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GIES Case Study on Liuhe Rice Permanent Basic Farmland

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[2] Zhao, L., Gao, J. Y., Wei, J. X., *et al*. GIES case dataset on Liuhe rice permanent basic farmland [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2026. https://doi.org/10.3974/geodb.2026.04.03.V1.

Abstract: Liuhe County is located on the western foot of the Changbai Mt. and in the hinterland of the Longgang Mt. in Jilin Province, China. Covering a total area of 3,348 km^2, it administers 15 townships, 3 subdistricts, and 219 administrative villages. In 2023, the county's permanent resident population was 251,900, and its regional GDP reached 9.227 billion CNY. Benefiting from a volcanic ash substrate formed by the weathering of Cenozoic basalt, natural mineral spring irrigation, a cool monsoon climate, and high vegetation coverage, the region has developed a distinctive ecological environment conducive to the production of nutrient-rich, safe, and high-quality volcanic-ash-substrate rice. This ecological foundation underpins the China Geographical Indication Certification Trademark of "Liuhe Rice". This study compiles and analyzes data on the location, geomorphology, meteorology, water quality, soil properties, rice variety characteristics, rice quality, and socio-economic conditions in Liuhe County. It systematically elucidates the nutritional and safety advantages of volcanic-ash-substrate rice cultivated on permanent basic farmland and proposes a sustainable development model integrating habitat conservation, green production, whole-chain management, brand development, and technological empowerment. The results indicate that irrigation water in Liuhe is rich in calcium and magnesium, while the soils contain abundant organic matter and mineral elements, with heavy metal concentration far below the risk screening thresholds. The rice is enriched in calcium, magnesium, phosphorus, selenium, and other nutrients, whereas lead and cadmium are either undetected or present only at extremely low concentrations, demonstrating significantly superior nutritional quality and safety compared with conventional rice. Through ecological redline protection, soil conservation, green cultivation practice, standardized production, traceability and monitoring, and the integration of agriculture, culture, and tourism, the study achieves a synergy balance between protecting this rare agricultural habitat and improving industrial quality and efficiency. The case dataset includes location data of the study area, physical geographic data, rice variety characteristic data, management data, photographs, and images. The dataset is archived in .shp, .tif, .xlsx, .docx, and .jpg formats, and consists of 67 files with data size of 79.3 MB (compressed into 1 file with 39.8 MB).

Keywords: Changbai Mountain; Liuhe County; rice; volcanic ash substrate; GIES; Case38

DOI: https://doi.org/10.3974/geodp.2026.03.11

Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: https://doi.org/10.3974/geodb.2026.04.03.V1.

1 Introduction

Against the backdrop of consumption upgrading and the deepening implementation of rural revitalization strategy, the protection and sustainable development of high-quality geographical indication products have thus become a major focus of market attention[1]. As one of China's most important ecological barriers and species gene pools, the Changbai Mt. have nurtured a large number of agricultural products with distinct regional characteristics, owing to their unique geology, landforms and climatic conditions. Volcanic-ash-substrate rice is a typical representative example among them (Figure 1). Liuhe County is located deep in the Longgang Mt. within the Changbai Mountain Nature Reserve, where basalt landforms formed by Cenozoic volcanic activity are widely distributed. Over long-term weathering, these volcanic rocks have gradually transformed into mineral-rich soils with

Figure 1 Liuhe County rice

physicochemical properties. Combined with irrigation from natural mountain springs originating from the residual ranges of the Changbai Mt. and the ample sunlight and large diurnal temperature range under a temperate continental monsoon climate, results in more stable rice growth and avoids the phenomenon of premature senescence in autumn. Together, these natural advantages endow Liuhe volcanic-ash-substrate rice with its unique quality. As a traditional agricultural area and a permanent basic farmland zone, Liuhe County is largely free from major industrial pollution sources. With a forest coverage rate of 56.8%, the region has maintained a relatively intact ecosystem, thereby providing an ideal habitat for the cultivation and sustainable development of volcanic-ash-substrate rice.

However, with the continuous growth in market demand, the development of volcanic-ash-substrate rice industry is facing a series of critical challenges. These includes how to expand cultivation areas while simultaneously safeguarding the fragile volcanic-ash ecosystem and preventing soil degradation and water contamination; how to enhance product added value and market competitiveness through standardized production, quality control and brand development; and how to establish a scientific monitoring and data management system to support the sustainable development of the industry.

2 Metadata of the Dataset

Information on the title, authors, geographical region, the year of the data, data files, data publisher, and data sharing policies of GIES case dataset on Liuhe rice permanent basic farmland[2] is shown in Table 1.

3 Case Dataset Development

3.1 Case Area

The case area is Liuhe County, located in the southeastern Jilin Province and northwest Tonghua City (Figure 2). Liuhe County extends from 41°54′N to 42°35′N and from 125°17′E to 126°35′E, and is situated within the transitional zone between the Changbai Mt. and the Songliao Plain, with a distance of 260 km from the main range of the Changbai Mt. It covers a total land area of 3,348 km^2, and administratively governs 15 townships, 3 sub-districts and 219 administrative villages. In 2023, the county's permanent resident population was 251,900.

3.2 Topography

Liuhe County is situated in the transitional zone from the Changbai Mt. to the Songliao Plain. The overall terrain is higher in the southeast and southwest and lower in the northeast, exhibiting an inclination from the southwest and southeast toward the northeast. The geomorphological landscape is composed primary of middle-low mountains, volcanic lava platforms, and river valley basins. Analysis of elevation and slope within the case area reveals that the middle-low mountains are mostly at elevations ranging from 400 m to 1,000 m, with the highest peak reaching 1,293 m, and are mainly concentrated in the central-southern and southeastern parts of the county (Figure 3). Lava platforms account for 5% of the county's total area, are primarily located in the southeastern part of the county, and belong to the Longgang volcanic cluster; the surface is relatively flat, but steep slopes often occur at the margins. River valley basins account for 15% of the county's total area and are mainly distributed along the Yitong, Santong, Hani, Woji Rivers systems. These areas are dominated by gentle slopes of less than 7° with low-relief and relatively flat terrain. The hydrological conditions are characterized by balanced water retention and drainage conditions, together with stable surface runoff, which are highly favorable for moisture and nutrient conservation in volcanic ash soils. Consequently, this is the core cultivation area for volcanic-ash-substrate rice (Figure 4).

Table 1 Metadata summary of GIES case dataset on Liuhe rice permanent basic farmland

Items	Descriptions
Dataset full name	GIES case dataset on Liuhe rice permanent basic farmland
Dataset short name	LiuheRiceCase38
Authors	Zhao, L., Jilin Agricultural University, zhaol@jlau.edu.cn Gao, J. Y., Jilin Agricultural University, 646882391@qq.com Wei, J. X., Jilin Agricultural University, 2385091066@qq.com Yue, Y. X., People's Government of Liuhe County, Jilin Province, 704184172@qq.com Gu, X. H., Liuhe County Market Supervision and Administration Bureau, 1992442074@qq.com Zhang, Q., Agricultural Technology Extension Station of Liuhe County, Jilin Province, joan1971@126.com Dong, J. W., Liuhe County Market Supervision and Administration Bureau, 510904565@qq.com Tao, Y., Liuhe County Market Supervision and Administration Bureau, taoyuan200808@126.com Li, Q., People's Government of Liuhe Town, Liuhe County, Jilin Province, 379372394@qq.com Gong, W. M., People's Government of Xiangyang Town, Liuhe County, Jilin Province, lhxydzb@163.com An, F. H., People's Government of Ankou Town, Liuhe County, Jilin Province, 1398344312@qq.com Zou, L. X., People's Government of Shengshui Town, Liuhe County, Jilin Province, sszdb@163.com Wang, M. H., People's Government of Hengtong Town, Liuhe County, Jilin Province, htdb123@163.com Zong, G. L., People's Government of Sanyuanpu Korean Ethnic Town, Liuhe County, Jilin Province, sypzf2008@163.com Qian, J. Q., People's Government of Wudaogou Town, Liuhe County, Jilin Province, wdgdjbgs.163.com Qin, Y., People's Government of Hongshi Town, Liuhe County, Jilin Province, liuhehongshi@163.com Zhang, M. L., People's Government of Tuoyaoling Town, Liuhe County, Jilin Province, hszml001@163.com Guo, R. G., People's Government of Liunan Township, Liuhe County, Jilin Province, 29602538@qq.com Yan, H. W., People's Government of Gushanzi Town, Liuhe County, Jilin Province, 29551541@qq.com Li, D. J., People's Government of Liangshuihezi Town, Liuhe County, Jilin Province, 110129446@qq.com Wang, J., People's Government of Luotongshan Town, Liuhe County, Jilin Province, ltsdb666@163.com Liu, T. C., People's Government of Shijiadian Township, Liuhe County, Jilin Province, 726417277@qqq.com Cao, D., People's Government of Jiangjiadian Korean Ethnic Town, Liuhe County, Jilin Province, lhxjjdcxzxrmzh@163.com Shi, Y., Jilin Academy of Agricultural Sciences (Northeast Innovation Center of Chinese Academy of Agricultural Sciences), shiyu9434@163.com Meng, X. J., Jilin University of Finance and Economics, mengxj617@163.com Yu, Y. B., Jilin Watian Agricultural Development Co., Ltd., Jilin Province, watian2007@126.com Hou, Z. F., Jilin Liuhe Guoxin Sheji Shangpin Agricultural Development Co., Ltd., 117407627@qq.com Guan, Y. L., Jilin Province Liuli Grain Co.Ltd., 583820333@qq.com Zhang, X. C., Sijiazi Village, Jiangjiadian Korean Ethnic Township, Liuhe County, Jilin Province, zxc20251209@163.com Yu, H. J., Liuhe County Jiangjiadian Fengtian Rice Industry Co., Ltd., Jilin Province, 815249569@qq.com Li, B., Liaoning University, 157642179@qq.com Qin, Z. S., Jilin Agricultural University, qinzhishuang@jlau.edu.cn Tang, D. W., Jilin Agricultural University, 745925172tdw@163.com Zhao, Z. Z., Jilin Agricultural University, 2814745700@qq.com
Geographical region	Liuhe County, Tonghua City, Jilin Province
Year	2000–2024
Data format	.shp, .tif, .xlsx, .docx, .jpg
Data size	79.3 MB
Data files	Location data, physical geographical data, rice variety characteristics data, management data, etc.
Publisher	Global Change Research Data Publishing System, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China

(*To be continued on the next page*)

(*Continued*)

Items	Descriptions
Data sharing policy	(1) *Data* are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use *Data* subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute *Data* subject to written permission from the GCdataPR Editorial Office and the issuance of a *Data* redistribution license; and (4) If *Data* are used to compile new datasets, the "ten percent principle" should be followed such that *Data* records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[3]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS, GEOSS, PubScholar, CKRSC

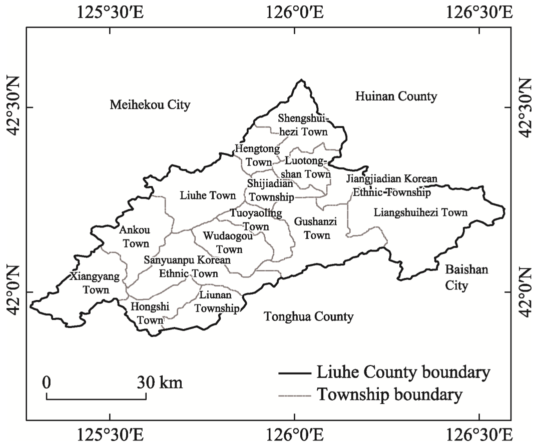

Figure 2 Map of the geo-location and administrative divisions of Liuhe County

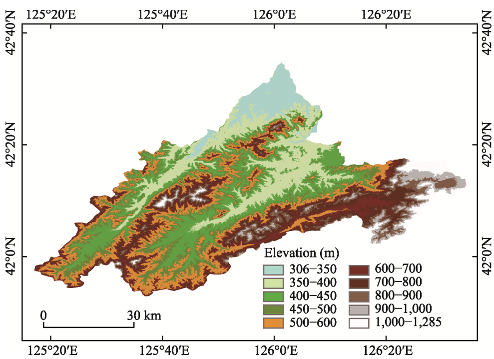

Figure 3 Elevation classification map of Liuhe County

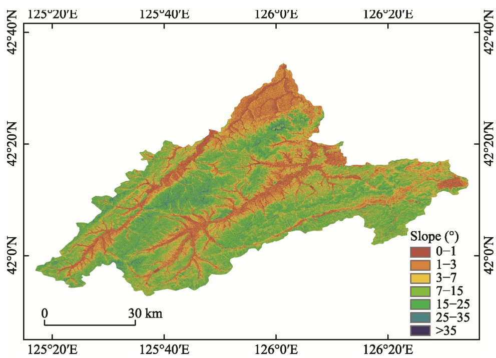

Figure 4 Slope classification map of Liuhe County

3.3 Land Use and Vegetation Cover

The authors utilized Landsat-5 and Landsat-9[1] imagery to derive the Normalized Difference Vegetation Index (NDVI) for the case area. Liuhe County exhibits distinct spatial characteristics in land use and vegetation: the mid-low mountainous areas are dominated by forestry, with significantly increased vegetation cover serving as an important ecological barrier; the lava platform shows increased vegetation cover and favorable hydrothermal conditions suitable for developing characteristic agriculture (e.g., rice cultivation); the valley basin maintains relatively stable vegetation cover and is dominated by agricultural land use (Figures 5 and 6).

Cultivated land in Liuhe County is mainly composed of thin volcanic ash-derived soils, with a single cropping system per year, representing a transitional black soil belt grain-

[1] EROS data center. https://earthexplorer.usgs.gov/.

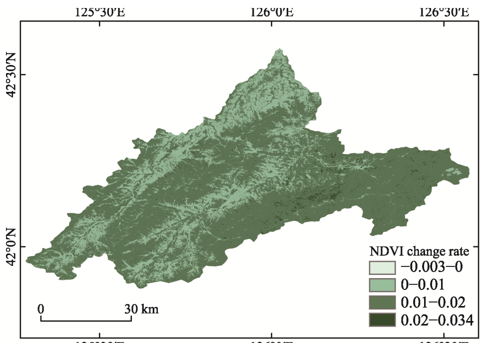

Figure 5 Change rate of NDVI in Liuhe County (2000–2025)

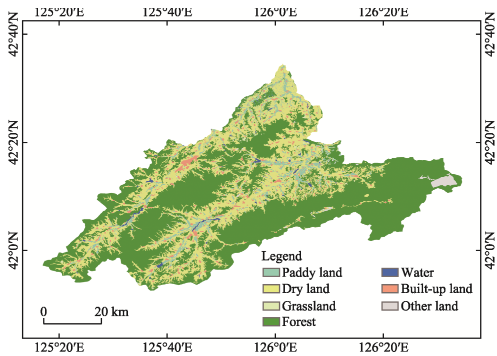

Figure 6 Land use map of Liuhe County (2024)

producing area. The relatively high NDVI values in this region indicate a sound ecological background and vigorous growth of paddy field vegetation. Dense vegetation cover helps maintain the stability of the paddy field ecosystem, reduce the risks of soil erosion and non-point source pollution, thereby forming a unique habitat support system characterized by the integrated framework of "basalt platform-volcanic ash substrate -wetlands/reservoir clusters".

3.4 Climatic Conditions

Liuhe County features a temperate continental monsoon climate, which is highly suitable for the growth of high-quality japonica rice. The coincidence of rainfall and heat during summer facilitates vigorous rice growth and dry matter accumulation. The large diurnal temperature variation in autumn accelerates the translocation of photosynthates to grains and promotes the synthesis of starch and flavor substances. Despite no rice cultivation in winter, the prolonged period of severe cold and snow cover effectively reduce overwintering pest and disease populations and lower pesticide applications.

According to data from the Liuhe Meteorological Bureau, the mean temperature is –15.001 ℃ in January and 21.548 ℃ in July. The annual precipitation averages 736.3 mm, mainly concentrated from June to August. The total annual sunshine duration is 2,560 h, among which 1,160 h occur during the rice growing period. The active accumulated temperature above 10 ℃ ranges from 2,214 ℃ to 2,948 ℃, with a frost-free period of 130 to 140 d (Figure 7). The relatively short frost-free period imposes natural selective pressure on

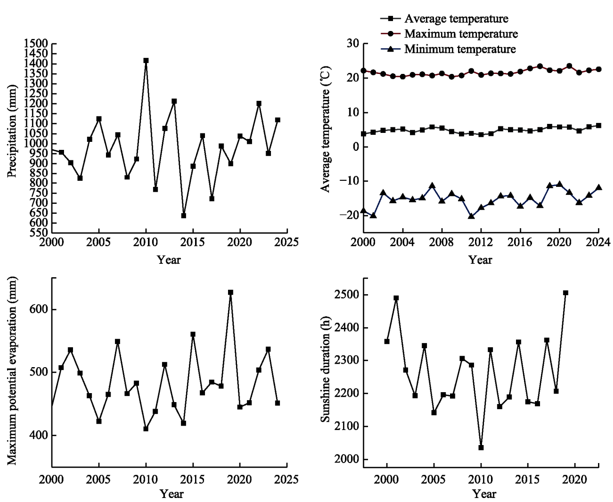

Figure 7 Climate characteristics change of Liuhe County

early-maturing rice varieties, concentrating grain filling in periods with optimal light and heat conditions, and comprehensively improving both the taste quality and food safety of Liuhe rice.

3.5 Water Conditions

The case area is endowed with abundant water resources, including 3 medium-sized reservoirs and 97 small reservoirs and more than 60 rivers of varying sizes originate from the Changbai Mt. The total water surface area reaches 7,600 ha, with an average annual total water resource volume of 1.28 billion m^3. The unique hydrological system characterized by abundant water yield, clean water quality, mineral replenishment and precise water regulation, not only meets the physiological water demand of rice, but also promotes dry matter accumulation. It serves as a critical ecological foundation for the distinctive properties of Liuhe rice, including green production, high quality and calcium enrichment.

A total of 11 water samples were collected from paddy fields, irrigation canals and sunning water ponds in the case area (Figure 8) and subsequently analyzed by the Institute of Agricultural Quality Standards and Testing Technology, Jilin Academy of Agricultural Sciences (Northeast China Innovation Center for Agricultural Science and Technology).

Water quality testing (Table 2) showed that pH ranged from 6.99 to 7.57, electrical conductivity ranged from 90.5 to 420 μS/cm, calcium content ranged from 5,844 to 63,018 μg/L, and magnesium content ranged from 1,908 to 20,605 μg/L. The water is rich in minerals and exhibits a low-salinity, neutral to weakly alkaline condition, ensuring rice safety and the formation of mineral-rich nutrition from the source.

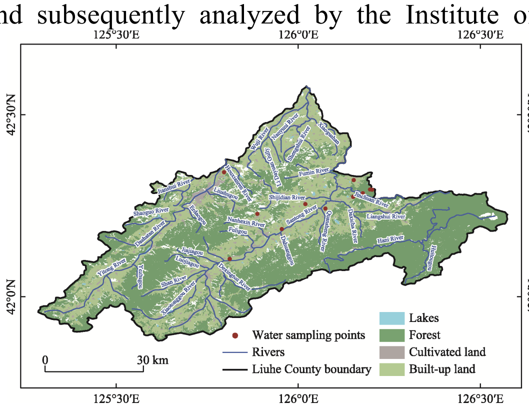

Figure 8 Distribution map of water sampling sites in Liuhe County

Table 2 Statistical testing results of water nutrient in Liuhe County

Samples	pH	Total water-soluble salt content (electrical conductivity at 25 ℃)	Mg	P	K	Ca	Mo	Mn	Fe
Unit	–	μS/cm	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L
W1	7.57	153	7,384	24.7	1,380	9,411	1.20	0.950	118
W2	7.38	110	5,301	42.1	586	5,844	0.72	0.982	432
W19	7.04	173	5,646	27.3	1,109	15,505	0.71	1.340	167
W21	7.30	188	9,260	55.4	901	13,648	0.99	1.160	101
W22	7.28	167	5,574	38.5	978	15,927	0.23	0.770	162
W23	7.12	90.5	1,908	61.8	1,871	6,785	0.46	3.110	449
W24	6.99	414	20,605	45.6	369	63,018	0.83	2,444	231
W25	7.37	420	18,163	67.0	452	54,753	0.78	11.700	71
W26	7.45	316	9,239	58.8	1,914	44,909	1.69	5.510	80
W27	7.48	327	8,146	69.1	426	41,162	0.55	3.700	164
W28	7.48	256	8,286	47.7	660	32,305	1.11	1.830	52

Note: water samples in this study were collected in multiple batches, with samples from each batch numbered independently according to the sampling sequence. Consequently, the sample IDs are non-consecutive, and this numbering scheme does not affect the reliability of subsequent statistical analyses or conclusions. The same below. – indicates no corresponding data.

Among the 11 tested water samples, the concentrations of all hazardous substances were far below the limit values specified in the national Standard for irrigation water quality (GB 5084—2021)[4] (Table 3).

Table 3 Statistical testing results of heavy metal content in water of Liuhe County Unit: μg/L

Samples	Cr	Ni	Cu	Zn	As	Se	Cd	Hg	Pb
W1	0.286	0.80	0.84	ND	0.78	0.378	ND	0.276	0.050
W2	0.410	1.34	1.16	ND	0.93	0.444	ND	0.194	0.141
W19	0.185	1.05	0.69	ND	1.01	0.185	ND	0.087	0.094
W21	0.278	1.35	1.36	ND	1.28	0.170	ND	0.090	0.107
W22	0.232	0.57	2.49	ND	1.07	0.064	ND	0.089	ND
W23	0.741	0.90	3.65	0.970	1.46	1.080	ND	0.089	0.094
W24	0.263	2.46	2.88	0.883	2.31	0.438	ND	0.100	ND
W25	0.123	1.22	2.55	ND	4.73	0.118	ND	0.092	ND
W26	0.386	0.71	4.42	ND	1.88	0.322	ND	0.088	ND
W27	0.316	0.45	2.23	ND	1.36	0.023	ND	0.086	ND
W28	0.299	0.70	3.03	ND	1.51	0.096	ND	0.086	ND
Limits[4]	≤100	≤200	≤500	≤2,000	≤50	≤20	≤10	≤1	≤200

Note: ND indicates not detected.

3.6 Soil Conditions

Liuhe County features a unique volcanic geomorphology. Basalt magma upwelled through massive crustal fractures, forming the extensive Changbai Mt. basalt platform. In this study, 9 soil samples were collected from concentrated rice cultivation fields in the case area (Figure 9). The concentrations of trace element contents in soil samples were analyzed by the Jilin Academy of Agricultural Sciences (Northeast Innovation Center for Agricultural Science and Technology of China).

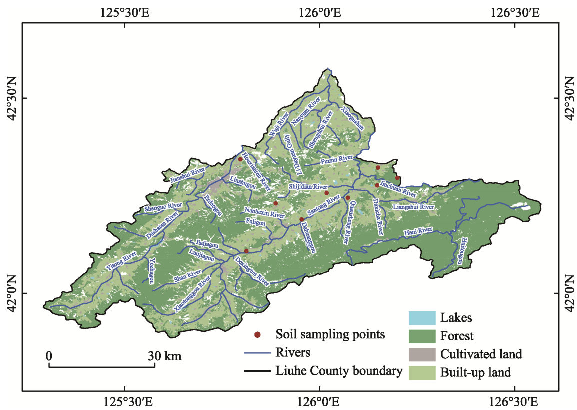

Figure 9 Distribution map of soil sampling sites in Liuhe County

The soil samples exhibited pH ranging from 5.36 to 6.26, organic matter content of 11.7–34.3g/kg, and total potassium concentration of 18,280–24,570 mg/kg, with abundant calcium, magnesium, iron, and manganese (Table 4). From the perspective of growth-promoting mechanisms, calcium can strengthen the cell wall structure of rice plants, enhancing their lodging resistance and disease tolerance. The abundant calcium in the soil results in significantly higher calcium content in Liuhe rice compared with conventional rice, markedly improving its nutritional value. Magnesium, as a core component of chlorophyll, can effectively improve photosynthetic efficiency.

Table 4 Statistical testing results of soil nutrient in Liuhe County

Test item	S19	S21	S22	S23	S24	S25	S26	S27	S28	Average value
pH	5.93	5.36	5.78	5.80	5.90	5.68	6.08	5.89	6.26	5.85
OM（g/kg)	34.3	27.40	20.60	31.00	20.70	17.10	20.00	26.30	11.70	23.23
TN (mg/kg)	1,950	1,690	1940	2,570	2,110	2,140	2,710	1,740	2,160	2,112.22
TP (mg/kg)	843.3	1,130	830	1,080	930	940	1,210	970	760	965.92
TK (mg/kg)	19,200	20,610	19,500	20,090	19,630	20,290	18,280	24,570	18,950	20,124.44
Mg (mg/kg)	8,336	6,449	7,974	9,074	6,726	8,081	11,867	8,309	8,042	8,317.56
Ca (mg/kg)	4,156	4,336	3,577	4,058	2,940	5,546	25,358	10,707	4,396	7,230.44
Mn (mg/kg)	533	679	473	368	439	828	549	509	563	549
Fe (mg/kg)	33,426	34,223	36,100	36,341	32,428	31,425	36,376	36,296	31,910	34,280.56

Among the 9 soil samples, the concentrations of chromium, nickel, copper, zinc, arsenic, cadmium, mercury, and lead were all far below the risk screening values specified in GB15618—2018[5]. The average values of copper, zinc, and cadmium were 27.8 mg/kg, 101.1 mg/kg, and 0.24 mg/kg, accounting for only 55.6%, 50.5%, and 62.2% of the screening values, respectively. The test results presented in Table 5 indicate that the soil environmental quality in this region is excellent, clean, and pollution-free, providing a fundamental guarantee for the production of safe and high-quality volcanic ash-based rice. The extremely low contents of chromium and nickel further confirm that when water flows through the basalt strata, it does not dissolve excessive heavy metals, reflecting the stability and safety of the volcanic rock filtration system.

Table 5 Statistical testing results of soil heavy metal contents in Liuhe County

Test item	S19	S21	S22	S23	S24	S25	S26	S27	S28	Average value	Limits[5]
Cr (mg/kg)	82.3	147.7	100.8	88.3	74.3	72.3	94.7	220.1	83.5	107.1	≤250
Ni (mg/kg)	37.7	32.3	30.6	35.6	30.8	31.7	37.3	30.9	34.8	33.5	≤70
Cu (mg/kg)	23.3	33.7	21.1	28.6	24.0	31.9	35.8	26.4	25.1	27.8	≤50
Zn (mg/kg)	88.8	90.5	89.5	111	83.8	99.8	173	83.1	90.6	101.1	≤200
As (mg/kg)	7.44	11.9	7.53	7.05	7.18	19.5	10.1	5.54	7.82	9.34	≤30
Cd (mg/kg)	0.261	0.260	0.228	0.337	0.205	0.295	0.2	0.212	0.240	0.28	≤0.4
Hg (mg/kg)	0.0511	0.0682	0.0388	0.0421	0.0363	0.0425	0.0478	0.0217	0.0386	0.043	≤0.5
Pb (mg/kg)	25.1	30.8	26.3	29.1	23.6	29.9	47.4	21.1	25.3	28.7	≤100

4 Liuhe Rice Product Characteristic Data

4.1 Characteristics of Major Rice Cultivars

(1) Wuyoudao No. 4

Wuyoudao No. 4 is a conventional late-maturing japonica rice cultivar characterized by translucent grains and excellent eating quality. It is cultivated using alternate shallow and intermittent irrigation, resulting in outstanding grain quality. The growth duration is 143 d, requiring an accumulated temperature above 10 ℃ of approximately 2,850 ℃, belonging to the medium-late maturing category. The cultivar exhibits a compact architecture with erect flag leaves, green stems and foliage and a plant height of 122.1 cm. It exhibits strong tillering ability, with an effective panicle number of 4.095 million per ha. Panicles are curved and 19.5 cm in length, containing an average of 115.8 grains per panicle, and a seed setting rate of 78.4%. Grains are spindle-shaped with yellow glumes and apiculi, sparse awns; and a thousand-grain weight of 27.7 g.

Regarding the main rice quality indicators, the brown rice rate is 84.7%, milled rice rate is 72.7%, head milled rice rate is 64.8%, grain length is 6.3 mm, length-to-width ratio is 2.7, chalky grain rate is 46.0%, transparency is grade 1, alkali spreading value is grade 7.0, gel consistency is 65 mm, amylose content is 16.6%, and protein content is 7.30%[6].

(2) Zhongkefa No. 5

Zhongkefa No. 5 is a conventional japonica rice cultivar with a whole growth duration of 150.1 d. Its plant height is 102.8 cm, and the panicle length is 17.8 cm. The effective panicle number reaches 4.095 million panicles per ha, with 118.3 grains per panicle, a seed setting rate of 79.9%, and a thousand-grain weight of 26.9 g. The comprehensive rice blast index was 2.0 and 2.4 in two consecutive years, and the maximum neck blast loss rate reached Grade 5, indicating moderate susceptibility to rice blast. The main grain quality indicators are as follows: the head rice rate is 70.1%, the chalky grain rate is 6.0%, the chalkiness degree is 1.8%, the amylose content is 16.1%, the gel consistency is 70 mm, and the length-to-width ratio is 3.0. This cultivar was awarded the Gold Medal in the japonica rice group at the Fifth National High-Quality Rice Evaluation[7].

(3) Jihong No. 6

Jihong No. 6 is a medium-to late- maturing, aromatic japonica rice variety belonging to the genus Oryza (family Poaceae). This variety has a growth duration of approximately 138 d, a plant height of 104 cm, a panicle length of 17.3 cm, and a thousand-grain weight of 24.0 g. In terms of disease resistance, it exhibits moderate resistance to seedling and leaf blast, but is susceptible to panicle blast.

Regarding the main rice quality indicators, the cultivar exhibits a brown rice rate of 82.6%, milled rice rate of 74.3%, head milled rice rate of 70.4%, grain length of 5.0 mm, length-to-width ratio of 1.7, chalky grain rate of 13.0%, chalkiness degree of 1.3%, transparency of grade 1, alkali spreading value of grade 6.7, gel consistency of 88 mm, amylose content of 15.6%, and protein content of 6.88%.

4.2 Product Quality Data

2 rice samples representing major local cultivars were analyzed in this study. Rice Sample 1 (named "Jitong" for laboratory submission) was randomly collected from a family farm in Jiangjiadian Township. This sample belongs to is the super rice category (including Jihong No. 6 and other varieties, which are all small-grain varieties with similar characteristics; they are not distinguished during purchasing, processing, and marketing, and are collectively referred to as super rice). Rice Sample 2 (named "Jiangdao" for laboratory submission) was a mixed sample sourced from family farms in Sijiazi Village, Jiangjiadian Korean Ethnic Township, as well as from Watian Rice and Guoxin Rice. The principal cultivar is Wuyoudao No. 4 (Daohuaxiang No. 2). All samples were analyzed by the Institute of Agricultural Product Quality Safety and Inspection, Heilongjiang Academy of Agricultural Sciences. The results are shown in Tables 6 and 7.

Table 6 Statistical testing results of trace element (nutrient) of Liuhe rice

Test item	Sample 1	Sample 2	Samples	Sample 1	Sample 2
Ca (mg/kg)	71.6	67.3	Co (mg/kg)	0.00477	0.00438
K (mg/kg)	888	652	Se (mg/kg)	0.043	0.097
P (mg/kg)	907	879	Cu (mg/kg)	1.92	1.74
Mg (mg/kg)	211	200	Mo (mg/kg)	0.426	0.436
Mn (mg/kg)	12.3	11.3	Ti (mg/kg)	0.167	0.134
Fe (mg/kg)	4.09	3.20	Si (mg/kg)	69.6	57.5
Zn (mg/kg)	12.9	13.3			

Table 7 Statistical testing results of safety and hygiene indicators of Liuhe rice

Test item	Sample 1	Sample 2	Limits[8]	Test item	Sample 1	Sample 2	Limits[8]
Pb (mg/kg)	ND	ND	0.2	Ni (mg/kg)	ND	ND	/
Cd (mg/kg)	0.0136	0.0164	0.2	As (mg/kg)	0.0993	0.128	0.35
Cr (mg/kg)	0.0911	0.0840	1.0	Hg (mg/kg)	0.00552	0.00464	0.02

The rice samples from the case area exhibited high concentrations of calcium, phosphorus, and magnesium. Specifically, the calcium concentrations ranged from approximately 67.3 to 71.6 mg/kg, phosphorus concentrations ranged from approximately 879 to 907 mg/kg, and magnesium concentrations ranged from approximately 200 to 211 mg/kg, reflecting the enrichment effect of mineral elements in the volcanic rock soil. In addition, trace elements including zinc, manganese, iron, and selenium were detected in all samples, further demonstrating the advantage of volcanic ash-based rice in terms of trace element concentrations. Magnesium is an important mineral involved in hundreds of biochemical reactions in the human body, and is essential for maintaining neuromuscular function and stabilizing blood glucose and blood pressure. Therefore, the products from the case area also exhibit strong competitiveness with respect to certain trace elements.

The heavy metal concentrations in both samples complied with the maximum permissible limits specified in the National food safety standard—maximum levels of contaminants in food (GB 2762—2022)[8] (Table 7). This reflects that Liuhe County performs well in controlling hazardous elements, with no detected exceedances, ensuring the food safety of the rice consumption.

5 Socioeconomic Development and Industrial Management

5.1 Socioeconomic Development of Liuhe County

From 2020 to 2023, Liuhe County experienced a continuous population outmigration, however, its overall economic development level continued to improve steadily, and the comprehensive agricultural production capacity continued to strengthen (Table 8). As a traditional advantageous and characteristic industry in Liuhe County, the rice industry has consistently played an important role in improving quality and efficiency, conserving water and soil resources, and diversifying the planting structure, leveraging the region's high-quality black soil resources and ecological conditions. By reducing low-efficiency planting areas and developing high-quality premium rice, the industry has effectively promoted high-quality agricultural development in the county.

Table 8 Socioeconomic statistics of Liuhe County (2020–2023)[2]

Year	Resident population (10^4 persons)	GDP (10^6 CNY)	GDP per capita (CNY)	Added value of primary industry (10^6 CNY)	Grain cultivated area (ha)	Grain yield (10^7 kg)	Rice cultivated area (ha)	Rice yield (10^7 kg)
2020	35.39	79.92	22,485	21.18	88,350	56.68	20,180	14.1
2021	26.49	82.74	30,782	21.56	88,400	57.7	18,458	13.2
2022	25.53	88.83	34,152	24.18	89,439	58.4	16,374	11.45
2023	25.19	92.27	36,384	23.81	89,664	59.4	16,136	11.41

5.2 History and Heritage of Rice Production

According to historical records, rice cultivation in Liuhe County can be traced back to the early Tang Dynasty (early 7th century). In the 32nd year of the Guangxu reign of the Qing Dynasty (1906 CE), irrigation canals were constructed to divert water for irrigation, leading to contiguous paddy field cultivation, marking the emergence of systematic irrigation engineering and rice cultivation techniques in this region. Liuhe rice gained renown for its plump grains, crystal clarity, rich aroma, delicate sweetness, high nutritional value, and pure taste, earning a distinguished reputation both domestically and abroad. Throughout the Song, Yuan, Ming, and Qing dynasties, Liuhe rice was consistently a tribute rice to the imperial court, ranking alongside the "Three Treasures of Northeast China" (ginseng, sable fur, and antler velvet) for royal consumption. Following the founding of the People's Republic of China, Liuhe rice, possessing unparalleled quality and edibility, became the designated rice for state banquets at the Great Hall of the People.

According to the Annals of Liuhe County, at the time of the county's establishment in 1902, approximately 3,300 ha of farmland had already been reclaimed. The main crops included soybean, sorghum, maize, millet, wheat, and adzuki bean, followed by rice and upland rice (dryland rice), barley, barnyard millet, buckwheat, broomcorn millet, and mung bean. In the early period of the county's establishment, some Korean ethnic groups migrated to Liuhe, introducing rice cultivation techniques, and paddy rice farming began.

By the time of the founding of the People's Republic of China in 1949, the rice planting area had expanded to 4,652 ha. Relying on the volcanic rock landforms, the Korean

[2] Data source: Liuhe County Statistical Yearbook.

ancestors, developed unique rice cultivation traditions. They selected indigenous japonica varieties that were tolerant to low fertility and had good taste, fertilized the land mainly with organic manure supplemented by limited chemical fertilizers, and followed seasonal rhythms including soaking seeds at the Spring Equinox and harvesting at the Autumn Equinox. These practices formed a characteristic agricultural tradition centered on farming in harmony with climate conditions. For irrigation, they used volcanic fissure water to construct "open canal and underground drain" systems: open canals for water diversion and underground drains for drainage, following the rule of "shallow irrigation at tillering stage, deep irrigation at booting stage, and field drying at maturity stage", achieving alternating wet-dry conditions. Rice processing and consumption retained the traditional habit of "grinding fresh for immediate eating", with stone mills preserving nutrients; brown rice was used for porridge, and rice milk for specialty foods. During the autumn harvest season, the "New Rice Festival" was held, where freshly harvested rice was steamed, rice cakes were made, and local community celebrated the harvest while showing reverence for farming culture. Regarding inheritance, the "master-apprentice" approach passed down techniques, while enterprises have integrated tradition with modern technology, introducing bio-organic fertilizers and intelligent monitoring equipment. Exhibition halls and training workshops have also been established, revitalizing the volcanic ash-based rice farming culture.

Furthermore, Liuhe County has made notable progress in integrating traditional cultivation techniques of volcanic ash-based rice with modern agricultural technologies. Through cultural activities such as the New Rice Festival and agricultural extention training programs, the county has not only preserved the century-old culture heritage of volcanic ash-based rice cultivation, but has also promoted the application of modern technologies in traditional agriculture, thereby injecting new momentum into the sustainable development of the volcanic ash-based rice industry.

5.3 Whole-Process Quality Control of Rice Production

Liuhe County has established a standardized planting and whole-process quality control system for rice cultivated on volcanic ash substrates. The system integrated seedling raising, field cultivation, irrigation, fertilization, green pest prevention, harvesting, processing, warehousing and quality inspection into a unified management framework. By implementing the "Six Unifications" management model, the county achieves classified harvesting and segregated storage, and ensures traceability at key production points throughout the whole chain, and thereby guarantee the stable and consistent quality of local rice products.

5.3.1 Seed Treatment

Before seed soaking, rice seeds are spread evenly into a thin layer with thickness of 5–7 cm and sun-dried under weak light for 2–3 d, with turning 3–4 times per day. Fungicides are applied for seed disinfection; the liquid level should be 15 cm above the seeds. The seeds are soaked for 5–7 d with an accumulated temperature of 100 ℃ and stirred twice daily. Seed coating agents can also be used as an alternative. During germination acceleration, the seed pile thickness shall not exceed 50 cm, the temperature is controlled at 28–30 ℃, and turning is conducted 3–4 times per day. After 80% of the seeds break through the glume, the seeds are transferred to a cool and shaded place for slow cooling before subsequent use.

5.3.2 Sowing

The greenhouse should be covered with plastic film 15 days prior to sowing. Seedbeds are shallowly tilled to a depth of 5–10 cm, and fully watered one day in advance. The seedbed soil is sieved and adjusted to a pH of 4.5–5.5 prior to use. Sowing is conducted from early to mid-April using either flat tray or bowl type blanket seedling cultivation methods. For machine-transplanting trays, 100–120 g of per-germinated seeds is sown per tray; whereas 60–80 g per tray is used for manual-transplanting trays. In bowl-type nursery trays, 4–6 seeds are sown in each cell.

5.3.3 Nursery Management

Stage-specific precision regulation is adopted for nursery management. From sowing to seedling emergence, the seedbed is thoroughly watered in a timely manner in case of water shortage. Plastic film covering would be removed once the seedling emergence rate exceeds 60%, and greenhouse temperature shall be controlled below 30 ℃. From seedling emergence to the 1.1-leaf stage, greenhouse temperature is maintained at 25 ℃–28 ℃ to keep bed soil consistently moist. During the 1.1–2.5 leaf stage, the greenhouse temperature is kept at approximately 25 ℃, and moderate ventilation is carried out on sunny days for seedling hardening. From the 2.5-leaf stage to transplanting, ventilation intensity is increased when the minimum nighttime temperature is higher than 10 ℃. Plastic film is removed at night 7–10 days before transplanting. Meanwhile, the "three-belt" management measures are implemented: 15–20 g of ammonium sulfate is applied per square meter of seedbed; thiamethoxam is sprayed to control rice leafminer; and Bacillus subtilis is applied to promote seedling regreening and tillering.

5.3.4 Transplanting

Transplanting is carried out from 15 to 25 May with a planting spacing of 30 cm × (13–20 cm), with a planting density of 17–25 hills per square meter. Uniform planting depth is maintained during transplanting to avoid seedling bending and missing hills.

5.3.5 Field Management

Field management strictly follows the principles of heavy base fertilizer application, nitrogen reduction and delayed application of tiller fertilizer during the tillering stage, and equal dosage rates of panicle fertilizer and tiller fertilizer. For base fertilizer, 20–40 m^3 of decomposed farmyard manure is applied per ha, combined with phosphorus fertilizer, potassium fertilizer and zoned quantitative nitrogen fertilizer. In saline-alkali soils, zinc sulfate is additionally applied to improve soil conditions and nutrient availability. Tillering fertilizer is applied in mid-June, and panicle fertilizer together with supplementary potassium fertilizer is supplied in early to mid-July.

A zone-specific irrigation regime is implemented throughout the growing season. Shallow water management is retained from transplanting to the tillering stage to protect seedlings and promote tillering, and moderate field drying is conducted at the late tillering stage. Intermittent shallow-wet irrigation and deep water irrigation under low temperature are adopted from young panicle differentiation to the milky-ripe stage for panicle protection. Alternating drying and wetting conditions with nighttime irrigation are maintained from the milky-ripe stage to pre-harvest, and irrigation is cut off one week before harvesting, so as to ensure the stable growth throughout the whole growth cycle.

5.3.6 Pest, Disease and Weed Control

The prevention and control of diseases, pests and weeds follow the principle of prioritizing agricultural, physical and biological control, with scientific chemical control as auxiliary measures, and strictly abides by pesticide application specifications.

Agricultural control measures mainly include varietal replacement, vigorous seedling cultivation, rational planting density and field sanitation. Biological control strategies adopt Trichogramma parasitoids, sex pheromone traps and biological agents. Physical control relies on insecticidal lamps to trap and kill pests. Targeted pesticides are selected for chemical control to prevent and treat rice blast, rice false smut, chilo suppressalis and field weeds, with strict compliance to the pesticide safety intervals and application regulations.

5.4 Rice Industry Development

In recent years, the number of rice brands in Liuhe County has grown to 35, including well-known brands such as "Liuhe Rice", "Watian", "Sheji Shangpin", and "Dami Jie". The county has achieved 19 certified green food-certified products, among which "Liuhe Rice" has obtained the China Geographical Indication Certification Trademark. Volcanic ash-based rice in Liuhe County has successively won numerous awards, including the title of China's Famous Agricultural Products, the Gold Medal Rice at the China Rice Expo, and "Jilin Provincial Famous Brand". Academician Yuan Longping inscribed a commendation for "Liuhe Rice" and gave it high praise.

In terms of industrial development, Liuhe County has effectively enhanced the brand value and market competitiveness of volcanic ash-based rice through multiple models such as "company+farmer" partnerships, standardized cultivation systems, ecological management practices, and scientific and technological cooperation. Leading enterprises such as Guoxin Sheji Shangpin and Jilin Watian Agricultural Development Industry have introduced advanced processing equipment, promoted organic certification, and expanded online and offline marketing channels[9]. These efforts have not only increased product added value but also raised the income of local farmers, achieving a positive interaction between ecological conservation and regional economic development.

5.5 Ecological Environment Traceability for Liuhe Rice

To improve the effective traceability of rice growth environment and cultivation processes, automatic observation stations for rice habitats have been constructed. Adopting a low-power low-power internet of things (IoT) sensing system, the stations can monitor, automatically identify and continuous record 10 targeted observation parameters in real time, including landscape video, air temperature, air humidity, air quality, wind speed and wind direction (Figure 10).

Figure 10 GIES ground station in Liuhe County

6 Discussion and Conclusion

Case studies confirm that the soil in the volcanic plateau of Liuhe County is derived from basalt weathering and rich in potassium, calcium, magnesium, phosphorus and other minerals and trace elements. These soil properties provide a continuous and stable nutritional supply for rice growth, laying a solid foundation for the high yield and superior quality of rice cultivated on volcanic ash substrates. Meanwhile, the irrigation water originates from natural spring water of the Changbai Mt. Naturally filtered through volcanic rock strata, the water is clean, clear and mineral-rich, with all indicators better than the national standard for farmland irrigation water, which fundamentally ensures a pure and safe growth environment for rice and highlights the natural advantages of Liuhe rice.

Taking ecological protection as the principal base of regional development, Liuhe County has established an integrated sustainable development system encompassing precise habitat management, eco-friendly cultivation practices, standardized whole-process production, brand-oriented operation, traceability management by science and technology, as well as rice culture inheritance, thereby realizing the organic integration of ecological, economic and social benefits. The findings indicates that volcanic ash substrate constitutes the core endowment for the high nutrition and safety of Liuhe rice; strict habitat protection serves as the fundamental premise for the sustainable development of the rice industry; standardized production, brand operation and digital management act as critical approaches to enhance product value.

The development model of Liuhe rice industry effectively embodies the ecological development philosophy of China. It not only promotes quality improvement and efficiency growth of local geographical indication products, but also provides a replicable and popularizable typical model for the protection and utilization of characteristic agricultural products in the Changbai Mt. and other volcanic rock areas nationwide, the high-quality development of geographical indication products, and the implementation of the rural revitalization strategy.

Author Contributions

Zhao, L. was responsible for the overall design of the study, conducting investigations, sampling, data collation, and manuscript writing. Yue, Y. X. provided overall guidance. Shi, Y. offered guidance on rice cultivation. Meng, X. J. offered guidance on ecological environment analysis. Zhang, Q. offered guidance on the production and management analysis of Liuhe rice and assisted in connecting with farmers. Gao, J. Y. created the spatial maps. Wei, J. X. collected and processed samples. Gu, X. H., Dong, J. W. and Tao, Y. coordinated the investigations. Tang, D. W. and Li, B. were responsible for investigations, sampling, and data collection. Qin, Z. S. and Zhao, Z. Z. were responsible for video production. The other authors participated in data collection. All authors contributed to the discussion of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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