [27]. The reference demand for nitrogen nutrients of each crop was extracted from related literature [28] (Table 1).

Table 1. The reference demand for nitrogen nutrients of each crop (kiloton/ thousand hectares)

Crop	Wheat	Corn	Beans	Sweet potato	Peanut	Sesame	Sugar cane	Fruits and melons	Vegetables
Reference demand	0.074	0.113	0.015	0.20	0.15	0.15	0.12	0.22	0.25

Table 2. The demand for nitrogen nutrients of each crop in each region of the study area in 2017 (kiloton)

Crop	Wheat	Corn	Beans	Sweet potato	Peanut
Xincheng Subdistrict Office	0.0143	0.0147	0.0009	0.0100	0.0009
Dongcheng Subdistrict Office	0.0531	0.0811	0.0000	0.0000	0.0000
Laocheng Subdistrict Office	0.0484	0.0781	0.0000	0.0000	0.0000
Huangzhai Town	0.2909	0.4130	0.0053	0.0130	0.0030
Lianji Town	0.1628	0.4139	0.0000	0.0000	0.0000
Weiji Town	0.2871	0.1765	0.0212	0.0220	0.0000
Guqiang Town	0.4113	0.5138	0.0078	0.0182	0.0123
Baisi Town	0.2355	0.2406	0.0232	0.0528	0.1212
Bacun Town	0.3108	0.4896	0.0018	0.0146	0.0090
Tanzhuang Town	0.3929	0.4462	0.0075	0.0378	0.0327
Dengcheng Town	0.3053	0.2921	0.0138	0.0381	0.0882
Huji Town	0.2658	0.1718	0.0161	0.0270	0.0419
Chengguan Township	0.1334	0.0953	0.0088	0.0458	0.0350
Pingdian Township	0.2594	0.3013	0.0100	0.0568	0.0152
Yuanlao Township	0.2580	0.1099	0.0209	0.1000	0.0240
Huahe Township	0.2302	0.1526	0.0116	0.0282	0.0254
Yaoji Township	5.5127	5.0161	0.4470	0.0000	0.0465
Shuzhuang Township	0.2915	0.3597	0.0046	0.0112	0.0542
Dawu Township	0.2913	0.4449	0.0000	0.0000	0.0000
Zhangming Township	0.3042	0.3894	0.0003	0.0186	0.0858
Haogang Township	0.2466	0.2410	0.0000	0.0666	0.0600
Zhangzhuang Township	0.3898	0.5258	0.0007	0.0026	0.0027
Tangzhuang Township	0.2351	0.1935	0.0175	0.0150	0.0120
Shangshui County Farm	0.0730	0.0662	0.0042	0.0001	0.0001
Total	11.0035	11.2270	0.6232	0.5784	0.6698

Crop	Sesame	Sugar cane	Fruits and melons	Vegetables	Sum
Xincheng Subdistrict Office	0.0000	0.0000	0.0004	0.0085	0.0498
Dongcheng Subdistrict Office	0.0000	0.0000	0.0000	0.1580	0.2923
Laocheng Subdistrict Office	0.0000	0.0000	0.0176	0.1445	0.2886
Huangzhai Town	0.0033	0.0000	0.0133	0.0931	0.8349
Lianji Town	0.0000	0.0000	0.0000	0.1248	0.7015
Weiji Town	0.0926	0.0000	0.0015	0.0759	0.6768
Guqiang Town	0.0171	0.0000	0.0009	0.0568	1.0382
Baisi Town	0.1212	0.0000	0.0103	4.4285	5.2334
Bacun Town	0.0000	0.0000	0.1100	0.2488	1.1846
Tanzhuang Town	0.0779	0.0000	0.0781	1.8785	2.9517
Dengcheng Town	0.0065	0.0000	0.0108	0.1165	0.8712
Huji Town	0.0578	0.0000	0.0171	0.0954	0.6928
Chengguan Township	0.0269	0.0264	0.0125	0.2925	0.6765
Pingdian Township	0.0600	0.0000	0.0505	0.2661	1.0191
Yuanlao Township	0.0554	0.0000	0.0090	0.0400	0.6173
Huahe Township	0.0066	0.0128	0.0128	0.0458	0.5258
Yaoji Township	0.0000	0.0000	0.0310	0.2960	11.3493
Shuzhuang Township	0.0000	0.0000	0.0671	0.0359	0.8242
Dawu Township	0.0000	0.0000	0.0103	0.2288	0.9753
Zhangming Township	0.0000	0.0000	0.0231	0.0330	0.8544
Haogang Township	0.0000	0.0000	0.0059	0.1863	0.8065
Zhangzhuang Township	0.0008	0.0000	0.1791	0.9483	2.0496
Tangzhuang Township	0.0047	0.0000	0.0075	0.0175	0.5027
Shangshui County Farm	0.0002	0.0000	0.0000	0.0000	0.1437
Total	0.5307	0.0392	0.6689	9.8192	35.1599

Among the regions, Yaoji Township raised the largest demand for nitrogen nutrients: 11.35 kilotons (32.28%), owing to the large planting area of crops. Meanwhile, Xincheng Subdistrict Office had the least demand: 0.05 kiloton (0.14%), due to the small planting area of crops in the residential areas.

According to the data in Table 1 and the planting area of each crop, the demand for nitrogen nutrients of each crop in each region of the study area was obtained by formula (1). As shown in Table 2, The total demand for nitrogen nutrients of crops in the study area was 35.16 kilotons. Wheat, corn, and vegetables had the highest demands: 11.00 kilotons (31.29%), 11.23 kilotons (31.94%), and 9.82 kilotons (27.93%), respectively. This is mainly attributable to the large planting area of wheat and corn, and the high reference demand for nitrogen nutrients of vegetables. By contrast, sugar cane had the least demand of 0.04 kiloton (0.11%), mainly because of the small planting area.

3.2 Supply calculation

3.2.1 Nitrogen nutrients content of crops

The nitrogen nutrients content of each crop was calculated in two steps. First, the straw amount W_{ij} of each crop was calculated by multiplying the crop yield H_{ij} with the grain-to-straw ratio R_{ij} of that crop:

$$W_{ij} = \sum \left(H_{ij} \times R_{ij} \right) \quad (2)$$

where, W_{ij} is the straw amount of each crop (kiloton); H_{ij} is the crop yield (kiloton); R_{ij} is the grain-to-straw ratio of each crop; j is the serial number of AOWs; i is the serial number of regions in the study area.

Next, the nitrogen nutrients content C_{ij} of each crop was calculated by multiplying the straw amount W_{ij} of the crop with the percentage of nitrogen in crop straw N_{ij}:

$$C_{ij} = W_{ij} \times N_{ij} \quad (3)$$

where, C_{ij} is the nitrogen nutrients content of each crop (kiloton); W_{ij} is the straw amount of each crop (kiloton); N_{ij} is the percentage of nitrogen in crop straw of each crop; j is the serial number of AOWs; i is the serial number of regions in the study area.

The yield of each crop was obtained from relevant statistical yearbooks [27]. The grain-to-straw ratio and percentage of nitrogen in crop straw of each crop were extracted from related literature [28, 29] (Table 3).

According to the data in Table 3 and data from the statistical yearbooks, the total amount of nitrogen nutrients converted from crop straws in the study area was obtained by formulas (2) and (3) as 12.41 kilotons in 2017. Wheat and corn contributed 85.31% of the total amount. Among the various regions, Guqiang Town produced the largest amount of nitrogen nutrients: 0.92 kiloton (7.41%).

3.2.2 Nitrogen nutrients content of LP manures

The nitrogen nutrients content of each LP manure was also calculated in two steps. First, the amount of each LP manure F_{ij} was calculated by multiplying the number of each LP Y_{ij} with the daily excretion coefficient E_{ij} of the LP, and the feeding period T_{ij} of that LP:

$$F_{ij} = \Sigma \left(Y_{ij} \times E_{ij} \times T_{ij} \right) \quad (4)$$

where, F_{ij} is the amount of each LP manure (kiloton); Y_{ij} is the number of each LP (each); E_{ij} is the daily excretion coefficient of each LP; T_{ij} is the feeding period of each LP; j is the serial number of the LPs; i is the serial number of regions in the study area.

Next, the nitrogen nutrients content B_{ij} of each LP manure was calculated by multiplying the amount of each LP manure F_{ij} with the percentage of nitrogen in that LP manure:

$$B_{ij} = F_{ij} \times M_{ij} \quad (5)$$

where, B_{ij} is the nitrogen nutrients content of each LP manure (kiloton); F_{ij} is the amount of each LP manure (kiloton); M_{ij} is the percentage of nitrogen in each LP manure; j is the serial number of the LPs; i is the serial number of regions in the study area.

The number of each LP was obtained from relevant statistical yearbooks [27]. The daily excretion coefficient of each LP and percentage of nitrogen in each LP manure were extracted from related literature [28, 29] (Table 4).

According to the data in Table 4 and data from the statistical yearbooks, the total amount of nitrogen nutrients converted from LP manures in the study area was obtained by formulas (4) and (5) as 13.45 kilotons. Among them, pig manures contributed the greatest portion of nitrogen nutrients: 30.71% (4.13 kilotons).

Table 3. The grain-to-straw ratio and percentage of nitrogen in crop straw of each crop

Crop	Wheat	Corn	Beans	Sweet potato	Peanut	Sesame
Grain-to-straw ratio	1.2	1.34	1.60	0.5	0.8	0.17
Percentage of nitrogen	0.65	0.92	1.81	2.37	1.82	1.31

Table 4. The daily excretion coefficient of each LP and percentage of nitrogen in each LP manure

LP type	Breeder pig	Market pig	Beef cattle	Dairy cow	Sheep	Rabbit	Poultry	Total
Daily excretion coefficient (kg/each)	3.30	2.10	18.00	45.50	2.10	0.16	0.13	71.29
Percentage of nitrogen	0.55	0.55	0.38	0.38	1.01	0.87	1.03	4.77

3.2.3 Supply of nitrogen nutrients

The supply of nitrogen nutrients Q_{ij} in each region was calculated by adding up the nitrogen nutrients content C_{ij} of every crop straw and that B_{ij} of every LP manure:

$$Q_{ij} = C_{ij} + B_{ij} \quad (6)$$

where, Q_{ij} is the supply of nitrogen nutrients in each region (kiloton); C_{ij} is the nitrogen nutrients content of each crop straw (kiloton); B_{ij} is the nitrogen nutrients content of each LP manure (kiloton); j is the serial number of AOWs; i is the serial number of regions in the study area.

By formula (6), the supply of nitrogen nutrients converted from AOWs in each region of the study area was obtained (Table 5). It can be seen that the total supply of nitrogen nutrients converted from AOWs stood at 25.86 kilotons, including 12.41 kilotons from crop straws (47.99%) and 13.45 kilotons (52.01%) from LP manures. The amounts of nitrogen nutrients from the two sources were similar in scale.

Table 5. The supply of nitrogen nutrients converted from AOWs in each region of the study area in 2017 (kiloton)

	Nitrogen nutrients from crop straws	Nitrogen nutrients from LP manures	Total supply of nitrogen nutrients
Xincheng Subdistrict Office	0.0657	0.0732	0.1389
Dongcheng Subdistrict Office	0.1344	0.1072	0.2416
Laocheng Subdistrict Office	0.1003	0.0741	0.1744
Huangzhai Town	0.6702	0.6392	1.3094
Lianji Town	0.0389	0.6829	0.7218
Weiji Town	0.5918	0.7326	1.3244
Guqiang Town	0.9171	1.2148	2.1319
Baisi Town	0.7363	0.6420	1.3783
Bacun Town	0.7373	0.6549	1.3923
Tanzhuang Town	0.8158	0.8482	1.6640
Dengcheng Town	0.7043	0.5885	1.2929
Huji Town	0.5378	0.6136	1.1514
Chengguan Township	0.2903	0.5987	0.8890
Pingdian Township	0.6022	0.6136	1.2158
Yuanlao Township	0.4918	0.5804	1.0722
Huahe Township	0.4235	0.5109	0.9345
Yaoji Township	0.6271	0.5752	1.2023
Shuzhuang Township	0.6686	0.7636	1.4322
Dawu Township	0.6538	0.6892	1.3430
Zhangming Township	0.7472	0.4860	1.2332
Haogang Township	0.4270	0.5149	0.9419
Zhangzhuang Township	0.7461	0.6808	1.4269
Tangzhuang Township	0.5094	0.5103	1.0198
Shangshui County Farm	0.1742	0.0565	0.2307
Total	12.4112	13.4513	25.8626

4. DEMAND-SUPPLY BALANCE ANALYSIS

Table 6 and Figure 1 illustrate the demand-supply ratio (amount of demand/supply quantity) of nitrogen nutrients converted from AOWs in each region of the study area in 2017.

As shown in Table 6 and Figure 1, in 2017, the total amount of nitrogen nutrients converted from AOWs in the study area reached 25.86 kilotons, while the total demand for nitrogen nutrients in the study area was 35.16 kilotons. Thus, the supply-demand ratio of nitrogen nutrients was 1.36. This means the supply falls short of demand. The short supply is the results of the large area of agricultural planting in the study area, which requires lots of nitrogen nutrients, and the relatively insufficient supply of nitrogen nutrients from AOWs.

In addition, the demand-supply ratios of Yaoji Township, Tanzhuang Town, Laocheng Subdistrict Office, Zhangzhuang Town, and Dongcheng Subdistrict Office were 9.44, 1.77, 1.65, 1.44, and 1.21, respectively. The greater-than-1.0 ratios indicate that the planting industry is highly developed in these regions. The demand-supply ratios in all the other regions were below 1.0. The lowest ratios were observed in Xincheng Subdistrict Office (0.36), Tangzhuang Township (0.49), and Guqiang Town (0.49). This is attributable to their close proximity to the downtown, limited area of farmlands, and mature LP breeding.

Table 6. The demand-supply ratio of nitrogen nutrients converted from AOWs in each region of the study area in 2017 (kiloton)

	Supply of nitrogen nutrients	Demand of nitrogen nutrients	Demand-supply ratio
Xincheng Subdistrict Office	0.0498	0.1389	0.36
Dongcheng Subdistrict Office	0.2923	0.2416	1.21
Laocheng Subdistrict Office	0.2886	0.1744	1.65
Huangzhai Town	0.8349	1.3094	0.64
Lianji Town	0.7015	0.7218	0.97
Weiji Town	0.6768	1.3244	0.51
Guqiang Town	1.0382	2.1319	0.49
Baisi Town	5.2334	1.3783	3.80
Bacun Town	1.1846	1.3923	0.85
Tanzhuang Town	2.9517	1.6640	1.77
Dengcheng Town	0.8712	1.2929	0.67
Huji Town	0.6928	1.1514	0.60
Chengguan Township	0.6765	0.8890	0.76
Pingdian Township	1.0191	1.2158	0.84
Yuanlao Township	0.6173	1.0722	0.58
Huahe Township	0.5258	0.9345	0.56
Yaoji Township	11.3493	1.2023	9.44
Shuzhuang Township	0.8242	1.4322	0.58
Dawu Township	0.9753	1.3430	0.73
Zhangming Township	0.8544	1.2332	0.69
Haogang Township	0.8065	0.9419	0.86
Zhangzhuang Township	2.0496	1.4269	1.44
Tangzhuang Township	0.5027	1.0198	0.49
Shangshui County Farm	0.1437	0.2307	0.62
Total	35.1599	25.8626	1.36

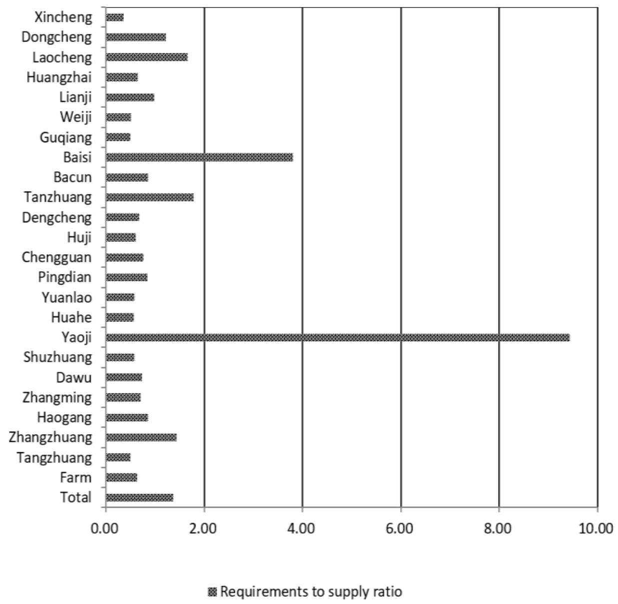

Figure 1. The demand-supply ratio of nitrogen nutrients converted from AOWs in each region of the study area in 2017 (kiloton)

5. CONCLUSIONS

Through literature query and field survey, this paper analyzes the demand-supply balance in the nitrogen nutrients converted from AOWs in 9 towns, 11 townships, 1 farm, and 3 subdistrict offices of Shangshui County. Firstly, the demand for nitrogen nutrients was derived from the planting area, and reference demand for nitrogen nutrients of each crop in the study area. Then, the supply of nitrogen nutrients of each crop was calculated based on its straw amount and grain-to-straw ratio; the supply of nitrogen nutrients of each LP manure was computed based on the number of each LP, as well as the daily excretion coefficient, and nitrogen nutrients content of each LP manure.

Through the calculations, the total demand for nitrogen nutrients in 2017 of the study area was 35.16 kiloton, while the total supply of nitrogen nutrients converted from AOWs stood at 25.86kiloton, including 12.41 kilotons from crop straws (47.99%) and 13.45 kilotons (52.01%) from LP manures. The demand-supply ratio (amount of demand/supply quantity) was 1.36, indicating that the AOWs (crop straws, and LP matures) in the study area cannot fully satisfy the demand for nitrogen nutrients in the region.

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