SPATIAL DISTRIBUTION AND COMPREHENSIVE UTILIZATION POTENTIAL OF FOUR MAJOR STRAW TYPES AND LIVESTOCK MANURE IN SHAANXI PROVINCE, CHINA

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Abstract. To clarify the distribution and characteristics of major agricultural organic wastes in Shaanxi Province, China, and explore their utilization potential, this study quantified major agricultural organic waste resources and analyzed their spatial distribution and utilization potential by using 2022 data on crop yields and livestock populations in the province. The results showed that in 2022, Shaanxi's collectable straw from four crops totaled 10.61 million t. The theoretical livestock-carrying capacity was 6.24 million cattle units or 31.20 million sheep units. This straw could theoretically provide 7.21 million t of organic matter, 33,500 t of nitrogen (N), 9900 t of phosphorus pentoxide (P_2O_5), 62,800 t of potassium oxide (K_2O), and 2.66 million t of organic fertilizer, or be converted into 4.94 million t of standard coal or 2.82×10^9 m^3 of biogas. The annual livestock and poultry manure output was 27.48 million t, which could theoretically provide 6.05 million t of organic matter, 145,900 t of N, 241,300 t of P_2O_5, 127,500 t of K_2O, and 12.87 million t of organic fertilizer, or be converted into 2.71 million t of standard coal or 1.44×10^9 m^3 of biogas. Therefore, straw hotspot counties should focus on fertilization, feed, and fuel applications, while explore substrate and raw material utilization tailored to local agricultural structures. Whereas, livestock manure hotspot counties should emphasize fertilization and energy use while considering bedding materials and ecological applications. Dual-hotspot counties can develop eco-friendly circular agriculture by integrating crop and livestock production systems.
Keywords: *agricultural organic waste, feed utilization, energy utilization, resource utilization, spatial hotspots*

Introduction

Agricultural organic waste originates from agricultural and animal husbandry production processes. As a major agricultural nation, China has a large and widely distributed output of crop straw (Wu et al., 2020). The livestock industry, as a vital component of China's primary sector, provides significant support for economic development. Straw and livestock manure are valuable biomass resources with rich organic content. Utilizing these resources to promote nutrient cycling in agricultural ecosystems is fundamental to green and sustainable agriculture. However, improper handling methods such as the random discarding and discharge of crop straws and livestock manure not only lead to a waste of resources, water and air pollution, but also seriously endanger human health (Li et al., 2020). The Second National Census of Pollution Sources Bulletin of China identified livestock farming as the primary agricultural pollution source. Furthermore, the 2025 Central No. 1 Document emphasized

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strengthening rural ecological governance, systematically managing agricultural non-point source pollution in critical areas, enhancing the resource utilization of livestock manure, and supporting comprehensive straw utilization. Therefore, rational utilization of straw resources and mitigation of non-point source pollution produced by livestock farming has become a significant challenge (Shi et al., 2021).

Accelerating the comprehensive utilization of agricultural organic waste is an essential pathway to promote high-quality development in agriculture and rural areas alongside high-level environmental protection, thus holding significant implications for advancing rural revitalization and accelerating agricultural and rural modernization. Understanding the distribution patterns and characteristics of regional crop straw and livestock manure, as well as exploring their utilization potential and pathways, serves as the foundation for achieving the efficient resource utilization of agricultural organic waste. While previous research has extensively reported on the resource quantities and utilization potential of agricultural waste in China, most studies have focused on the national scale (Zhao et al., 2011; Zhang et al., 2012) or northeast (Wei et al., 2023), central (Li et al., 2023), eastern (Zhang et al., 2019), northern (Du et al., 2019), or western China (Zhang and Li, 2022; Yang et al., 2025), with limited research specific to Shaanxi Province. Notably, the spatial distribution of straw and livestock manure in Shaanxi Province remains understudied, which has constrained the identification of optimal resource utilization strategies.

The present study investigated the primary agricultural organic waste resources in Shaanxi Province (i.e., crop straw and livestock manure), based on 2022 data on crop yields and livestock inventories at the county level. Through constructing Geographic Information System (GIS) models to analyze the spatial aggregation of straw and manure production and by integrating regional characteristics, the study explored optimal solutions for utilizing crop straw and livestock manure as resources. The findings aim to provide a theoretical foundation for advancing the resource utilization of agricultural waste in Shaanxi Province.

Materials and methods

Overview of the research area

Shaanxi Province is located in northwestern China, in the middle reaches of the Yellow River, between 105°29′–111°15′ E and 31°42′–39°35′ N. The terrain exhibits a distinct stepped pattern, with high elevations in the northern and southern regions and a lower central area. From south to north, Shaanxi Province comprises three major geographical units: the Qinba Mountainous Region in southern Shaanxi, the Guanzhong Plain, and the Shanbei Loess Plateau. Owing to its flat terrain and fertile soil, the Guanzhong Plain serves as the core area for grain production and animal husbandry.

Data sources

In 2022, the production of wheat, maize, and soybeans in Shaanxi Province accounted for 83.0% of the total grain crop production. Rapeseed is also widely cultivated in the province. Therefore, this study selected four crops (wheat, maize, soybeans, and rapeseed) for a regional analysis of straw production. In 2022, pork, mutton, beef, and poultry accounted for 99.6% of the total meat produced in Shaanxi Province. Thus, this study primarily calculated the manure produced by pigs, sheep, cattle, and poultry. The

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year-end stock numbers of livestock and poultry are utilized for the calculations and analysis in the present study. The data on crop production and livestock stock numbers are drawn from the Shaanxi Statistical Yearbook 2023 and the statistical yearbooks of various cities for 2023.

Calculation of agricultural organic waste resources

The straw-to-grain ratio is an important basis for estimating crop straw production. In the present study, the straw: grain ratios and collection coefficients of crops were adopted based on the values recommended by the Ministry of Agriculture and Rural Affairs for Shaanxi Province. Considering the development trend of agricultural modernization in Shaanxi Province, mechanized collection coefficients were selected for all crops. The specific values are shown in *Table 1*. The calculation method (Che et al., 2024; Wang et al., 2023) is as follows:

$$M = \sum_{i=1}^{n} T_i \times G_i \times N_i \qquad \text{(Eq.1)}$$

where M is the total collectible amount of straw (t); i is the type of straw (i = 1,…, n); T_i is the yield of the i-th crop (t); G_i is the straw-to-grain ratio of the i-th crop; N_i is the collection coefficient of the i-th crop.

Table 1. *Straw-to-grain ratios and collectible coefficients of the major crops in Shaanxi Province*

Items	Wheat	Maize	Rapeseed	Soybean
Straw-to-grain ratio	1.24	0.94	1.23	1.98
Collectable coefficient	0.79	0.95	0.86	0.89

The production of livestock and poultry manure was calculated using the emission coefficient method (Wang et al., 2023). The emission coefficients are shown in *Table 2* (Jiang et al., 2024). The formula is as follows:

$$P = \sum_{i=1}^{n} S_i \times Z_i \times X_i \qquad \text{(Eq.2)}$$

where P is the total annual production of livestock and poultry manure (t); i is the type of livestock or poultry (i = 1,…, n); S_i is the number of the i-th type of livestock or poultry raised (heads or units); Z_i is the breeding cycle of the i-th type of livestock or poultry (days); and X_i is the excretion coefficient of manure and urine (kg·d^{-1}).

The breeding cycles of cattle and sheep exceed one year. Therefore, in this study the annual manure and urine production was calculated using a value of 365 days. In a small number of regions for which the statistical yearbook did not distinguish between dairy and beef cattle, a uniform emission coefficient value of 20.42 kg·d^{-1} was adopted for calculations (Wang et al., 2023). The breeding cycle for pigs was taken as 199 days, while the breeding cycle for poultry was set at 210 days.

Table 2. *Excretion coefficient of different kinds of livestock and poultry (kg·d^{-1})*

Beef cattle	Dairy cattle	Sheep	Pig	Poultry
23.71	46.84	0.87	2.97	0.22

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Calculation of the potential for straw utilization as feed

Referring to the studies (Li et al., 2020; Yang et al., 2025), the average annual straw consumption per head of cattle was taken as 1.70 t, and that per sheep was set at 0.34 t. The formula (Yang et al., 2025) used to calculate the potential of straw utilization as feed is as follows:

$$Q_i = \frac{M}{V_i} \tag{Eq.3}$$

where Q_i is the theoretical livestock carrying capacity for the i-th type of straw (heads); i is the type of livestock or poultry; M is the total collectible amount of straw (t); and V_i is the annual straw consumption per type of livestock or poultry (t).

Calculation of nutrient content and energy potential of organic waste

The nutrient content in organic waste was calculated with reference to previous research (Du et al., 2019; Wang et al., 2023). The formula is as follows:

$$A_j = \sum_{i=1}^{n} W_i \times F_{i,j} \tag{Eq.4}$$

where A_j is the content of the j-th nutrient element in straw (or livestock and poultry manure) (t); i - the type of straw (or livestock and poultry manure); W_i is the production amount of the i-th type of straw (or livestock and poultry manure) (t); $F_{i,j}$ is the content of the j-th element in the i-th type of straw (or livestock and poultry manure) (%).

The relevant calculation formulas (Wang et al., 2023; Yang et al., 2025) for the conversion of organic waste into standard coal and biogas are as follows:

$$B = W_i \times S_i \times K_i \times \alpha_i \tag{Eq.5}$$

$$C = W_i \times S_i \times K_i \times \delta_i \tag{Eq.6}$$

where B is the coal equivalent of straw (or livestock and poultry manure) (t); C is the biogas equivalent of straw (or livestock and poultry manure) (m^3); W_i is the amount of the i-th type of straw (or livestock and poultry manure) (t); S_i is the recoverability coefficient of the i-th type of straw (or livestock and poultry manure); K_i is the dry matter proportion of the i-th type of straw (or livestock and poultry manure) (%); α_i is the standard coal conversion coefficient of the i-th type of straw (or livestock and poultry manure); and δ_i is the unit biogas production of the i-th type of straw (or livestock and poultry manure) ($kg \cdot d^{-1}$). The relevant parameters are presented in *Table 3* (Wang et al., 2023).

Hotspot analysis

The spatial distribution and hotspot characteristics of major organic wastes in Shaanxi Province were analyzed using ArcGIS 10.8. The Hotspot Analysis (Getis-Ord Gi*) cluster mapping tool was employed to identify the hotspot regions for various types of waste (Jiang et al., 2024). The formula (Wang et al., 2023; Jiang et al., 2024; Yang et al., 2025) utilized to calculate the Getis-Ord Gi* index is as follows:

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$$Gi^* = \frac{\sum_{j=1}^{n} W_{i,j} \times x_j - \bar{X}\sum_{j=1}^{n} W_{i,j}}{S\sqrt{\frac{n\sum_{j=1}^{n} W_{i,j}^2 - \left(\sum_{j=1}^{n} W_{i,j}\right)^2}{n-1}}} \quad \text{(Eq.7)}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad \text{(Eq.8)}$$

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad \text{(Eq.9)}$$

where x_j is the attribute value of feature j; $W_{i,j}$ is the spatial weight between feature i and j (1 if adjacent, 0 if not adjacent); n is the total number of features; S is the standard deviation; and $\bar{X}$ is the mean value of feature j.

The Z-value is the statistical result of Gi*, representing the number of standard deviations. In statistics, a positive Z-value indicates a hotspot; the higher the Z-value, the more the color tends towards red, signifying a tighter clustering of hotspots. Conversely, a negative Z-value indicates a cold spot, where the lower the Z-value, the more the color tends towards blue, reflecting a tighter clustering of cold spots. The spatial locations of these attribute values can be displayed using GIS maps, allowing for the analysis of whether these attributes exhibit clustering effects.

Table 3. *Utilization potential parameters of straw and livestock manure*

Agri-waste	Species	Organic matter/%	N/%	P/%	K/%	Conversion coefficient of standard coal	Biogas production per unit/($m^3 \cdot kg^{-1}$)	Collectable coefficient	Ratio of dry matter/%
Straw	Wheat	64.2	0.31	0.04	0.65	0.50	0.3	/	85
	Maize	70.3	0.30	0.04	0.38	0.53	0.3	/	94
	Rapeseed	69.6	0.27	0.04	0.61	0.53	0.2	/	85
	Soja	71.4	0.58	0.06	0.37	0.54	0.3	/	85
Livestock and poultry dung	Beef cattle	18.0	0.383	0.218	0.277	0.47	0.3	0.6	18
	Dairy cattle	18.0	0.383	0.218	0.277	0.47	0.3	0.6	18
	Sheep	32.5	1.014	0.495	0.638	0.53	0.3	0.6	40
	Pig	23.7	0.547	0.561	0.353	0.43	0.2	1.0	20
	Poultry	28.5	0.761	0.757	0.715	0.64	0.3	0.6	80

The collection coefficient of straw has been calculated in the estimation of resource quantity and is marked as "/". The conversion factor for elemental phosphorus to P_2O_5 is 2.29, and the conversion factor for elemental potassium to K_2O is 1.2

Results

Distribution of crop straw yield and hotspot areas

In 2022, the total collectible amount of crop straw in Shaanxi Province was 10.61 million t. The straw resources were mainly concentrated in the central and northwestern regions of Shaanxi (*Fig. 1a*). The primary types of straw were wheat and maize straw. The areas with the richest straw resources were Pucheng County, Fuping County, and Linwei District in Weinan City, which produced collectible straw amounts of 0.41, 0.40, and 0.39 million t, respectively.

The distribution of straw resources in Shaanxi Province exhibited significant spatial heterogeneity, with distinct hotspot and coldspot areas (*Fig. 1b*). The distribution of straw

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collection hotspots was primarily influenced by wheat and maize, and was concentrated in the Guanzhong Plain region of Shaanxi. Among the four types of straw resources, there were 24 hotspot counties and 1 coldspot county. At a 99% confidence level, there were 9 straw hotspot counties, with a total collectable straw volume of 2.09 million t, accounting for 19.74% of the total collectable straw volume in Shaanxi Province.

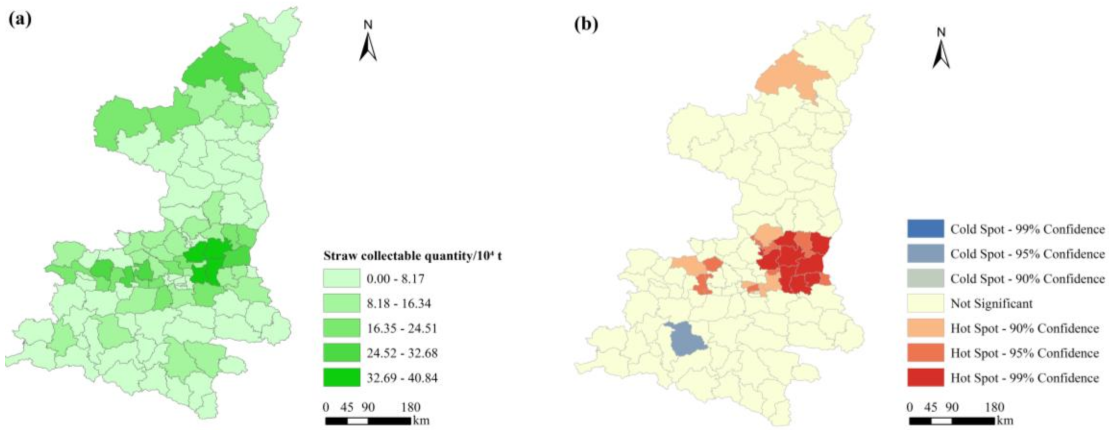

Figure 1. *Distribution of total amount of collectable crop straw (a) and hotspot (b) distribution*

The collectable volumes of straw from the four crops showed significant differences (*Fig. 2*). Wheat straw had a collectable volume of 4.13 million t, accounting for 38.98% of the total collectable straw volume. It was chiefly distributed in the eastern part of the Guanzhong Plain (*Fig. 2a*). Among these areas, Pucheng County in Weinan City had the highest collectable wheat straw volume at 255,700 t, while Fuping County, Linwei District, and Fengxiang District had volumes exceeding 200,000 t. Maize straw had the highest collectable volume at 5.59 million t, representing 52.70% of the total collectable straw volume. Maize straw was primarily distributed in the Shanbei Loess Plateau (*Fig. 2b*). Yuyang District in Yulin City (289,500 t), Jingbian County (223,500 t), and Dingbian County (194,700 t) had the largest collectable maize straw volumes. Soybean straw had a collectable volume of 503,200 t, accounting for 4.74% of the total collectable straw volume. It was mainly distributed in the Shanbei Loess Plateau (*Fig. 2c*). Jia County (40,200 t) and Mizhi County (30,100 t) had relatively high collectable soybean straw volumes, while Zizhou County, Shenmu (county-level city), and Suide County had volumes exceeding 20,000 t. The collectable volume of rapeseed straw was 379,500 t, accounting for 4.74% of the total collectable straw volume. It was primarily distributed in the Qinba Mountain region of Southern Shaanxi (*Fig. 2d*). Hanbin District had the highest collectable rapeseed straw volume at 42,300 t, while Nanzheng District, Yang County, Mian County, and Hanyin County had volumes exceeding 22,000 t.

The hotspots of the four types of crop straw were discretely distributed (*Fig. 3*). Wheat straw hotspots were mainly concentrated in the Guanzhong Plain (*Fig. 3a*), with significant clustering. There were 21 hotspot areas at a 99% confidence level, with over 8 counties have Z-values above 3.5. The top three counties in terms of Z-values were Pucheng County (4.7), Dali County (3.8), and Fufeng County (3.8). Maize straw hotspots were concentrated in the Guanzhong Plain and the Shanbei Loess Plateau (*Fig. 3b*). At a 99% confidence level, six counties were identified as hotspots, namely, Pucheng County, Dali County, Baishui County, Chengcheng County, Yuyang District, and Hengshan District, with Yuyang

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District (4.3) and Pucheng County (4.0) having the highest Z-values. Soybean straw hotspots were identified in the Shanbei Loess Plateau, with seven hotspot counties: Jia County, Wubu County, Mizhi County, Suide County, Qingjian County, Zizhou County, and Hengshan District. Coldspot areas were detected in the Guanzhong Plain (*Fig. 3c*), where six areas had Z-values greater than 5, with Suide County having the highest Z-value of 6.8. Rapeseed straw hotspots were concentrated in the Qinba Mountains of southern Shaanxi (*Fig. 3d*), displaying significant clustering. Seventeen counties were identified as hotspots, and four counties had Z-values above 5 at a 99% confidence level.

Annual production and distribution of livestock and poultry manure and hotspot areas

In 2022, the total amount of livestock and poultry manure produced in Shaanxi Province reached 27.48 million t. Manure was mainly distributed in the Shanbei Loess Plateau and the Guanzhong Plain (*Fig. 4a*). Yuyang District produced over 1 million t of manure (1.17 million t), accounting for 4.26% of the total. The distribution of manure hotspot areas was not significantly clustered and was relatively scattered (*Fig. 4b*). There were eight hotspot areas in total. At a 99% confidence level, Yuyang District was the only hotspot county, with a Z-value of 3.25. There were four hotspot areas at a confidence level of 95%, with a total manure volume of 1.80 million t, accounting for 6.55% of the total. At a 90% confidence level, there were three counties, with a total manure volume of 1.63 million t, contributing 5.94% of the total.

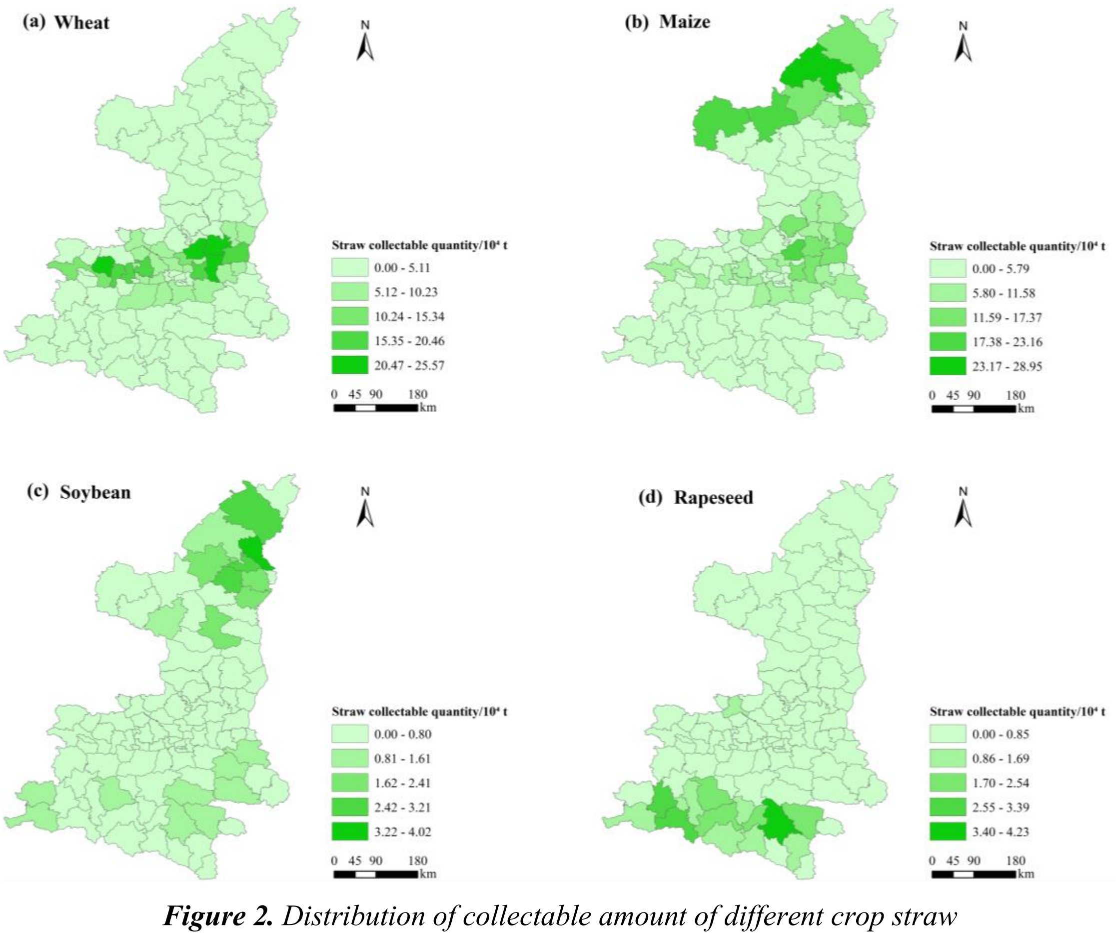

***Figure 2.** Distribution of collectable amount of different crop straw*

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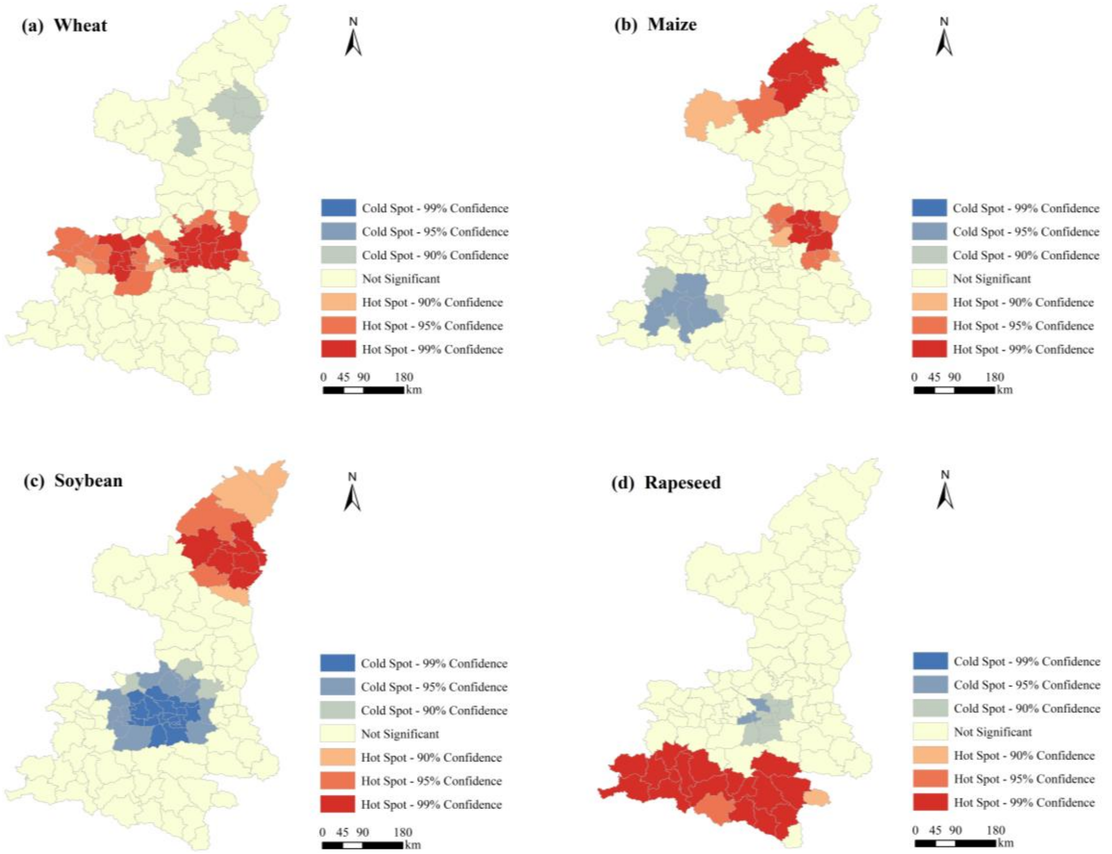

Figure 3. *Hotspot distribution of different crop straw*

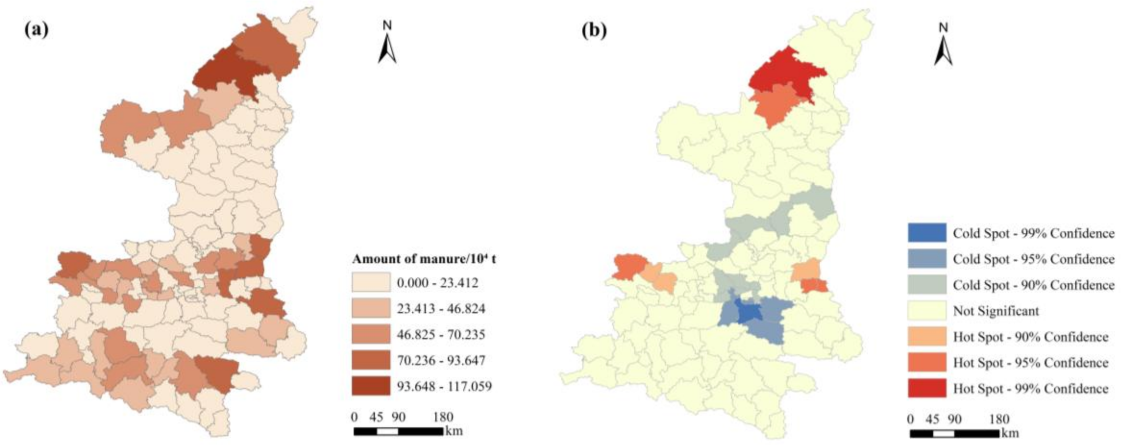

Figure 4. *Total amount (a) and hotspot (b) distribution of livestock and poultry manure*

In Shaanxi Province, the distribution of the annual production of the four types of livestock and poultry manure varied significantly (*Fig. 5*). Cattle manure had an annual output of 15.68 million t, accounting for 57.05% of the total volume of the four types of manure. Cattle manure was mainly distributed in the Shanbei Loess Plateau and the Guanzhong Plain (*Fig. 5a*). Counties with outputs exceeding 600,000 t included Long County (668,400 t), Heyang County (649,600 t), Luonan County (631,700 t), and Qianyang

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County (631,400 t), which together constituted 16.47% of the total cattle manure output. Sheep manure had an annual output of 2.95 million t, making up 10.73% of the total manure volume, and was mainly distributed in the Shanbei Loess Plateau (*Fig. 5b*). Yuyang District had the highest sheep manure output at 342,500 t. Other counties with significant output included Hengshan District (307,300 t), Jingbian County (289,600 t), Dingbian County (232,900 t), and Shenmu (county-level city) (216,700 t). These 5 counties contributed 47.13% of the total sheep manure output in Shaanxi Province. Pig manure had an annual output of 5.33 million t, representing 19.38% of the total manure volume, and was more scattered in distribution (*Fig. 5c*). Chengcheng County had the highest pig manure output at 207,200 t. Other areas with outputs exceeding 150,000 t included Xixiang County (194,400 t), Yuyang District (193,200 t), Hanbin District (191,300 t), and Xunyi County (162,900 t). Together, these five counties accounted for 17.81% of the total pig manure output. The annual output of poultry manure was 3.53 million t, accounting for 12.84% of the total manure volume, and was mainly distributed in central and eastern Shaanxi (*Fig. 5d*). Pucheng County had the highest poultry manure output at 196,700 t, contributing 5.57% of the total poultry manure volume. Other counties with relatively high outputs included Dangfeng County (178,900 t) and Fuping County (156,800 t).

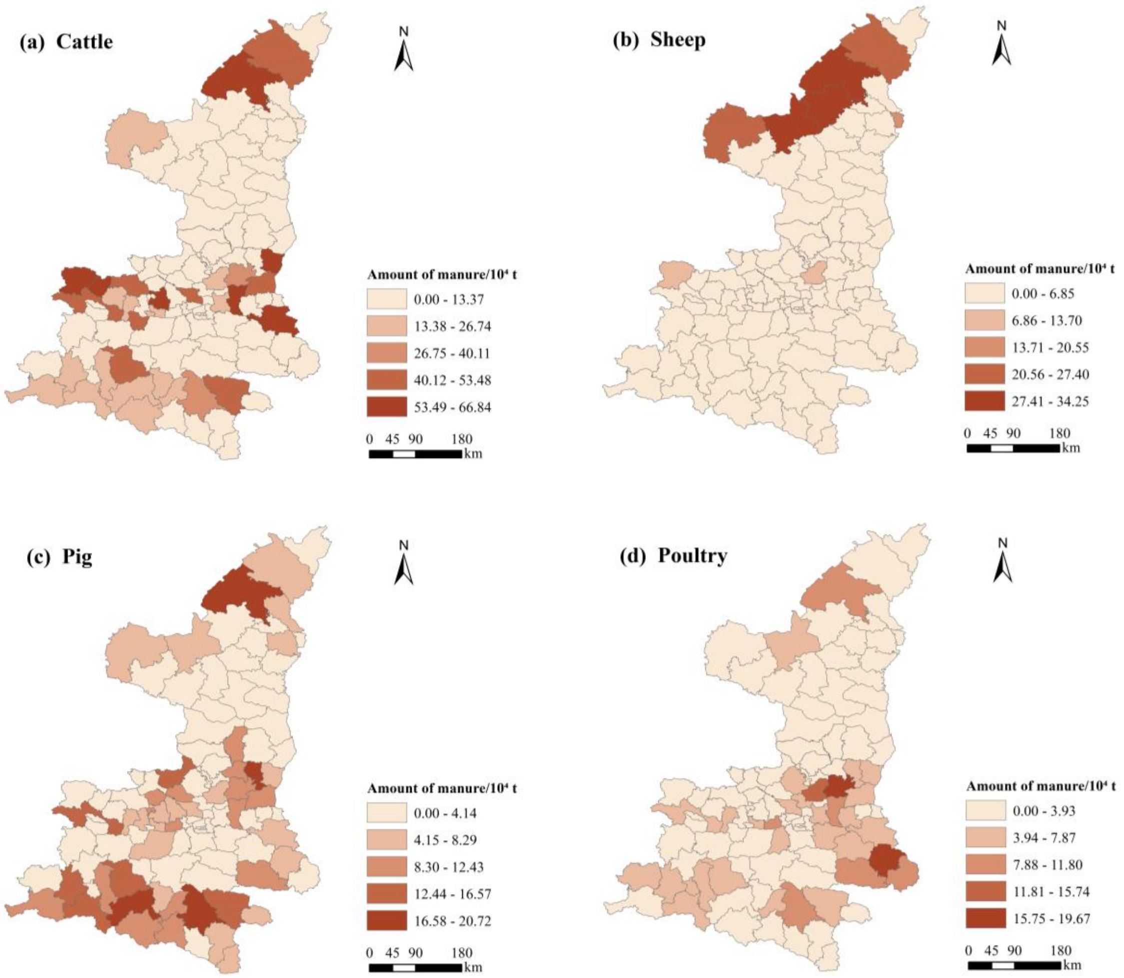

***Figure 5.** Annual production amount distribution of livestock and poultry manure*

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The distribution of the four types of livestock and poultry manure resources displayed significant differences (*Fig. 6*). Cattle manure hotspot counties were mainly located in the Baoji area of the Guanzhong Plain (*Fig. 6a*). At a 99% confidence level, there were 4 cattle manure hotspot counties: Long County (Z-value 3.3), Qianyang County (3.1), Fengxiang County (3.1), and Huayin (county-level city) (2.7). Sheep manure hotspot counties were concentrated in northwestern Shaanxi (*Fig. 6b*). At a 99% confidence level, four hotspot counties were identified: Yuyang District, Hengshan District, Jingbian County, and Mizhi County. Notably, Yuyang District exhibited a Z-score of 7.0, while Hengshan District reached 5.4, positioning both as regions with remarkably significant agglomeration of livestock and poultry manure. Pig manure hotspot counties were mainly found in southern Shaanxi (*Fig. 6c*), with pronounced clustering. At a 99% confidence level, 4 counties were identified as hotspots: Zhenba County, Shiquan County, Xixiang County, and Chenggu County, with Chenggu County and Xixiang County each recording Z-values of 3.3. Poultry manure hotspots were detected in eastern Guanzhong and northeastern Shaanxi (*Fig. 6d*). At a 99% confidence level, 6 counties were identified as poultry manure hotspots with Z-values above 3: Pucheng County, Huayin (county-level city), Shangzhou District, Dangfeng County, Shanyang County, and Shangnan County.

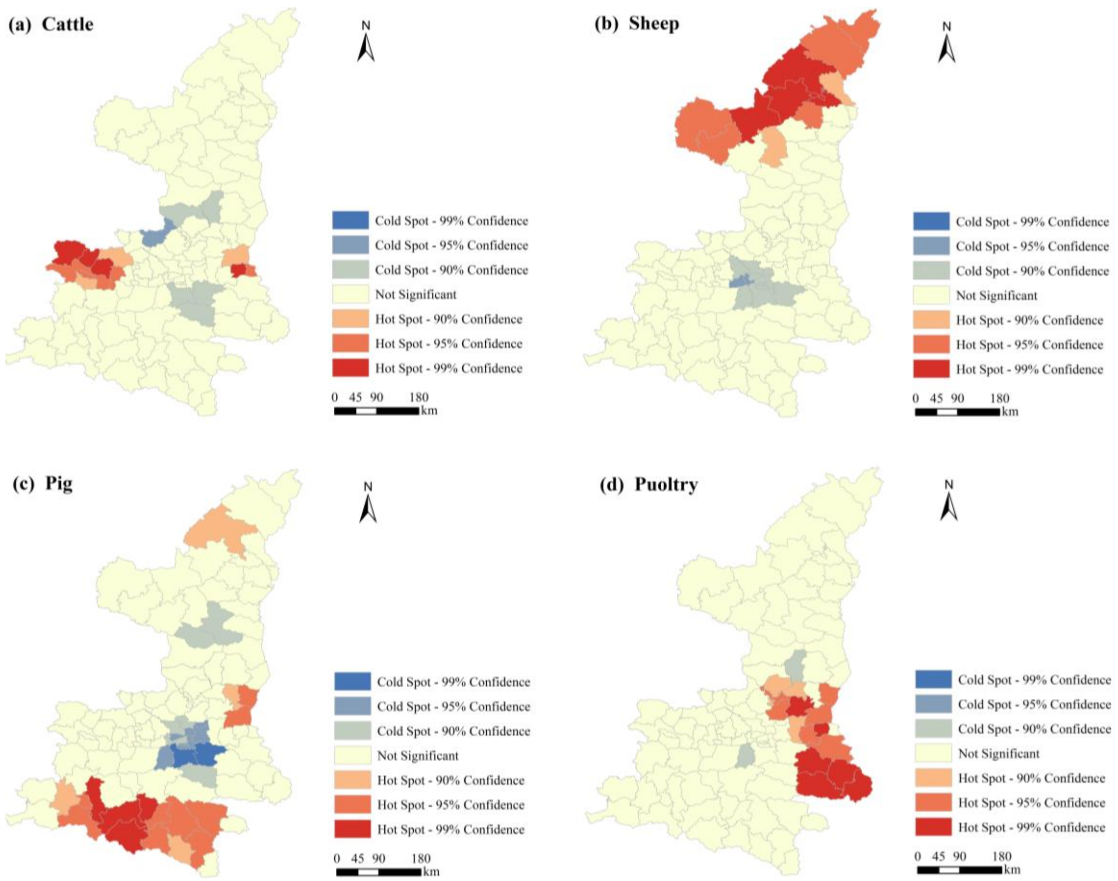

Figure 6. *Hotspot distribution of livestock and poultry manure*

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Analysis of the utilization potential of major organic waste

In 2022, all 4 types of straw in Shaanxi Province were fully utilized as feed, theoretically supporting a livestock capacity of 6.24 million cattle units or 31.20 million sheep units. The fertilization use of straw was equivalent to 7.21 million t of organic matter, 33,500 t of nitrogen (N), 9,900 t of phosphorus pentoxide (P_2O_5), and 62,800 t of potassium oxide (K_2O). Based on the requirements of the standard Organic Fertilizer (NY 525-2021), which specifies a minimum organic matter content of ≥30% and a total nutrient content of ≥4%, this could theoretically be converted into 2.66 million t of organic fertilizer. If all straw was employed for energy, it could theoretically be equivalent to 4.94 million t of standard coal or 2.82×10^9 m^3 of biogas. Pucheng County produced the highest collectable straw volume, offering the greatest potential for feed, fertilizer, and energy use. Specifically, straw used as feed could support 240,300 cattle units or 1.20 million sheep units. The straw in Pucheng County could be converted into 1.53 million t of organic matter, 13,000 t of N, 4000 t of P_2O_5, 27,000 t of K_2O, 184,600 t of standard coal, and 1.08×10^8 m^3 of biogas.

In 2022, the fertilization of livestock and poultry manure in Shaanxi was equivalent to 6.05 million t of organic matter, 145,900 t of N, 241,300 t of P_2O_5, and 127,500 t of K_2O. Based on the requirements of the standard Organic Fertilizer (NY 525-2021), which specifies a minimum organic matter content of ≥30% and total nutrients of ≥4%, this quantity of manure could theoretically be converted into 12.87 million t of organic fertilizer. The energy use of livestock and poultry manure could be equivalent to 2.71 million t of standard coal or 1.44×10^9 m^3 of biogas. Yuyang District had the highest levels of organic matter, N, P_2O_5, K_2O, standard coal, and biogas converted from livestock and poultry manure, at 279,700 t, 7300 t, 10,500 t, 6000 t, 176,800 t, and 9.79×10^7 m^3 respectively.

Composition of coldspot and hotspot counties for straw and livestock manure

Overlay analysis was separately conducted on the hotspot counties of the four straw types and four livestock manure types across the province. At a 99% confidence level, the structural characteristics of straw and livestock manure hotspot counties were relatively similar, with more single-type hotspot counties and fewer overlapping hotspots. Straw hotspots include 19 wheat straw hotspot counties, 3 maize straw hotspot counties, 6 soybean straw hotspot counties, and 17 rapeseed straw hotspot counties. Single-type straw hotspots account for 43.24% of the province's total straw volume. There were two wheat-maize straw dual-hotspot counties (Pucheng County and Dali County) and one maize-soybean straw dual-hotspot county (Hengshan District) (*Fig. 7a*). Livestock manure hotspots were similar, with three cattle manure hotspot counties, four sheep manure hotspot county, four pig manure hotspot county, and five poultry manure hotspot counties. Single-type livestock manure hotspots made up 26.15% of the province's total manure volume. The only dual-hotspot county was Huayin (county-level city) (*Fig. 7b*), for cattle and poultry manure. Overlay analysis of straw and livestock manure hotspots in the province revealed eight dual-hotspot counties (*Fig. 7c*): Pucheng County, Huayin (county-level city), Yuyang District, Hengshan District, Mizhi County, Chenggu County, Xixiang County, and Shiquan County.

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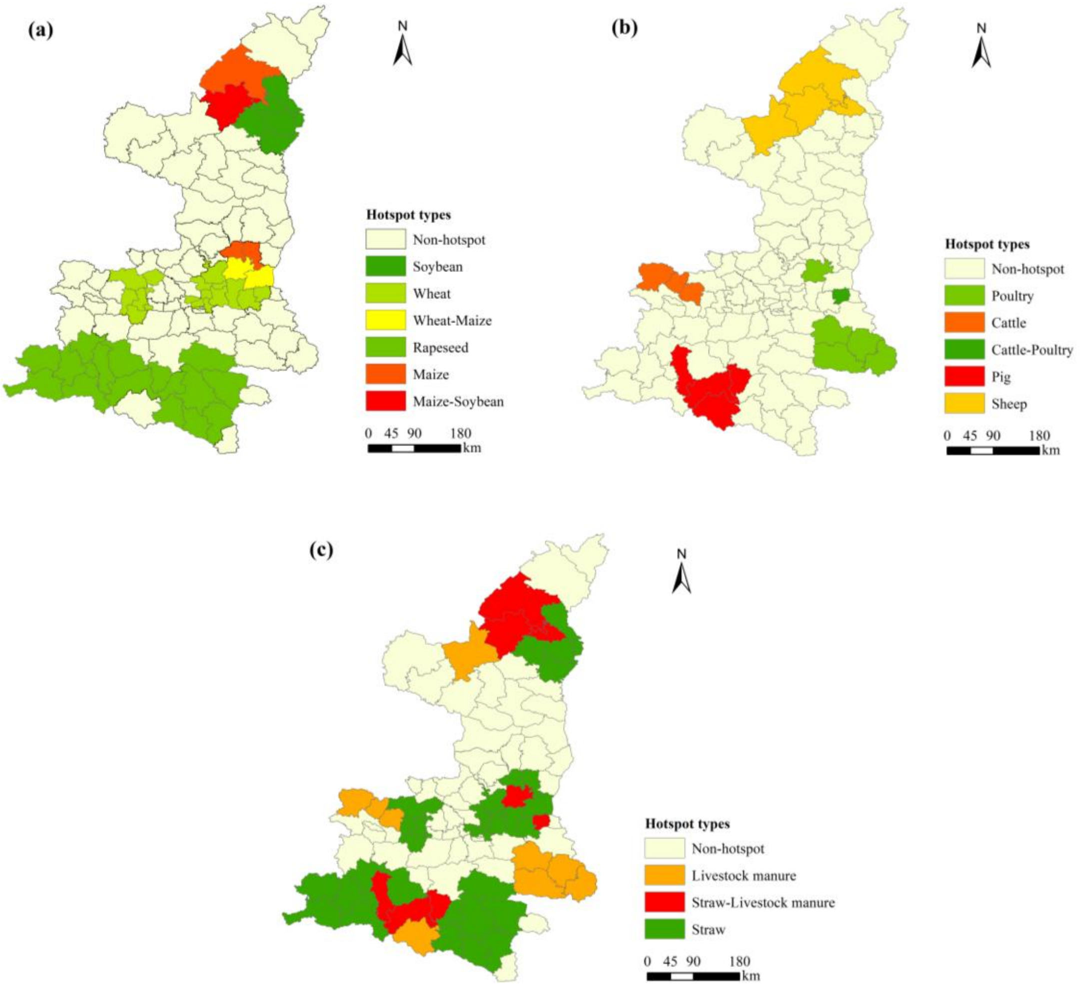

Figure 7. *Composition of hot counties with straw and livestock and poultry manure in Shannxi Province: (a) Composition of straw in hotspots counties; (b) Composition of livestock and poultry manure in hotspots counties; (c) The superposition analysis of straw and livestock and poultry manure in hotspot counties*

Discussion

Analysis of utilization potential of major agricultural wastes

According to the *National Report on the Comprehensive Utilization of Crop Straw* and the *China Agricultural Green Development Report 2023*, the comprehensive utilization rate of crop straw nationwide reached 89.8% in 2022, with the proportions of fertilizer-oriented, feed-oriented, energy-oriented (fuel-oriented), substrate-oriented and raw material-oriented utilization accounting for 60%, 18%, 8.5%, 0.7% and 0.9% respectively; the comprehensive utilization rate of livestock and poultry manure stood at 78% in the same year. Relevant data released by the Shaanxi Provincial Department of Agriculture and Rural Affairs in 2022 indicated that the comprehensive utilization rates of crop straw and livestock and poultry manure in Shaanxi Province hit 94% and 90.6% respectively, both significantly higher than the national average. Nevertheless, straw utilization in Shaanxi was primarily based on fertilizer application (straw returning to the field), with relatively low proportions of diversified utilization approaches such as feed and energy utilization, which revealed a notable disparity with the national structure of diversified straw

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utilization. This leaves substantial room for structural optimization and potential exploration, as the fertilizer-oriented and energy-oriented utilization of agricultural organic wastes in the province exhibits remarkable practical value in terms of fertilizer saving, efficiency improvement, carbon emission reduction and pollutant abatement.

In 2022, Shaanxi Province used 1.94 million t of agricultural fertilizers (pure nutrient content), including 734,200 t of nitrogen fertilizer, 172,300 t of phosphorus fertilizer, and 197,600 t of potassium fertilizer (Shannxi Provincial Bureau of Statistics, 2024). Straw fertilizer use in 2022 could save 4.56% of nitrogen fertilizer, 5.75% of phosphorus fertilizer, and 31.78% of potassium fertilizers. Livestock manure fertilizer use could save 19.87% of nitrogen and 64.52% of potassium fertilizers, meeting the annual phosphorus fertilizer demand. Fertilization using straw and livestock manure could produce or replace 15.52 million t of organic fertilizer. At CNY 500~700 per ton (Du et al., 2019), this represents an economic value of CNY 7.76~10.87 billion.

In 2022, straw energy use in Shaanxi Province could replace 4.94 million t of standard coal, reducing emissions CO_2 by 12.41 million t, SO_2 emissions by 370,800 t, and NOx emissions by 185,300 t (Huo et al., 2019). The energy use of livestock and poultry manure was equivalent to 2.71 million t of standard coal, cutting CO_2 by 6.81 million t, SO_2 by 20,350 t, and NOx by 10,170 t (Huo et al., 2019).

Analysis of utilization directions of major agricultural wastes

The amount and types of straw and livestock manure determine their optimal utilization paths. Wheat straw is rich in cellulose and can be made into fuel ethanol (Dai et al., 2021). Maize straw, which has high soluble sugar and crude protein (Huo et al., 2019), is a good feed ingredient. Maize and soybean straw, having less cellulose and lignin than wheat straw, are suitable for direct soil return (Niu et al., 2016; Hao et al., 2022). Soybean straw can also be used as biofuel (Velvizhi et al., 2022). Rapeseed straw, with low ash content, can be pyrolyzed into fuel (Jiang et al., 2022). Although the relatively high water content of cattle manure makes fuel production costly and environmentally risky (Zhang et al., 2023), it can be utilized for vermicomposting. Pig manure, which is high in N and P (He et al., 2022), can be used for phosphorus recovery to make fertilizer or directly composted (Li et al., 2021). Sheep and poultry manure, rich in organic matter, are good for soil structure improvement and can be used as fertilizer. Chicken manure can be used for power generation or processed into feed for cattle or pigs (Jiang et al., 2024).

When selecting the primary utilization directions for major agricultural wastes in Shaanxi Province, factors including resource types, planting and breeding structures, transportation accessibility and infrastructure of each county must be taken into account, and differences in planting and breeding structures across regions directly influence the utilization directions of crop straw and livestock manure. For regions with a single concentration of crop straw or livestock manure, circular utilization models should be tailored to their respective priorities. Among counties with a single concentration of crop straw, those rich in wheat and corn straw are mainly distributed in the Guanzhong area, soybean straw in northern Shaanxi, and rapeseed straw in southern Shaanxi, where utilization should focus on fertilization, feed processing and substrate production as the core, while expanding energy and raw material utilization in combination with county-level agricultural structures.

As a typical county with a single concentration of rapeseed straw in southern Shaanxi, Hanbin District is characterized by fragmented planting in hilly areas and a lack of supporting large-scale livestock and poultry breeding, leading to practical challenges for

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straw resource utilization such as great difficulties in decentralized collection and storage and limited high-value utilization pathways. Based on these characteristics, a utilization model of "decentralized adaptation + circular high-value utilization" is proposed: on the one hand, popularize small and portable straw crushing equipment to carry out on-site composting for organic fertilizer production according to plot characteristics, with the finished product directly supplied to local characteristic planting industries such as tea and konjac to reduce collection, storage and transportation costs; on the other hand, relying on the climatic advantages of southern Shaanxi, encourage farmer cooperatives to jointly carry out straw substrate cultivation of Pleurotus ostreatus and Lentinus edodes to extend the industrial chain and increase added value, and the mushroom residue is returned to the field after harmless treatment to realize a closed-loop cycle of "straw - edible fungi - organic fertilizer". This model provides a diversified resource utilization pathway independent of large-scale breeding for straw-concentrated hilly counties in southern Shaanxi, and further enriches the county-level practical cases for optimizing the provincial straw utilization structure.

Among counties with a single concentration of livestock and poultry manure, those with a high output of cattle manure are mainly distributed in the Guanzhong area, sheep manure in northern Shaanxi, pig manure in southern Shaanxi, and poultry manure also predominantly in southern Shaanxi. For these counties, the utilization should prioritize fertilization and energy production, while also considering bedding material and ecological utilization. Notably, livestock and poultry breeding in some regions of Shaanxi such as Hanzhong and Ankang has exceeded the local maximum environmental capacity, posing a high risk of nitrogen and phosphorus pollution (Qiao et al., 2024). As a typical county with a single concentration of sheep manure in northern Shaanxi, Yuyang District is characterized by concentrated large-scale breeding and massive manure generation, and its livestock manure resource utilization faces practical challenges including a local shortage of fermentation raw materials such as crop straw and low benefits of traditional disposal methods. Based on this, a utilization model of "centralized resource utilization of manure + crop-livestock synergy to address shortcomings" is proposed: on the one hand, relying on local large-scale organic fertilizer processing plants, promote the raw material connection between manure and surrounding straw collection and storage outlets to produce compound organic fertilizer for large-scale planting industries such as soybean and forage grass; on the other hand, encourage breeding bases to be equipped with straw processing facilities, reduce breeding costs through straw feed processing, and simultaneously advance manure returning to fields for soil fertility improvement, thus realizing an efficient cycle of "breeding waste - organic fertilizer - planting". This model provides a practical pathway for counties with a single concentration of livestock and poultry manure in intensive breeding areas of northern Shaanxi to compensate for raw material shortages and improve circular utilization efficiency, and further contributes to the optimization of the provincial crop-livestock synergetic development pattern.

In dual-hotspot counties, policies should be tailored to local conditions. The Guanzhong Plain, a major farming and large-scale livestock area, can promote circular agriculture systems (e.g., straw-feed-livestock-manure-organic fertilizer-crop chains) or co-produce biogas and organic fertilizer from straw and manure to achieve efficient resource use and carbon-emission reduction goals. The Qinba Mountain area in southern Shaanxi Province can integrate ecological farming with small-farmer economies, promoting decentralized composting and straw-based substrates. In the Shanbei Loess Plateau, given the dry climate, straw mulching can be utilized for soil moisture

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conservation, and manure composting can be employed to enhance soil structure. As a typical dual-concentration county in the Guanzhong Plain, Pucheng County boasts industrial advantages of abundant wheat-corn straw resources and concentrated poultry breeding, featuring improved crop-livestock matching, large poultry manure discharge and a solid foundation for circular utilization. Based on this, it is recommended to further advance the model of synergistic high-value utilization of crop straw and poultry manure: on the one hand, promote the parallel implementation of crushed straw returning to fields and straw feed processing via the grain-straw dual harvesting method, and apply straw organic fertilizer combined with biogas slurry fermented from poultry manure to meet the fertility demands of local large-scale grain cultivation; on the other hand, relying on existing organic fertilizer processing plants and straw collection and storage outlets, promote the collaborative processing of compound organic fertilizer from crop straw and poultry manure, which can be supplied to the surrounding characteristic planting industries such as crisp pears in a radiation pattern, thus realizing a closed-loop cycle of crop straw - poultry breeding - manure resource utilization - high-quality fertilizer - crop cultivation. This model provides a replicable pathway for the synergistic utilization of agricultural wastes in dual-concentration counties of intensive crop-livestock areas in the Guanzhong Plain, and further contributes to the development of green and circular agriculture across Shaanxi Province.

Conclusions

This study systematically conducted statistics on the resource quantities of straw and livestock and poultry manure (the main agricultural organic wastes in Shaanxi Province), analyzed their spatial distribution characteristics, and evaluated the potential for resource utilization. The key findings are as follows:

In 2022, the total collectable amount of straw (wheat, maize, soybean, rapeseed) in Shaanxi Province was 10.61 million t, mainly distributed in the eastern Guanzhong Plain and northern Shanbei Plateau. Wheat and corn straw accounted for the main types, accounting for 91.68% of the total straw. The theoretical livestock carrying capacity for feed utilization was 6.24 million bovine units or 31.20 million sheep units. For fertilizer utilization, it could replace 2.66 million t of organic fertilizer. In terms of energy utilization, it could replace 4.94 million t of standard coal or 2.82×10^9 m^3 of biogas.

In 2022, the annual production of livestock and poultry manure (cattle, sheep, pig, poultry) in Shaanxi Province was 27.48 million t. Cattle and pig manure dominated, accounting for 76.43% of the total animal manure. For fertilizer utilization, it could replace 12.87 million t of organic fertilizer. In terms of energy utilization, it could substitute 2.71 million t of standard coal or 1.44×10^9 m^3 of biogas.

The distribution and aggregation degree of straw and animal manure in Shaanxi Province showed significant regional differences. At a 99% confidence level, there were 45 single-type straw hotspot counties, 16 single-type livestock manure hotspot counties, and 8 dual-hotspot counties for straw and livestock manure. The dual hotspots counties of straw and livestock and poultry manure are suitable for developing the green circular agricultural development model combining planting and breeding.

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REFERENCES

[1] Che, Q. F., Chen, X. Y., Hu, T. T., Zhang, J., Zhang, J., Huang, W. H., Tu, Q. H. (2024): Analysis of utilization potential of major crop straws and livestock manure in Jiangxi Province. – Journal of Henan Agricultural Sciences 53(12): 86-98.

[2] Dai, X. H., Chen, S. X., Cai, C., Dai, L. L., Hua, Y. (2021): Research and economic analysis of mainstream energy technologies for straw. – Environmental Engineering 39(1): 1-17.

[3] Du, Y. L., Zhou, H. P., Cheng, M., Xie, W. Y., Yang, Z. X., Guo, J., Lyu, Q. Q., Wang, Z. W. (2019): Study on composition and utilization potential of waste from planting and breeding in Shanxi Province, China. – Journal of Agricultural Resources and Environment 36(3): 329-336.

[4] Hao, X. X., Han, X. Z., Wang, S. Y., Li, L. J. (2022): Dynamics and composition of soil organic carbon in response to 15 years of straw return in a Mollisol. – Soil and Tillage Research 215: 105221.

[5] He, L. T., Wang, D. H., Wu, Z. Y., Li, S. C., Lv, Y. Z. (2022): Co-pyrolysis of pig manure and magnesium-containing waste residue and phosphorus recovery for planting feed corn. – Journal of Water Process Engineering 49: 103146.

[6] Huo, L. L., Zhao, L. X., Meng, H. B., Yao, Z. L. (2019): Study on straw multi-use potential in China. – Transactions of the Chinese Society of Agricultural Engineering 35(13): 218-224.

[7] Jiang, J. X., Li, X. H., Shao, S. S., Sun, J. Y., Yu, Z. N., Cai, Y. X. (2022): Experimental study on catalytic pyrolysis of rape straw with the active cathode material of spent lithium-ion batteries and HZSM-5 as the tandem catalysts. – Renewable Energy 204: 803-811.

[8] Jiang, X. S., Lu, M. F., Liu, Y., Li, H. Z., Yuan, S. R., Lin, B. Z. (2024): Spatial distribution and comprehensive utilization potential of four main types of straw and livestock manure in Jiangsu Province. – Journal of Agro-Environment Science 43(3): 675-687.

[9] Li, S. N., Ji, X. H., Deng, K., Zhu, J., Li, C. J., Jian, Y., Pang, H. (2020): Analysis of regional distribution patterns and full utilization potential of crop straw resources. – Transactions of the Chinese Society of Agricultural Engineering 36(12): 221-228.

[10] Li, X. X., Shi, Z. L., Wang, J. C., Jiang, R. F. (2021): The quality of dissolved organic matter extracted at different times from pig compost and its copper binding capacity based on EEM-PARAFAC. – Ecotoxicology and Environmental Safety 207: 111545.

[11] Li, Y. J., Cheng, P., Wang, X. Y., Yang, Y., Li, L., Zhang, Z. Y., Yang, Q., Xiao, Y. Z. (2023): Evaluation of the collectable resource amount and energy utilization potential of crop straws in Hunan Province – Hunan Agricultural Sciences (7): 101-105.

[12] Niu, W. J., Han, L. J., Liu, X., Huang, G. Q., Chen, L. J., Xiao, W. H., Yang, Z. L. (2016): Twenty-two compositional characterizations and theoretical energy potentials of extensively diversified China's crop residues. – Energy 100: 238-250.

[13] Qiao, M., Zhu, J., Li, R., Pan, J., Xiao, R., Wang, H., Tang, K. H. D., Zhang, Z. (2024): Spatiotemporal distribution, environmental risk and carbon emission reduction potential of livestock manure in Shaanxi Province, China. – Frontiers of Agricultural Science and Engineering 11(3): 381-396.

[14] Shannxi Provincial Bureau of Statistics (2024): Shannxi Statistical Yearbook 2024. – China Statistics Press, Beijing, China.

[15] Shi, X. X., Zheng, G. D., Gao, D., Chen, T. B. (2021): Quantity of available nutrient in livestock manure and its potential of replacing chemical fertilizers in China. – Resources Science 43(2): 403-411.

[16] Velvizhi, G., Balakumar, K., Shetti, N. P., Ahmad, E., Pant, K. K., Aminabhavi, T. M. (2022): Integrated biorefinery processes for conversion of lignocellulosic biomass to value added materials: paving a path towards circular economy. – Bioresource Technology 343: 126151.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2402_26252641

[17] Wang, Y., Li, L., Kuang, F. H. (2023): County distribution characteristics and resource utilization potential of straw and livestock manure in Sichuan Province. – Journal of Agricultural Resources and Environment 40(2): 455-467.
[18] Wei, Y. J., Tian, J. Y., Cai, C. F. (2023): Spatial distribution and nutrient utilization potential of organic fertilizer resources in the black soil region of northeast China. – Journal of Agricultural Resources and Environment 40(4): 745-754.
[19] Wu, H. W., Sun, X. Q., Liang, B. W., Chen, J. B., Zhou, X. F. (2020): Analysis of livestock and poultry manure pollution in China and its treatment and re source utilization. – Journal of Agri-Environmental Science 39(6): 1168-1176.
[20] Yang, Y., Liu, R., Ma, J., Li, H., Liu, C., Yue, X., Zhang, W., Hong, Y., Liu, R., Shi, R. (2025): Spatial distribution and utilization potential of agricultural organic waste in Ningxia Hui Autonomous Region. – Journal of Agricultural Resources and Environment 42(1): 118-129.
[21] Zhang, H., Li, J. (2022): Research on the Utilizable Potential and Environmental Benefits of Agricultural Wastes in the Western Region. – Ecological Economy 38(10): 111-118.
[22] Zhang, L. L., Reaihan, E., Ali, M. M., Lin, H. J., Zhang, S., Jin, S. Q., Zhu, Z. P., Hu, J. J., Yao, Y. Q., Sun, Y., Yan, S. P., Liu, Z. D. (2023): Livestock and poultry manure management from the perspective of carbon neutrality in China. – Frontiers of Agricultural Science and Engineering 10(3): 341-362.
[23] Zhang, T., Bu, M. D., Geng, W. (2012): Pollution status and biogas-producing potential of livestock and poultry excrements in China. – Chinese Journal of Ecology 31(5): 1241-1249.
[24] Zhang, Y., Shao, L., Leng, S., Pang, L., Jiang, K., Wang, L. (2019): Assessment of livestock and poultry excrement resources in Shan dong and its fertilizer and energy utilization potential. – China Biogas 37(3): 93-99.
[25] Zhao, J. N., Zhang, G. L., Yang, D. L. (2011): Estimation of carbon emission from burning of grain crop residues in China. – Journal of Agro-Environment Science 30(4): 812-816.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2402_26252641