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The Environmental Impacts of the Grassland Agricultural System and the Cultivated Land Agricultural System: A Comparative Analysis in Eastern Gansu

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Abstract: "Introducing grass into fields", the major approach to modern grassland agriculture, is the crucial direction of agricultural structure adjustment in the farming-pastoral zone of Northern China. However, there have been few studies on the environmental impacts of agricultural production in this pattern. We used the life cycle assessment (LCA) method for the first time from the perspective of the entire industry chain from agricultural material production to livestock marketing, which involves the combination of planting and breeding. A comparative analysis of the environmental impact processes of beef and pork, the main products of the two existing agricultural systems in Eastern Gansu, was conducted. The findings showed that based on the production capacity of the 1 ha land system, the comprehensive environmental impact benefit of the grassland agricultural system (GAS) in the farming-pastoral zone was 21.82%, higher than that of the cultivated land agricultural system (CLAS). On Primary energy demand (PED) and environmental acidification potential (AP), the GAS needs improvement because those values were 38.66% and 22.01% higher than those of the CLAS, respectively; on global warming potential (GWP), eutrophication potential (EP), and water use (WU), the GAS performed more environment-friendlily because those values were 25.00%, 68.37%, and 11.88% lower than those of the CLAS, respectively. This indicates that a change in land use will lead to a change in environmental impacts. Therefore, PED and AP should be focused on the progress of grassland agriculture modernization by "introducing grass into fields" and new agricultural technologies.

Keywords: agricultural system; modern grassland agriculture; life cycle assessment; farming-pastoral zone

1. Introduction

Modern grassland agriculture, a sort of eco-agriculture, is developed from the combination of conventional Chinese intensive and meticulous farming and Western "livestock agriculture" [1]. This modern agricultural method takes into account not only ecology and production but also food and feed. Therefore, it has the advantage of being energy-saving, efficient, environment-friendly, and sustainable [2]. Li characterized modern grassland agriculture as "three over-50%s," meaning that the proportions of grassland feed in agricultural land, the grass-feeding livestock output value in the whole livestock husbandry, and the livestock husbandry output value in the whole agriculture are all over 50% [3]. In agriculture-developed countries, the major approach to modern grassland agriculture is "introducing grass into fields" along with new agricultural technologies [4,5]. Through combining crop planting and livestock breeding, the single planting mode is replaced and a comprehensive agricultural system is established. Meanwhile, new agricultural technologies are powerful and indispensable aids. For example, precise pig breeding, carbon-based straw fertilizer, and GPS-based wheat planting are all advanced technologies that lead to clean and efficient production [6]. Moreover, with the advancement of the "grain-to-feed" policy from China's 13th Five-Year Plan (the 13th five-year national economic and social development scheme promoted by the Chinese government), forage was strongly encouraged to be planted, and the ratio of grain, cash crop, and forage planting areas was proposed to be adjusted to about 4:3:3 in Northern China's farming-pastoral zone in 2016 [7]. This has guaranteed enough space for the development of modern grassland agriculture in the entire industrial chain. In Northern China, the farming-pastoral zone has increasingly become a vulnerable ecotone [8], where the grassland agricultural system (GAS) and the cultivated land agricultural system (CLAS) are the two main agricultural systems, and the land use change is a major concern for the management of the local fragile ecosystem [9]. In the GAS, forage planting and grass-feeding livestock breeding are the core; in the CLAS, grain and crop planting with poultry and livestock fed by them is the core. Eastern Gansu, as a typical ecotone, has formed a pattern of the coexistence of the GAS and the CLAS. In this region, the GAS mainly consists of grain/*alfalfa* planting and beef cattle breeding, and the CLAS mainly consists of grain planting and pig breeding. In recent years, the structure of China's food demand has shown a trend that the proportion of direct grain consumption is decreasing year by year while the demand for feed grain is increasing year by year [10]. Currently, most research is focused on economic benefits analysis in the process of agricultural framework adjustment from cultivated land agriculture to grassland agriculture. Yu et al. analyzed the scale and industrial advantages of grassland livestock husbandry in Qinghai Province through output value analysis, input-output analysis, and other methods, and suggested upgrading the local livestock husbandry to modern grassland industry [11]; Li and Zhang observed grassland agriculture in Guilin from the perspective of economic analysis and strongly recommended developing intensive grassland agriculture there [12]. However, the environmental impacts of land use change from cultivated land agriculture to grassland agriculture and must be emphasized and analyzed because land use conversion in agricultural systems could have significant impacts on the environment, including biodiversity and ecosystem structure and function [13].

The life cycle assessment (LCA) method is an environmental assessment tool that complies with the International Organization for Standardization (ISO) standard [14] and is the most commonly used method among assessments of the agricultural environment. So far, some LCA studies have successfully assessed the environmental impacts of a series of agricultural production processes, but in most of them, planting and breeding were separated. Brentrup et al. discussed the environmental impact of different amounts of nitrogen fertilizer on winter wheat through its whole life and concluded that the LCA methodology was basically suitable to assess the environmental impact associated with agricultural production [15]; Nemecek et al. used the LCA method to study the environmental impact of two long-term farming system experiments and found that the system boundaries were the plant production system and the storage and application of farm manure [16]; Spyros used this tool to evaluate and compare the conventional and organic lettuce cultivation systems in Northern Greece, and it came out that the environmental footprint and CO_2 emission of organic production were lower than those of conventional cultivation [17]; Casey evaluated and analyzed the greenhouse gas emissions (GHGs) of Ireland's milk production system and found that 49% of the GHGs per cow were from enteric fermentation [18]; Pelletier also used the LCA method to study the environmental impact of material and energy input and emission output in the broiler supply chain of the U.S., and proposed to satisfy public food demand by minimizing environmental harms [19].

The goals of our research are: (1) to build up a life cycle model from the perspective of the entire industry chain from agricultural material production to livestock marketing, (2) to compare and analyze the differences in the environmental impacts of beef and pork production, (3) to find out which production stage contributes to the most environmental impacts, and (4) to provide feedback from all results to explore how to better establish a modern grassland agriculture system. From the perspective of the entire industry chain, which combines planting and breeding, the life cycle assessment of the GAS and the CLAS in Eastern Gansu can provide more comprehensive empirical evidence for the adjustment of agricultural structures in this region and similar regions worldwide.

2. Materials and Methods

2.1. Study Area

The farming-pastoral zone of Eastern Gansu Province includes Pingliang City and Qingyang City (Figure 1). Located in the typical Loess Plateau area, the landforms are vertical and horizontal, with mountains and fault valleys alternately distributed. Its climate is semi-arid continental monsoon climate, with a large difference between day and night and uneven rainfall among seasons. The landform and climate there have made the area a dry-land-dominated farming-pastoral zone.

The production data of the GAS and the CLAS in Pingliang and Qingyang was collected in 2017 by investigating farmers there. Stratified random sampling [20] was intensively launched in Kongtong District, Chongxin County, and Jingchuan County of Pingliang, and in Huan County and Zhenyuan County of Qingyang (Figure 1). The sample included 134 households.

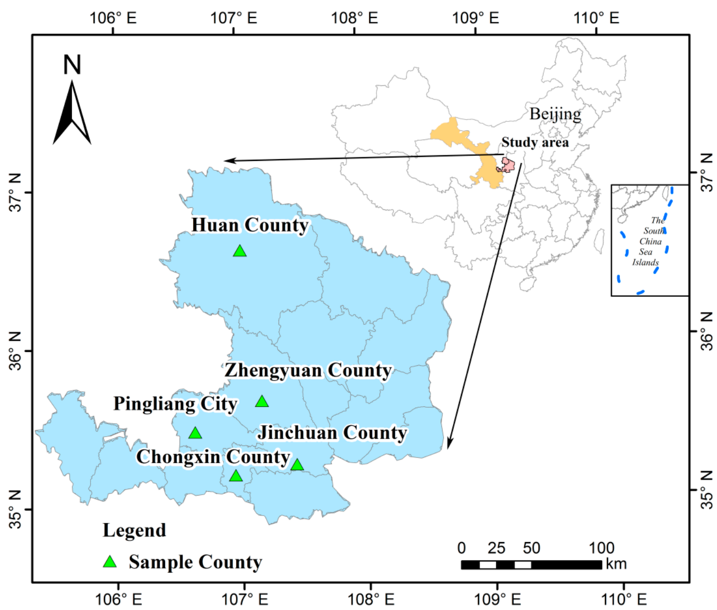

Figure 1. Location of the study area and distribution of sample counties/districts.

2.2. Methods

2.2.1. Hypotheses of Agricultural Systems

The samples could be divided into the GAS and CLAS groups. We hypothesize that the GAS group refers to the grain/*alfalfa* planting and beef cattle breeding agricultural system. The sampling of the GAS included 104 households with 1289 beef cattle raised in total, and the feed consumption ratio of corn:wheat:flax:*alfalfa* per 1 kg beef production was 6:5.2:0.22:6. We also hypothesize that the CLAS group refers to the grain planting and pig breeding agricultural system. This sample included

30 households with 1861 pigs raised in total. The feed consumption ratio of corn:wheat:soybean was 2.1:2.73:0.41.

2.2.2. Life Cycle Assessment Framework

Goal and Scope Definition

The goal and scope is defined as the process from agricultural material (fertilizer, agricultural film, and seed) production to livestock marketing, and the functional unit as the output from 1 kg beef or pork. The emissions from agricultural material production to the environment are the start and the emissions from livestock manure treatment to the environment the end. The life cycle of the two systems (GAS and CLAS) is divided into six stages: agricultural material production, crop planting, crop harvesting and transportation, feed processing, livestock fattening, and manure treatment (Figure 2).

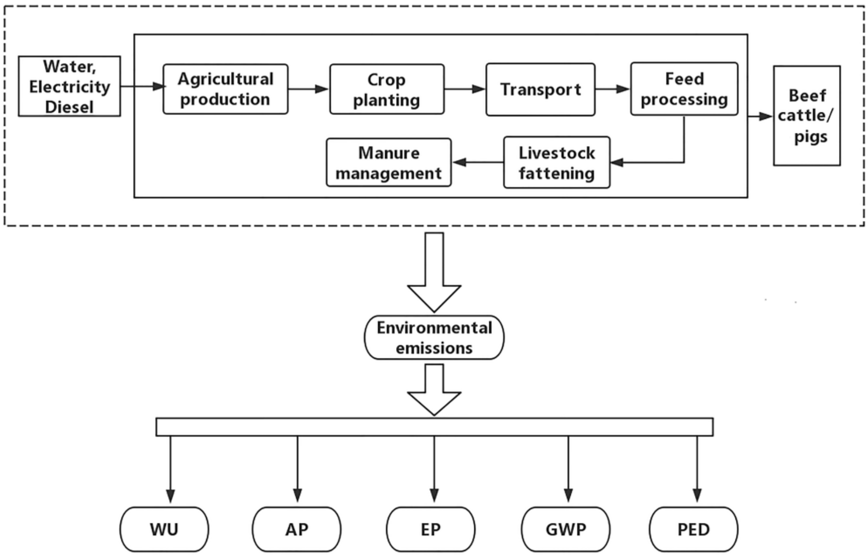

Figure 2. System boundary and pollution emission situation. (WU: water use, AP: environmental acidification potential, EP: eutrophication potential, GWP: global warming potential, PED: primary energy demand.).

Inventory Analysis

Inventory data sources preferentially used measured data (obtained by the 2017 field survey of farmers' production data); data on farmland emissions, livestock respiration, fecal pollution, etc. came from relevant references; upstream resources consumed by chemical fertilizers, diesel, electricity, etc., such as data on mining, transportation, and waste disposal, came from the Core Data for China Life Cycle (CLCD) of eBalance software (Table 1).

Table 1. List of data sources.

Inventory Data	Data Sources
Agricultural production process	
Fertilizer type, manufacturer, dosage	Field research
Various fertilizer production background data	eFootprint database
Agricultural film	[21,22]
Seed	[23,24]
Crop planting process	
Mechanical diesel consumption and emissions of cultivated land	Field research and references [25–29]
Water consumption for irrigation	Field research
Farmland greenhouse gas emissions	[26,28–31]
Crop yield	Field research
Diesel consumption and emissions of harvested machinery	Field research and database
Transport and distance of agricultural products	Field research
Crop harvesting and transportation process	
Hay consumption of cornstalk, wheat straw, and *alfalfa*	Field research
Grass-to-grain ratio	Field research, [21,30,32,33]
Concentrated feed consumption and ratio	Field research
Conversion coefficient of each component of concentrated feed corresponding to crop	[31–33]
Beef cattle/pig fattening process	
Column weight	Field research
Feed-to-meat ratio	Field research
Electricity production background data	eFootprint database
Water and electricity consumption	Field research
Respiratory and enteric fermentation gas emissions	[34–37]
Manure management process	
Manure production and pollutant discharge	Field research and references [34,35,38,39]

The production data collected by field research was averaged based on households for the convenience of analysis. Crops' average consumptions of diesel oil and electricity per mu (1 ha = 15 mu) were 2.28 kg and 3.75 kWh, respectively. The yield per mu of crops and the consumption of chemical fertilizer were converted into the production of 1 kg of beef or pork (Table 2).

Table 2. List of inputs and emissions of each production process.

	Grassland Agriculture System (GAS)	Cultivated Land Agricultural System (CLAS)	Unit
Inputs			
Crop planting (wheat, corn, *alfalfa*, soybean)	17.2	5.24	kg/kg
Fertilizer	3.984	1.634	kg/kg
Seed	0.324	0.1762	kg/kg
Agricultural film	0.06	0.021	kg/kg
Emissions			
CO_2	18,097.30	17,216.05	g/kg
CH_4	498.80	529.12	g/kg
N_2O	327.27	3.06	g/kg
$N0_X$	31.00	43.60	g/kg
NO_3^-	7.08	2.48	g/kg
NH_3	19.30	12.59	g/kg
SO_2	12.40	30.84	g/kg
P_2O_5	40.80	86.59	g/kg
K_2O	40.80	21.56	g/kg
TC	1.09	-	g/kg
MgO	19.20	1.97	g/kg
COD	0.37	10.50	g/kg
TP	0.01	4.02	g/kg
TN	0.05	9.47	g/kg

Note: Free seed input and agricultural material input for *alfalfa* planting were supported by the Chinese government.

Impact Assessment

The life cycle assessment software, eFootprint, jointly developed by Sichuan University and Yike Environmental Technology Co., Ltd., was chosen. It is the most authoritative and the widest-used LCA processing tool in China, and its database can better match the production situation in China for its data was collected from China's realistic production situations [40]. Data from field research, references, and another database was input in eFootprint and calculated along with data from the eFootprint database. This online software also has some in-built characteristic indicators in its system. According to the LCA method by Owens [41], water use (WU), primary energy demand (PED), environmental acidification potential (AP), eutrophication potential (EP), and global warming potential (GWP) were selected as five environmental impact types. Using the eFootprint indicator manager's default ISCP2009 weighting scheme and the comprehensive energy saving and emission reduction indicator from China's 13th Five-Year Plan, the comprehensive environmental impact values for 1 kg of beef and 1 kg of pork produced by the two main agricultural systems in Eastern Gansu were calculated. They were further divided and calculated by the five environmental impact indices, different plants, and different stages.

3. Results

3.1. The Environmental Impacts of the GAS and the CLAS

The comprehensive environmental impact values for 1 kg of beef and 1 kg of pork produced by the grassland agricultural system (GAS) and the cultivated land agricultural system (CLAS) in Eastern Gansu were 2.69×10^{-11} and 1.18×10^{-11}, respectively.

3.1.1. The Environmental Impacts of the Life Cycle of 1 kg of Beef Produced by the GAS

From the perspective of the contribution levels of the production process to the five indices of environmental impacts, the eutrophication potential (EP) and global warming potential (GWP) of the GAS in the beef cattle breeding stage had the largest contributions, accounting for 82.26% and 61.27%, respectively. In the production stage of corn and wheat, the contribution of water use (WU), primary energy demand (PED), and environmental acidification potential (AP) accounted for 89.19%, 73.58%, and 89.49%, respectively. The *alfalfa* production stage had relatively low environmental effects with WU, PED, AP, EP, and GWP accounting for just 0.22%, 2.49%, 0.21%, 0.04%, and 7.1% of the entire system (Table 3).

Table 3. Environmental impacts of 1 kg of beef produced by the GAS (grassland agricultural system).

Index	WU (Water Use) (kg)	PED (Primary Energy Demand) (MJ)	AP (Environmental Acidification Potential) (kg SO_2 eq)	EP (Eutrophication Potential) (kg PO_4^{3-} eq)	GWP (Global Warming Potential) (kg CO_2 eq)
Characterized total value	1.38×10^2	9.54×10	9.00×10^{-2}	9.30×10^{-2}	3.30×10
Corn production	5.30×10	3.55×10	5.61×10^{-2}	1.21×10^{-2}	6.97
Wheat production	7.03×10	3.48×10	2.44×10^{-2}	4.38×10^{-3}	3.46
Alfalfa production	3.08×10^{-1}	2.37	1.92×10^{-4}	3.67×10^{-5}	2.34
The beef cattle breeding stage	1.46×10	2.28×10	9.27×10^{-3}	7.65×10^{-2}	2.02×10

3.1.2. The Environmental Impacts of the Life Cycle of 1 kg of Pork Produced by the CLAS

The CLAS had a decisive effect on the EP and GWP during the pig breeding stage, representing 94.91% and 79.78%, respectively, from the perspective of the contribution rate of the production cycle to the five major environmental impact indices. WU, PED, and AP had a decisive impact in the production stage, representing 80.90%, 93.51%, and 89.62%, respectively. Since soybeans existed only in concentrated soybean meal, its amount was much smaller than those of corn and wheat. Specifically, WU, PED, AP, EP, and GWP of soybean production accounted for only 2.18%, 1.24%, 8.47%, 0.41%, and 0.32% of the whole system, respectively (Table 4).

Table 4. Environmental impacts of 1 kg of pork produced by the CLAS (cultivated land agricultural system).

Index	WU (Water Use) (kg)	PED (Primary Energy Demand) (MJ)	AP (Environmental Acidification Potential) (kg SO_2 eq)	EP (Eutrophication Potential) (kg PO_4^{3-} eq)	GWP (Global Warming Potential) (kg CO_2 eq)
Characterized total value	8.39×10	3.55×10	3.94×10^{-2}	1.57×10^{-1}	2.36×10
Corn production	3.17×10	2.11×10	2.30×10^{-2}	5.13×10^{-3}	2.99
Wheat production	3.63×10	1.35×10	1.24×10^{-2}	2.24×10^{-3}	1.73
Soybean production	1.83	4.41×10^{-1}	3.33×10^{-3}	6.42×10^{-4}	7.65×10^{-2}
The pig breeding stage	1.42×10	1.86	7.54×10^{-4}	1.49×10^{-1}	1.88×10

3.2. Differences in Environmental Impact between the GAS and the CLAS Based on 1 ha of Land

When 1 ha of land was regarded as the benchmark, the comprehensive environmental impact value of the GAS was 21.82% higher than that of the CLAS. In terms of PED and AP, those of the GAS were, respectively, 38.66% and 22.01% higher than those of the CLAS; when it comes to GWP, EP, and WU, those of the GAS were, respectively, 25.00%, 68.37%, and 11.88% lower than those of the CLAS (Figure 3).

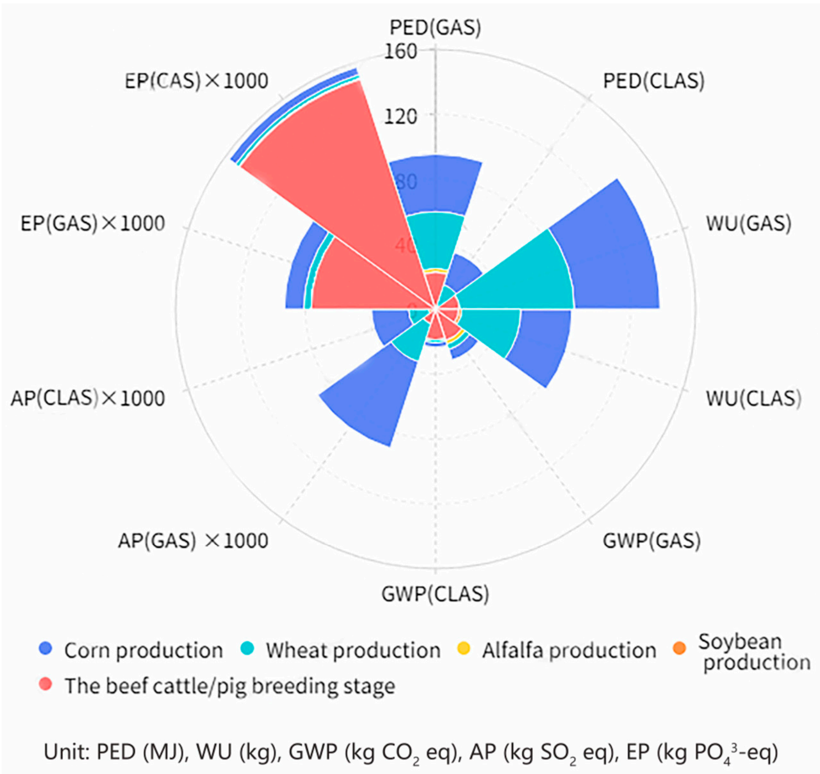

Figure 3. Differences of PED's, WU's, GWP's, AP's, and EP's environmental impacts in the two systems based on 1 ha of land. (PED: primary energy demand, WU: water use, GWP: global warming potential, AP: environmental acidification potential, and EP: eutrophication potential.) (GAS: grassland agricultural system, referring to the grain/*alfalfa* planting and cattle breeding agricultural system; CLAS: cultivated land agricultural system, referring to the grain planting and pig breeding agricultural system.)

Concerning WU, no matter which of the two systems it was, the biggest water consumption came from corn and wheat planting, primarily because of the large amount of water use during the application of chemical fertilizers. However, in the breeding stage, beef cattle's WU was only 55.23% of pigs' as a result of the much smaller amount of water demand for cleaning beef cattle's manure. Cattle excreted much but single-type waste, leading to a modest demand for water cleaning, while pigs' waste needed a large amount of water to clean out. In line with WU's situation, PEDs were large in the planting stages of corn and wheat for machines and diesel were required to support plowing and harvesting them. In the breeding stage, the electricity consumption of beef cattle breeding was 6.5 times that of pig breeding primarily due to feed crushing and secondarily due to the high intake of beef cattle. As for GWP, that of the GAS was 18.41% higher than that of the CLAS. The major contribution came from CO_2 produced by respiration, CH_4 produced by enteric fermentation, and pollution caused by the electricity used to produce crushed feed (Figure 3).

In terms of AP, that of the GAS was 1.2 times that of the CLAS, with the corn planting stage contributing the largest and wheat and corn planting accounting for 89.7%. The biggest contribution to EP was the livestock breeding stage. EP of the pig breeding stage was 3.64 times that of the cattle breeding stage mainly because pigs' manure and urine had a phosphorus content as high as 86.59 g/kg (Figure 3).

4. Discussion

In our study, impacts on the environment were focused on PED and AP during the land use transition from the CLAS to the GAS because of two reasons. One major reason was that farmers in Eastern Gansu's farming-pastoral zone had inappropriately treated livestock manure by directly discharging it into fields. If biogas fermentation tanks made full use of livestock manure and wastewater, environmental pollution can be reduced the most to cover the increasing environment-protection requirements [42]. The treatment technology of livestock manure has been well developed abroad and many researchers have evaluated the anaerobic digestion process of livestock manure compost to seek cleaner manure fermentation technologies [43–46]. The other key reason was that the local agricultural mode was still conventional farming. The planting of corn and wheat mainly relied on high nitrogenous fertilizer inputs while the field volatilization of chemical fertilizers was a key contributor to environmental acidification [47]. The environmental impact of the *alfalfa* production stage was significantly smaller than that of the corn and wheat production stages mainly because the various inputs and production operations of *alfalfa* in the production stage were far fewer than those of corn and wheat. However, in the field research, it was found that corn and wheat accounted for 65% of beef cattle feed in the GAS in Eastern Gansu, which indicates that the current grassland agriculture in the area was not modern grassland agriculture, since its grassland feed proportion was below 50%. Therefore, the planting area of *alfalfa* should be increased and the proportion of grain feed should be declined. In these years, conventional industrial agricultural practices have emitted much waste to the soil, resulting in its salinization and eutrophication, while modern grassland agriculture, a system which uses pasture as the link to combine planting and breeding, can both meet people's food demand and realize the compatibility of ecology and production [48–51]. Thus, the environmental impact of modern grassland agriculture will be smaller than that of the existing local grassland agriculture. More specifically, in the agricultural structure adjustment of Eastern Gansu, the implementation of the "grassland agriculture" mode by "introducing grassland into fields" has simultaneously elevated the utilization per unit of land, guaranteed the economic return of agricultural production, and improved the production environment. Besides, new agricultural technologies, especially clearer production technologies such as anaerobic digestion and drip irrigation, are also indispensable. Moreover, the adjustment of public food intake structure and the advancement of agricultural modernization reform have provided grassland agriculture with prospects on development space and policy respectively, indicating that "introducing grassland into fields" and new agricultural technologies should be emphasized and stuck to. That is to say, to fully realize modern grassland agriculture, the combination of "introducing grassland into fields" and new agricultural technologies is the major direction towards which agricultural planting structure adjustment in the farming-pastoral zone develops. In the U.S., modern grassland agriculture has been introduced as a new agricultural mode and has gathered wide recognition [5]. This should also be a national strategy in China as it will contribute to addressing "Three Rural Issues" (agriculture, countryside, and peasants). Furthermore, with a more comprehensive productive system and clearer modes of production, it has pointed out a prospective way to achieve circular economy and sustainable development worldwide [52].

This study innovatively used the LCA method to conduct a comparative analysis of the environmental impacts of the GAS and the CLAS in the farming-pastoral zone of Northwestern China. The system boundary of the study included the entire process of the two main systems from cradle to grave, involving not only the planting stage of feed crops but also all the inputs and emissions of pigs and beef cattle from stocking to marketing. Their environmental impacts run through the whole industrial chain. However, LCA still faces large challenges [53], especially when applied to agriculture. This method limits the comprehensive assessment of complex and interconnected food chains and is limited by data availability and the multi-output nature of production [54]. Because agricultural production is greatly affected by seasonal and geographic factors and involves multiple industries, LCA that incorporates new impact categories such as soil function and land use will be more suitable for agriculture [55]. The environmental impacts of downstream links, such as packaging, transportation, and consumption of beef/pork, will be the focus of our future research.

5. Conclusions

Through the life cycle assessment in Eastern Gansu, the main goals of this research were to compare the entire industry chains of the GAS and the CLAS to explore the differences of impacts they impose on the environment and to find out the focus factors and stages that affect the environment and then provide suggestions according to them. The key conclusions are as follows.

In total, the comprehensive environmental impact values of 1 kg of beef produced by the GAS and 1 kg of pork produced by the CLAS were 2.69×10^{-11} and 1.18×10^{-11}, respectively. Based on 1 ha of land, the comprehensive environmental impact value of the GAS was 21.82% higher than that of the CLAS. Specifically, on PED and AP, the GAS needs improvement because those values were 38.66% and 22.01% higher than those of the CLAS, respectively. On GWP, EP, and WU, the GAS is more environment-friendly because those values were 25.00%, 68.37%, and 11.88% lower than those of the CLAS, respectively.

It can be suggested that *alfalfa* planting should be strongly encouraged, the proportion of commissariat feed in the GAS should be lowered, and the anaerobic fermentation technology should be applied to processing livestock manure. Finally, through "introducing grass into fields" and new agricultural technologies, the conventional CLAS will be replaced and modern grassland agriculture will be established. In summary, our work can provide researchers, farmers, herders, and policy-makers with feedback on the impact differences between the GAS and the CLAS on the environment. This will help solve agricultural issues and promote agricultural sustainability in China and worldwide.

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