Original Research

Demand-Supply Balance Analysis of Agricultural Organic Waste Recycling in Northern Henan Province, China

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Abstract

For more efficient utilization of agricultural organic waste composts, this research formulates the demand of agricultural organic waste composts and the supply of compost converted from agricultural organic waste in the region, and models the demand-supply balance of agricultural organic waste compost in some regions. Objects of study include 6 urban districts, 5 county-level cities, and 21 counties in northern Henan Province, China. The crops' latent demand for compost and the latent supply of compost converted from agricultural organic wastes (straw and livestock manure) in each region is computed for an analysis of demand-supply balance. According to the findings, there is a large deviation in both the ratio of the supply of livestock manure composts to that of straw composts and the demand-supply ratio of composts in the studied regions. To be specific, the overall demand-supply ratio in the studied regions is about 1.21, showing that demand is greater than supply. Theoretically, all agricultural organic wastes can be used for agricultural production in these regions. In addition, actual demand ratio (actual demand/latent demand) is found in the utilization of composts. Supposing the actual demand ratio is 50%, research again analyzes the demand-supply balance, revealing that all livestock manure composts can be utilized, but that straw compost is surplus in large amounts in the studied regions.

Introduction

In recent years, attention has been paid to the development of circular agriculture. An important countermeasure for the development of circular agriculture is to recover the land of agricultural organic wastes [1-3]. Efficient utilization of agricultural organic wastes is constantly stressed, but they are not so efficiently utilized in many areas [4]. Henan Province's annual output of agricultural organic wastes includes straw and livestock manure coming first throughout China [5-6]. For example, its annual output of various livestock manures is more than 130 million tons, approx. 31 million tons after being dried; and there are more than 130 registered compost production enterprises in the whole province and their annual production capacity is approx. 1.8 million tons, but safely fermented manure is no more than 500,000 tons [7]. Based on the
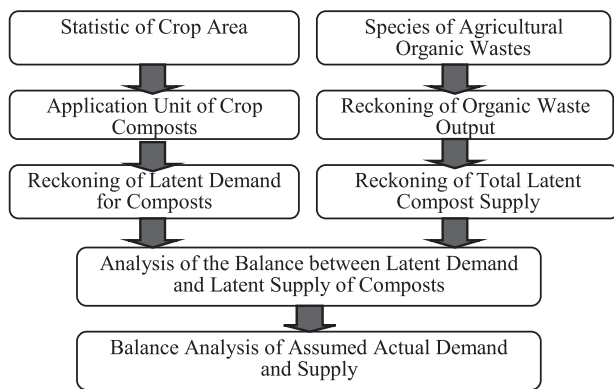
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Fig. 1. Analysis process of the demand-supply balance of agricultural organic waste.

above data, it can be reckoned that these enterprises' production capacity accounts for 6% of total occurrence quantity, and their actual production output is about 1.6% of total occurrence quantity. However, the rate of livestock manure has reached 97% in Japan as computed by the Ministry of the Environment (the state of garbage classification, occurrence, and disposal in Japan) [8-9]. For the past few years, China has reached a world-class level in terms of research on composting technology and agricultural organic waste pollution treatment [10-12]. Now that the application of agricultural organic waste composts requires a large amount of labor and is affected by movement limit and regional coverage [13], a probability analysis of the demand and supply of agricultural organic waste composts in some regions is a scientific means to enhance their efficient utilization [14]. Nevertheless, there is no research in a region wider than Henan Province. For this reason, it is of great importance to analyze the demand-supply balance of agricultural organic waste composts and to study countermeasures for their utilization.

This research takes regions to the north of the Yellow River in Henan Province (hereinafter referred to as northern Henan Province) as objects of study and assumes that agricultural organic wastes including straws and livestock manures in these regions are utilized. These regions are chosen for the following reasons:

– Regional limitations in the recycling application of agricultural organic waste compost; the studied regions are separated by the Yellow River from other regions in Henan Province, so they have better intra-regional movement efficiency of agricultural organic waste composts.

– Agricultural organic wastes in these regions, as resources like those in other regions of Henan Province, are not fully utilized; besides, related research on the demand-supply balance of agricultural organic waste composts in the studied regions is lacking.

– The studied regions, developed in planting and breeding industries, have sufficient demand and supply of agricultural organic waste compost.

Material and Methods

Study Area

Northern Henan Province has about 20.3723 million citizens (19.11% of Henan Province's total population) and a cultivated area of approx. 18,600 km^2, or 22.71% of Henan Province's total cultivated area. Enjoying a warm temperate continental monsoon climate and an average temperature of 13-14.5ºC, the area has four distinctive seasons: dry spring, hot summer, cool autumn, and cold winter. Its abundant rain, fertile soil, and rich light and heat are suitable for the growth of crops and the development of the livestock industry [15]. Main livestock in northern Henan Province includes cattle, sheep, pigs and fowl, and main crops are wheat and corn. Moreover, this area has high-level output and planting technology of soybean, cotton, peanut, rapeseed, and sesame [16].

The studied regions include urban districts (a generic term of districts in a prefecture-level city), counties, and county-level cities in six prefecture-level cities such as Xinxiang City, Jiaozuo City, Jiyuan City, Anyang City, Hebi City, and Puyang City. Jiyuan City covers a small area without county-level city and county in its administrative division, so this region is studied as a whole. The studied regions consists of 6 urban districts, 5 county-level cities, and 21 counties. In this paper, crops' theoretical maximum demand for composts (hereinafter referred to as latent demand), and the occurrence quantity of agricultural organic wastes including straws and livestock manures and theoretical maximum supply of converted composts (hereinafter referred to as supply) are reckoned respectively. A quantitative analysis of the demand-supply demand of agricultural organic waste composts and their utilization probability in the studied regions is made to provide a scientific basis for the effective utilization of agricultural organic wastes in these regions. The specific research process is shown in Fig. 1.

Table 1. Original fertilization unit of crops (wet basis; t/ha).

Crop species	Summer crops	Autumn CROPS	Oil crops	Fruit trees	Vegetables	Cotton	Chinese herbs	Others
Application Unit	10	10	15	20	20	15	20	20

Table 2. The latent demand for composts in the studied regions (wet basis) (10,000 t/year).

Jiyuan city		Xinxiang City		Jiaozuo City		Anyang City		Puyang City		Hebi City	
Region	Latent demand	Region	Latent demand	Region	Latent demand	Region	Latent demand	Region	Latent demand	Region	Latent demand
Jiyuan city	155.39	Xinxiang City	1541.95	Jiaozuo City	393.42	Anyang City	861.85	Puyang City	593.58	Hebi City	211.19
Qinyuan subdistrict	0.45	Hongqi district	14.08	Jiefang district	0.56	Wenfeng district	9.35	Puyang county	194.80	Qibin	20.13
Beihai subdistrict	0.49	Weibin district	8.30	Zhongzhan district	3.63	Beiguan district	6.40	Qingfeng county	143.98	Shancheng district	10.52
Tiantan subdistrict	1.32	Fengquan district	19.74	Macun district	8.77	Yindu district	5.23	Nanle county	97.92	Heshan district	7.75
Yuquan subdistrict	4.18	Kafa district	7.98	Shanyang district	1.58	Longan district	17.01	Fan county	63.53	Kaifa district	2.59
Kejing town	14.67	Muye district	15.59	Gaoxin district	3.09	Anyang county	137.86	Taiqian county	40.21	Qi county	45.46
Wulongkou town	11.77	Xinxiang county	84.40	Xiuwu county	41.60	Tangyin county	94.68	Hualong district	13.41	Xun county	124.75
Zhicheng town	44.23	Huojia county	109.02	Boai county	52.88	Hua county	311.54	Kaifa district	39.73		
Chengliu town	10.80	Yuanyang county	263.79	Wuzhi county	96.03	Neihuang county	186.15				
Shaoyuan town	16.88	Yanjin county	194.96	Wen county	57.01	Linzhou city	93.63				
Potou town	3.39	Fengqiu county	240.98	Qinyang city	68.94						
Lilin town	12.64	Changyuan county	238.73	Mengzhou city	59.33						
Dayu town	7.38	Weihui city	130.40								
Sili town	3.64	Huixian city	214.13								
Wangwu town	12.37										
Xiaye town	11.18										

Methods

Reckoning of Talent Compost Demand

Crops' latent demand for composts is calculated on the basis of the cultivated area of crops and the application standards (hereinafter referred to as original fertilization unit) of crop composts. This research uses Formula (1) to calculate the latent demand for composts in the studied regions:

$$D_i = A_i B_n \qquad (1)$$

...where:
D_i: latent demand for composts (t/year)
A: cultivated area of crops (ha)
B: original fertilization unit of crops (t/ha)
n: crops
i: regions

The cultivated area of various crops A in the studied regions is obtained from The Statistical Yearbook of Henan Province [17]. Different crops have different demand for composts (see literature data [18] for the original fertilization unit of crops B, as shown in Table 1.). According to Formula (1), the original fertilization unit, and the cultivated area of crops, the latent demand for composts in the studies regions is calculated, with results shown in Table 2. The annual latent demand for composts in the studied regions is approx. 37.57 million tons. Since Jiyuan City has the smallest crop area among the six prefecture-level cities, it has the lowest annual latent demand for compost, at approx. 1.5539 tons. Xinxiang City has the highest latent demand for compost through the whole year, at approx. 15.4195 million tons, accounting for 40% of northern Henan Province's total demands. Due to its biggest latent demand for compost, Xinxiang is the center of demand for compost in northern Henan Province.

Reckoning of Latent Supply of Livestock Manure Compost

The number of various livestock in each region T_{ij} multiplies by the daily occurrence quantity of various livestock manures S_j (hereinafter referred as original unit) and then multiplies by the raising days in a year to get the annual occurrence quantity of various fresh livestock manures. Now that fresh manures need to be made into composts in accordance with national standards by fermenting and drying, the weight will be reduced after fresh manure is converted into compost. This paper defines the ratio of the weight of composts to the weight of fresh manures as composting rate. Different livestock's fresh manures have different water content, so the composting rate of different livestock manures differs. The annual occurrence quantity of various fresh livestock manures multiplies by the composting rate of various livestock manures E_j to get the latent supply of livestock manure composts in the studied regions H_{ij} (Formula (2)):

$$H_{ij} = (T_{ij} S_j 365) E_j \qquad (2)$$

...where:
H_{ij}: the latent supply of livestock manure compost (t/year)
T_{ij}: the number of livestock in the studied regions
S_j: the original occurrence unit of various livestock manures (kg/day)
E_j: the composting rate of livestock manure
j: livestock
i: regions

The number of various livestock in the studied regions is obtained from The Statistical Yearbook of Henan Province [17] (see literature data for the original occurrence unit of different livestock manures [19] and calculate the composting rate of various livestock

Table 3. Original occurrence unit and the composting rate of livestock manure.

Livestock Species	Dairy Cattle	Beef Cattle	Horse, Donkey and Mule	Pig	Sheep	Rabbit	Chicken
Original Occurrence (kg/day)	45	20	14	3	1.7	0.15	0.14
Composting Rate (%)	40	40	40	40	60	60	60
Livestock Species	Dairy Cattle	Beef Cattle	Horse, Donkey and Mule	Pig	Sheep	Rabbit	Chicken
Original Occurrence (kg/day)	45	20	14	3	1.7	0.15	0.14
Composting Rate (%)	40	40	40	40	60	60	60
Livestock Species	Dairy Cattle	Beef Cattle	Horse, Donkey and Mule	Pig	Sheep	Rabbit	Chicken
Original Occurrence (kg/day)	45	20	14	3	1.7	0.15	0.14
Composting Rate (%)	40	40	40	40	60	60	60

*Composting rate: the rate of converting fresh livestock manures into compost (the weight of livestock manure compost/the weight of fresh livestock manure)*100%

Table 4. Annual latent supply of livestock manure compost in the studied regions of northern Henan Province (wet basis; 10,000 tons/year).

Jiyuan city		Xinxiang City		Jiaozuo City		Anyang City		Puyang City		Hebi City	
Region	Latent supply	Region	Latent supply	Region	Latent supply	Region	Latent supply	Region	Latent supply	Region	Latent supply
Jiyuan city	69.18	Xinxiang City	356.39	Jiaozuo City	212.74	Anyang City	310.05	Puyang City	256.83	Hebi City	204.09
Qinyuan subdistrict	0.26	Hongqi district	1.40	Jiefang district	0.86	Wenfeng district	0.78	Puyang county	56.17	Qibin	19.28
Beihai subdistrict	0.71	Weibin district	1.76	Zhongzhan district	1.50	Beiguan district	0.95	Qingfeng county	41.71	Shancheng district	11.93
Tiantan subdistrict	0.30	Fengquan district	2.69	Macun district	1.90	Yindu district	0.38	Nanle county	85.13	Heshan district	14.12
Yuquan subdistrict	2.27	Kafa district	1.01	Shanyang district	1.46	Longan district	2.99	Fan county	38.81	Kaifa district	0.68
Kejing town	10.26	Muye district	2.72	Gaoxin district	1.17	Anyang county	47.01	Taiqian county	22.49	Qi county	91.50
Wulongkou town	3.48	Xinxiang county	24.53	Xiuwu county	33.52	Tangyin county	34.61	Hualong district	6.53	Xun county	66.58
Zhicheng town	12.14	Huojia county	25.47	Boai county	28.81	Hua county	95.24	Kaifa district	6.00		
Chengliu town	6.96	Yuanyang county	53.84	Wuzhi county	64.75	Neihuang county	49.47				
Shaoyuan town	4.73	Yanjin county	29.22	Wen county	26.14	Linzhou city	78.63				
Potou town	4.43	Fengqiu county	48.00	Qinyang city	29.56						
Lilin town	8.28	Changyuan county	38.81	Mengzhou city	23.07						
Dayu town	3.28	Weihui city	70.82								
Sili town	2.80	Huixian city	58.84								
Wangwu town	4.64										
Xiaye town	4.64										

Table 5. Occurrence coefficient of crop straws.

Occurrence Coefficient of Crop Straw	Unit	Barley, Wheat	Rice	Corn	Bean	Oil	Cotton
	t/t	1.0	1.0	1.5	3.0	2.0	4.0

manure based on literature data [4].). Table 3 shows the original occurrence unit and the composting rate of various livestock manures.

The annual latent supply of livestock manure composts in the studied regions of northern Henan Province is calculated according to Formula (2), the number of various livestock, the original occurrence unit of fresh manure, and the composting rate, with results shown in Table 4. The annual latent supply of livestock manure composts in the studied regions is approx. 14.08 million tons. The sum of Xinxiang City and Anyang City is 6.69 million tons, about 48% of the total quantity in northern Henan Province, implying sufficient raw materials of livestock manure compost in the two regions.

Reckoning of Latent Supply of Crop Straw Composts

The latent supply of crop straw composts is calculated according to Formula (3). During the harvest season of crops, straws are basically dry and their water content meets the standard of compost, so they can fully work as compost. The harvest yield of various crops U_{ij} multiplies by the occurrence coefficient of various crop straws V_j (the occurrence quantity of straws/the harvest yield of crops) to get the latent supply of various crop straw composts P_{ij}:

$$P_{ij} = U_{ij} V_j \qquad (3)$$

...where:
P_{ij}: latent supply of straw compost (t/year)
U_{ij}: harvest yield of crops (t/year)
V_j: occurrence coefficient of various straws
j: crops
i: regions

The harvest yield of various crops in the studied regions is obtained from The Statistical Yearbook

of Henan Province [17]. The occurrence coefficient of different crop straws is calculated on the basis of literature data [20] (Table 5).

The annual latent supply of straw composts in the studied regions is calculated according to Formula (3), the harvest yield of various crops and the occurrence coefficient of different crop straws, with results shown in Table 6. The annual latent supply of straw compost in the studied regions is approx. 16.91 million tons. Xinxiang and Anyang's annual latent supply of straw compost totals 8.99 million tons, or about 53% of the all supplies in northern Henan Province, revealing that the two regions have sufficient raw materials of straw compost.

Results and Discussion

Analysis of Latent Demand-Supply Balance

In the studied regions of northern Henan Province, the overall latent demand of agricultural organic waste compost is approx. 37.5738 million tons a year and the latent supply of compost is about 31.0007 million tons a year. Fig. 2 shows the demand-supply ratio (demand/supply) of compost in this area. If the ratio is above 1.0, it indicates more latent demand than latent supply. According to the data above, it can be reckoned that the overall compost demand-supply ratio in northern Henan Province is 1.21. Theoretically, if there is more demand than supply, agricultural organic wastes can be fully used for agricultural production in this area. Among the studied regions, Xinxiang City, with a developed planting industry, has a demand-supply ratio of above 1.0 in all regions and the highest overall average demand-supply ratio in northern Henan Province, at approx. 1.83. Xun County, Hebi City, with the smallest planting area, has the lowest demand-supply ratio of 0.35. The ratio in all studied regions of Hebi is above 1.0 and the overall demand-supply ratio is about 0.59, at the lowest level among the six prefecture-level cities. The research reveals a big deviation in the demand-supply ratio of composts in the studied regions of northern Henan Province.

Fig. 3 lists the ratio of the latent demand of compost to the latent supply of agricultural organic waste composts in the studied regions. Regarding large-size livestock, cattle contribute 12% manure compost, and horses, donkeys, and mules about 0.1%, totaling 12.1%. 11% of compost is from pig manure, 4.3% from sheep manure, and 18% from chicken (hereinafter referred to as fowl). The sum of composts from various livestock manures is about 45.4% of aggregate supply, and the
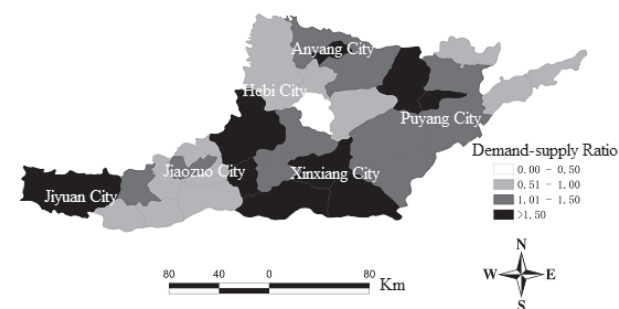

Fig. 2. Latent demand-supply ratio of agricultural organic waste compost in the studied regions of northern Henan Province.

Table 6. Annual latent supply of straw compost in the studies regions of northern Henan Province (10,000 tons/year).

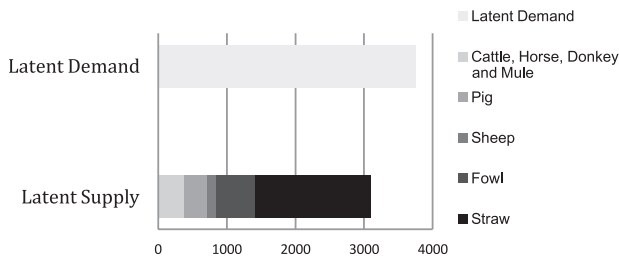| Jiyuan city		Xinxiang City		Jiaozuo City		Anyang City		Puyang City		Hebi City	
Region	Latent supply	Region	Latent supply	Region	Latent supply	Region	Latent supply	Region	Latent supply	Region	Latent supply
Jiyuan city	27.20	Xinxiang City	488.20	Jiaozuo City	271.85	Anyang City	410.41	Puyang City	342.05	Hebi City	151.24
Qinyuan subdistrict	0.32	Hongqi district	4.89	Jiefang district	0.37	Wenfeng district	3.60	Puyang county	116.07	Qibin	14.43
Beihai subdistrict	0.25	Weibin district	2.77	Zhongzhan district	1.21	Beiguan district	2.18	Qingfeng county	75.42	Shancheng district	2.81
Tiantan subdistrict	1.63	Fengquan district	36.02	Macun district	4.42	Yindu district	3.33	Nanle county	62.07	Heshan district	1.30
Yuquan subdistrict	1.52	Kafa district	2.45	Shanyang district	0.64	Longan district	6.61	Fan county	42.18	Kaifa district	2.22
Kejing town	3.46	Muye district	6.60	Gaoxin district	1.78	Anyang county	74.38	Taiqian county	24.45	Qi county	37.71
Wulongkou town	2.71	Xinxiang county	31.96	Xiuwu county	26.76	Tangyin county	49.20	Hualong district	7.50	Xun county	92.77
Zhicheng town	4.99	Huojia county	36.25	Boai county	26.76	Hua county	170.02	Kaifa district	14.36		
Chengliu town	2.35	Yuanyang county	84.72	Wuzhi county	100.57	Neihuang county	63.29				
Shaoyuan town	1.52	Yanjin county	58.72	Wen county	35.14	Linzhou city	37.81				
Potou town	1.20	Fengqiu county	72.77	Qinyang city	38.07						
Lilin town	3.28	Changyuan county	147.12	Mengzhou city	36.12						
Dayu town	1.11	Weihui city	42.68								
Sili town	1.26	Huixian city	65.84								
Wangwu town	0.81										
Xiaye town	0.79										

Fig. 3. Ratio of latent demand to latent supply of agricultural organic waste compost in northern Henan Province (10,000 tons/year).

Fig. 5. Demand-supply ratio when actual compost demand rate reaches 50% in the studied regions of northern Henan Province

compost from straws accounts for approx. 54.6%.

Fig. 4 shows the ratio of the latent supply of livestock manure compost to that of straw compost in the 6 prefecture-level cities of northern Henan Province. Among the 6 cities, Xinxiang has the largest latent supply of livestock manure and straw compost, and Jiyuan has the smallest. According to the ratio of the latent supply of livestock manure compost to that of straw compost, Jiyuan and Hebi have more livestock manure compost than straw compost. Developed feeding industry but small crop planting area are the reasons why Hebi's demand-supply ratio is only 0.59. Jiyuan has a demand-supply ratio of 1.61. Notwithstanding small crop planting area, its wide vegetable cultivation area contributes to a great demand for compost. The other four prefecture-level cities have less latent supply of livestock manure compost than that of straw compost. Findings show that there is also a big deviation in the ratio of latent supply of livestock manure compost to that of straw compost in the studied regions of northern Henan Province.

Analysis of Demand-Supply Balance when Actual Demand Rate Reaches 50%

The above-noted results reveal that the demand of agricultural organic waste compost falls short of supply in the studied regions of northern Henan Province. Nevertheless, the province's crops are fertilized with chemical fertilizers in actual fertilizer utilization of agricultural production. The average use intensity of

chemical fertilizer in the 6 prefecture-level cities of northern Henan Province is 1.9 times as much as China's average level, and 3 times developed countries' standard [18], severely exceeding the limit. In view of this, it is difficult to use compost for all crop production in the studied regions. Moreover, using compost of equal effect with chemical fertilizers requires several times and even dozens of times the labors and transportation costs compared with chemical fertilizer, which is another region why chemical fertilizers are increasingly used year by year in this area. Considering the actual demand rate in practical application of agricultural organic waste composts (actual demand/latent demand), this research assumes the actual demand rate to be 50% and then analyzes the demand-supply balance of composts in corresponding condition. The demand-supply ratio when the actual demand rate is 50% in the studied regions of northern Henan Province is shown in Fig. 5.

As shown in Fig. 5, among the 6 urban districts, 5 county-level cities and 21 countries in the studied regions, only Yanjin County, Xinxiang City has a demand-supply ratio of 1.11, 13 studied units have a demand-supply ratio of lower than 0.50, and it is between 0.51-1.00 in 18 studied units. The overall demand-supply ratio of compost in northern Henan Province is approx. 0.61, lower than 1.0 and revealing an oversupply of agricultural organic waste composts. When the actual demand rate reaches 50%, the ratio of the actual demand rate of composts to the supply of
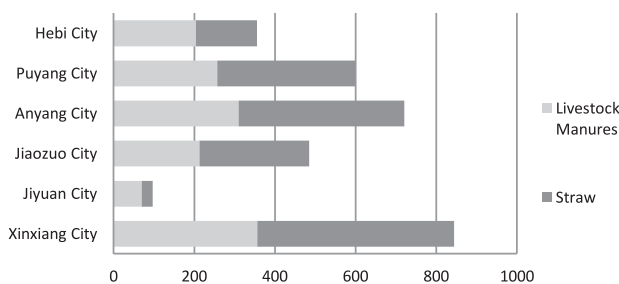

Fig. 4. Ratio of latent supply of livestock manure compost to that of straw compost in the 6 prefecture-level cities of northern Henan Province (10,000 tons/year).
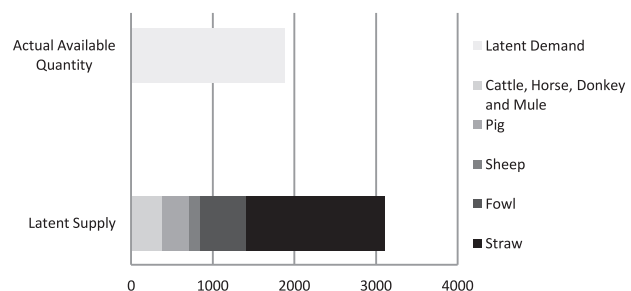

Fig. 6. Ratio of actual compost demand rate to latent supply of composts in northern Henan Province (10,000 tons/year).

agricultural organic waste compost in northern Henan Province is shown in Fig. 6.

As shown in Fig. 6, the annual demand of compost is approx. 18.78 million tons a year in northern Henan Province, and the annual supply of livestock manure compost totals 14.1 million tons a year, accounting for 75% of actual demand. Consideration is first given to livestock manure with high nutrient content and then to straws in case of insufficient livestock manure in practical application of agricultural organic waste composts. Therefore, when the actual demand rate reaches 50%, all livestock manure composts in this area can be utilized, but only a small amount of straw compost can be utilized, with 12.2295 million tons of surplus a year.

Conclusions

For more efficient utilization of agricultural organic waste compost, this research formulates the latent demand of agricultural organic waste compost and the latent supply of compost converted from agricultural organic waste in the region, and models the demand-supply balance of agricultural organic waste composts in some regions. The research assumes that agricultural organic wastes including livestock manure composts and straw composts are utilized in northern Henan Province. Objects of study include 6 urban districts, 5 county-level cities, and 21 counties of the 6 prefecture-level cities in this area. The crops' latent demand for composts and the latent supply of organic fertilizers converted from agricultural organic wastes are reckoned for a quantitative analysis of demand-supply balance, with results as follows.

1) The overall ratio of latent demand for agricultural organic waste compost to latent supply is approx. 1.21 in the studied regions of northern Henan Province, showing that demand is greater than supply. Theoretically, all agricultural organic waste can be used for agricultural production in these regions. However, there is a large deviation in the demand-supply ratio in the studied regions.

2) The sum of livestock manure compost is about 45.4% of latent supply in the studied regions of northern Henan Province, but there is a big deviation in the ratio of latent supply of livestock manure compost to that of straw compost in the six prefecture-level cities.

3) When the actual demand rate of compost is assumed to be 50% in the studied regions of northern Henan Province, the overall demand-supply ratio is approx. 0.61, revealing an oversupply of agricultural organic waste compost in this area. Nevertheless, all livestock manure compost can be used for agricultural production in the studied regions, but straw compost is surplus in a large amount.

Apart from providing a scientific basis for the utilization of agricultural organic waste compost in

the studied regions, this research also lays a solid foundation for the reduction of movement costs and the improvement of utilization efficiency in the future application of compost. As a research subject henceforth, an investigation on the expansion of limit movement area and the reduction of labor costs in the application of agricultural organic waste compost is essential for their efficient utilization.

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