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Rice Field Carrying Capacity as A Source of Ruminant Feed in the Rice-Cattle Integration System

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ABSTRACT. Kolaka Regency is recognised not only as a major rice producer but also as an important centre for smallholder livestock farming. The Rice-Cattle Integration System (R-CIS) has been identified as an effective approach to optimize local agricultural resources for smallholder livestock development. However, its dissemination has remained limited due to the uneven carrying capacity of rice fields across different regions. This study aimed to analyse the current and projected carrying capacity of rice fields in Kolaka Regency, Southeast Sulawesi (2023–2024), considering land availability, livestock population, and feed resources. Data analysis included assessments of land carrying capacity, livestock density, livestock concentration index (LCI), and feed concentration index (FCI). Results indicated that Kolaka had 12,203 ha of rice fields, producing 3,188 tons of crude protein (CP) annually from unfermented rice straw and 10,539 tons CP/year from fermented straw. Feed distribution within the regency was uneven: in districts such as Baula, Pomalaa, Samaturu, Wolo, and Wundulako, livestock populations could be increased, whereas Toari and Watubangga exceeded carrying capacity even after straw fermentation. The study estimated that fermented straw could support an additional 24,335 livestock units (LU) across Kolaka Regency, equivalent to about 2,028 LU per district annually. These findings highlight the need for inter-district feed substitution and livestock redistribution. Overall, fermented rice straw significantly enhanced feed availability, thereby supporting sustainable livestock production.

Keywords: beef cattle, fermented rice straw, integration system, land carrying capacity

INTRODUCTION

Kolaka Regency is one of the potential regions for implementing the Rice–Cattle Integration System (R-CIS), yet its dissemination remains limited due to ecosystem constraints and uneven carrying capacity across districts. The R-CIS is considered an effective strategy to optimize local agricultural resources for smallholder livestock development. However, its adoption is still constrained by challenges that extend beyond technical assistance and field implementation. Previous studies (Cahyani et al., 2022; Fyka et al., 2021) emphasize the potential of R-CIS, yet these studies also highlight that its adoption is still constrained by ecosystem suitability and lack of integrative analysis (Hidayati et al., 2020; Mulyono et al., 2021). This condition indicates obstacles resulting from the uneven distribution of rice field carrying capacity among regions, which hampers the widespread adoption of R-CIS. Therefore, an analysis of land carrying capacity based on ecosystem conditions and local potential in each region must be conducted to formulate appropriate policies to enhance R-CIS implementation. In this context, understanding the biophysical factors that determine land carrying capacity—particularly those related to feed resources—becomes crucial for assessing the sustainability of integration systems.

The dynamics of land carrying capacity in R-CIS are influenced by several factors. Straw availability is determined by the harvested rice field area, as not all rice fields in Kolaka Regency are irrigated, leading to dependence on the rainy season. The integration model also affects carrying capacity since R-CIS implementation involves the use of either fermented or unfermented straw. Key factors influencing rice field carrying capacity include seasonal straw availability, the application of fermented versus unfermented straw, and livestock density. Fermented straw improves nutritional quality (Dara Santi et al., 2025; Musdalifa et al., 2018; Sukaryani and Mulyono, 2019; Yusriani et al., 2015), thereby increasing the amount of crude protein available from rice residues. This improvement directly enhances land carrying capacity, as better-quality feed allows more livestock to be sustained per unit of land. Consequently, fermentation plays a pivotal role in supporting the long-term sustainability of the R-CIS. In addition, manure utilization enhances soil fertility (Harsela et al., 2024; Phooi et al., 2022), potentially creating a positive feedback loop in the integration system**.** However, the effective contribution of these feed resources to livestock productivity is largely determined by the spatial distribution of animal populations across regions, which consequently influences the regional carrying capacity.

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Livestock population dynamics also influence land carrying capacity. Spatial factors determine differences in ecosystem conditions and local potential. In Kolaka Regency, the spatial distribution of rice fields and cattle populations is uneven, affecting feed availability and regional livestock development potential. The distribution of agricultural centers in Kolaka Regency indicates variations in local potential. Such disparities highlight the need for a comprehensive spatial analysis integrating feed resources and livestock population dynamics. In regions where fermented straw is more widely adopted, the carrying capacity increases, enabling farmers to maintain a larger number of cattle without depleting local feed resources. This linkage illustrates that improving feed quality through fermentation not only enhances productivity but also stabilizes livestock populations within sustainable limits. Based on these considerations, this study aims to analyze the current and projected rice field carrying capacity in Kolaka Regency by integrating spatial feed availability, livestock population dynamics, and ecosystem suitability. The findings are expected to inform region-specific strategies for optimizing R-CIS implementation.

MATERIALS AND METHODS

Type and Source of Data

This study employed a descriptive-quantitative approach using both primary and secondary data. Secondary data were collected from institutional sources, including the Department of Forestry and Livestock, the Department of Horticulture, and the Statistics Agency of Kolaka Regency, covering the period from 2021 to 2023. The data included harvested rice field area, rice grain production, and livestock population. Additional references and previous studies were also used to support the analysis.

Land Carrying Capacity Analysis

To achieve the research objectives, an analysis of the carrying capacity of rice-livestock integration was conducted, requiring both literature data and rice field area data from Kolaka Regency. The carrying capacity of rice straw is defined as the measure of the ability of rice fields to produce a certain amount of straw to meet the needs of a specific livestock population. The estimated weight of rice straw is based on milled dry grain production in Southeast Sulawesi Province with the following stages (Sudia et al., 2020).

a. Rice Straw Weight (kg) = Harvested Grain Production (ton) × 1.25
b. Total CP from Straw (kg) = Rice Straw Weight × CP content (%)
c. Total CP from Fermented Straw (kg) = Rice Straw CP Weight × content after fermentation (%)

The annual feed requirement per head of cattle, in terms of crude protein, was calculated using the following formula:

a. Annual CP Requirement= 250 kg (body weight) ×2.6% (dry matter intake) ×10.67% (CP content) ×365 days=252,945 kg CP/head/year

The rice straw carrying capacity (RSCC) and fermented straw carrying capacity (FSCC) were then calculated by dividing the total available CP from straw by the annual CP requirement per head:

a. RSCC = Total CP from Straw / 252,945
b. FSCC = Total CP from Fermented Straw / 252,945

Table 1. Criteria for the status of the animal feed carrying capacity index

FCCI	Criteria	Description
≤1	= Very critical	Livestock had no choice in utilizing available resources, leading to depletion of resources in the agro-ecosystem with no natural forage or waste cycling
>1–1.5	= Critical	Livestock had some choices for resource utilization, but conservation aspects were not yet fulfilled
>1.5–2	= Vulnerable	Organic material development was minimal
>2	= Safe	The availability of feed resources was functionally sufficient to meet environmental needs efficiently

Feed Carrying Capacity Index (FCCI)

The Feed Carrying Capacity Index (FCCI) was used to assess whether the available straw feed could meet the nutritional needs of the existing livestock population in each district (Rahayu et al., 2020):

$$\mathrm{FCCI} = \frac{\text{Carrying capacity rice straw (LU)}}{\text{Livestock population (LU)}}$$

The FCCI values were interpreted based on the classification by (Heriawati, 2015), as presented in Table 1.

Livestock Density Analysis

Livestock density was analyzed using two approaches:

1. Economic Density: measured by the number of livestock units (LU) per 1,000 inhabitants, categorized as:
   a. Very dense: >300 LU
   b. Dense: 100–300 LU
   c. Moderate: 50–100 LU
   d. Sparse: <50 LU
2. Regional Density: measured by the number of LU per square kilometres (km^2), with the following classifications:
   a. Very dense: >50 LU/km^2
   b. Dense: 20–50 LU/km^2
   c. Moderate: 10–20 LU/km^2
   d. Sparse: <10 LU/km^2

Source: (Direktorat Jenderal Peternakan dan Balai Penelitian Ternak, 1995; Mariam and Syamsu, 2021)

Livestock Concentration Index (LCI)

The Livestock Concentration Index (LCI) was used to evaluate the concentration of cattle populations across districts. It was calculated using the formula (Syamsu and Achmad, 2002):

$$\text{LCI} = \frac{\text{The Population of beef cattle in a subdistrict (LU)}}{\text{The average population beef cattle in the district (LU)}}$$

Interpretation of LCI:
a. LCI ≥ 1.0: High concentration
b. 0.5 ≤ LCI < 1.0: Moderate concentration
c. LCI < 0.5: Low concentration

Feed Concentration Index (FCI)

The Feed Concentration Index (FCI) was used to assess the distribution of rice straw-based crude protein availability across districts (Syamsu, 2006):

$$\text{FCI} = \frac{\text{Total crude protein from rice strow in a subdistrict}}{\text{Average crude protein rice straw in the district}}$$

This index helps identify districts with feed surpluses or deficits, informing inter-district feed substitution strategies for effective livestock population distribution.

RESULTS AND DISCUSSION

Dynamics of Harvested Land Area and Rice Straw Production

The harvested land area reflected the extent of rice cultivation and determined the potential availability of rice straw as livestock feed. In Kolaka Regency, rice farming covered a substantial portion of agricultural land, positioning it as one of the main rice-producing regions in Southeast Sulawesi. Nevertheless, disparities in harvested land area across districts created unequal carrying capacities for the R-CIS. For instance, Table 2 showed that Samaturu and Wolo dominated in terms of harvested area, while Toari contributed marginally. Such differences highlighted that not all regions benefited equally from the integration potential. Therefore, evaluating harvested land area alongside straw yield was crucial for identifying the districts that could sustainably support livestock production.

The research findings demonstrated that total rice straw production in Kolaka Regency reached 63,755 tons/year, with the highest output in Samaturu (11,191 tons) and the lowest in Toari (57 tons) (Table 2). This variation directly influenced the potential feed supply for ruminants. Processing technologies, particularly fermentation, significantly improved straw quality by enhancing crude protein content. Wahyuni et al. (2020) reported that straw fermentation could double protein content compared to untreated straw, a finding that aligned with the Kolaka case. The comparison indicated that without fermentation, much of the straw had limited feed value. Thus, adopting fermentation technology was essential for maximizing the nutritional contribution of rice straw. An analysis of Table 2 showed that six districts including Samaturu, Wolo, Watubangga, Wundulako, Baula, and Tanggetada contributed nearly 79% of the total rice field area in Kolaka. These districts represented the primary clusters for the development of R-CIS. The concentration of production suggested that integration policies should be spatially targeted rather than uniformly applied across the regency. Previous studies in other regions, such as Rahayu et al. (2020) in Trenggalek showed similar patterns, where specific districts drove most of the integration potential. However, unlike Trenggalek, Kolaka had more pronounced disparities between surplus and deficit regions. This observation reinforced the need for localized strategies in planning livestock–crop integration.

Rice straw, as a by-product of harvesting, provided a valuable feed source even though it was underutilized. Its yield per hectare varied between 12–15 tons of straw or 4–5 tons of dry matter depending on rice variety and growing conditions (Ahmad and Nashir, 2008; BPS Kolaka, 2021). Furthermore, approximately 58% of the rice plant biomass consisted of straw, a figure consistent with the FAO’s global estimates for cereal residues. This conversion factor enabled reliable projections of potential feed supply across districts. For Kolaka, it confirmed that straw was not merely agricultural waste but a significant feed reserve. However, its economic value depended on whether farmers adopted appropriate collection, storage, and processing practices.

According to Table 2, the 12,203-ha harvested area yielded 51,004 tons of DMG annually, producing an estimated 172,311 tons of rice straw per year. This supply corresponded to 3,188 tons of CP per year for untreated straw and up to 10,539 tons of CP per year after fermentation. Samaturu consistently emerged as the district with the highest feed potential, followed by Wolo, Watubangga, and Wundulako. Such figures revealed that fermentation technology could increase available crude protein by more than threefold, significantly improving feed sufficiency. Yet, the uneven spatial distribution meant that surplus in certain districts did not offset deficits in others without coordinated redistribution. Therefore, the integration system in Kolaka had to combine both feed quality improvements and inter-district feed transfer mechanisms.

Table 2. Area of harvested land area and rice straw production between districts in Kolaka Regency

Sub-District	Paddy field area (ha)	Milled dry grain production (ton/year)	Rice straw production (ton/year)	CP production rice from non- fermented rice straw (ton/year)	CP production fermented rice straw (ton/year)
Baula	1,488	6,220	7,775	389	1,285
Iwoimendaa	220	918	1,147	57	190
Kolaka	408	1,704	2,130	107	352
Latambaga	196	819	1,024	51	169
Polinggona	764	3,192	3,990	199	660
Pomalaa	927	3,873	4,842	242	800
Samaturu	2,142	8,953	11,191	560	1,850
Tanggetada	1,148	4,798	5,997	300	991
Toari	11	46	57	3	9
Watubangga	1,610	6,731	8,414	421	1,391
Wolo	1,694	7,078	8,848	442	1,463
Wundulako	1,596	6,672	8,340	417	1,379
Total	12,203	51,004	63,755	3,188	10,539

Livestock Population Dynamics

The results of this study showed that Kolaka Regency had a total of 24,708 beef cattle or equivalent to 17,296 livestock units (LU), with the largest populations concentrated in Watubangga (8,425 head/5,898 LU) and Toari (4,658 head/3,261 LU). These areas exerted the greatest feed pressure, while districts such as Samaturu, Wundulako, and Baula had surplus carrying capacity. Kolaka Regency is recognized not only as a major rice producer but also as an important centre for smallholder livestock farming. The sustainability of beef cattle production in this region depended heavily on the availability and quality of feed resources. Previous studies emphasized that the development of cattle farming was supported by three key pillars: genetics, feed, and farm management (Ahmad Fauzan et al., 2024; Alemneh and Getabalew, 2019; Ojo et al., 2024). Among these, feed contributed up to 70–80% of input costs, making it the most critical factor in farm sustainability (Ikanubun et al., 2021; Labatar and Wosiri, 2018; Udding et al., 2014). Adequate forage ensured both survival and productivity, reflected in growth, carcass yield, and calf production. Therefore, assessing livestock population dynamics had to be closely linked with feed resource potential, particularly rice straw, which remained the primary local feed source.

Table 3. Beef cattle population by district in Kolaka Regency

District	Beef cattle population (Head)	Livestock unit (LU)
Baula	790	553
Iwoimendaa	889	622
Kolaka	869	608
Latambaga	546	382
Polinggona	2,507	1,755
Pomalaa	996	697
Samaturu	1,010	707
Tanggetada	2,050	1,435
Toari	4,658	3,261
Watubangga	8,425	5,898
Wolo	1,004	703
Wundulako	964	675
Total	24,708	17,296

Despite the abundance of rice straw, the distribution of cattle across districts in Kolaka is uneven, creating imbalances in feed demand and supply. Table 3 showed that cattle population was concentrated in a few districts, where demand for feed resources greatly exceeded local straw production. To measure this imbalance, livestock populations were expressed in Livestock Units (LU), a standardised measure of ruminant biomass. One LU equalled 0.7 head of adult cattle (Ashari et al., 1996), reflecting a mix of breeding females, bulls, and calves. With a total of 24,708 heads or 17,296 LU, Kolaka's cattle population exerted a substantial demand on feed resources. Since each LU required approximately 252,945 kg CP/year, increases in population directly raised feed requirements, thereby influencing the carrying capacity index (Heriawati, 2015).

Analysis of Table 3 indicated that four districts Watubangga, Toari, Polinggona, and Tanggetada account for 69% of total feed demand in Kolaka Regency. This concentration showed that feed deficits were not evenly distributed but were localised in areas with dense cattle populations. For instance, Watubangga and Toari alone required over two million kilograms of crude protein annually, far exceeding their local straw supply. Such patterns resembled findings from Trenggalek, East Java, where Rahayu et al. (2020) reported that cattle clustering caused feed shortages despite regional surpluses. Conversely, more evenly distributed cattle populations in West Papua enabled better utilisation of crop residues (Labatar and Wosiri, 2018). These comparisons suggested that Kolaka faces sharper disparities than many other regions, reinforcing the urgency of redistribution policies, either through feed transfer or livestock relocation.

Analysis of the Land Carrying Capacity of each sub-District

Land carrying capacity (LCC) for beef cattle describes a region's ability to provide sufficient forage resources to sustain its livestock population. In this study, the LCC was calculated based on the amount of crude protein (CP) produced from rice straw relative to the annual CP requirements of one livestock unit (LU). One LU represents 0.7 adult cattle, and its feed requirement was estimated at 252,945 kg CP/year (Heriawati, 2015). The calculation thus linked rice production systems with the actual capacity to support livestock. Table 4 presented the carrying capacity of rice straw for each district, offering a clear picture of how local feed production aligned with cattle populations. This method provided an essential benchmark for evaluating whether Kolaka Regency could sustain current and future livestock numbers under the R-CIS.

The results of the LCC analysis revealed stark disparities between districts in Kolaka. Table 4 showed that Watubangga (FCCI= 0.28) and Toari (FCCI= 0.00) fell into the very critical category, as their straw production was unable to meet the livestock feed requirement. In contrast, Samaturu (FCCI= 3.13) and Wundulako (FCCI = 2.44) exhibited favourable feed conditions, capable of sustaining their cattle populations. These results were consistent with (Suprapto and Kustantinah, 2019), who found that the carrying capacity of paddy fields strongly depended on the balance between straw production and cattle population in each locality. The comparison suggested that districts with large rice cultivation areas but moderate cattle populations tend to achieve a safe FCCI, while areas with higher livestock density remain feed-deficit. Thus, disparities in FCCI values across districts reflected the uneven spatial alignment of crop and livestock systems.

Fermentation significantly improved the effective carrying capacity of rice straw, as shown in Table 4. In districts such as Baula, Samaturu, Wolo, and Wundulako, the LCC increased by more than threefold once straw was fermented. For instance, Samaturu's LCC rises from 2,210 LU (non-fermented) to 7,308 LU (fermented), indicating the substantial effect of processing technologies. However, in Toari and Watubangga, fermentation did not resolve the deficit indicated by <1 FCCI values, meaning that livestock numbers still exceeded available feed resources. This finding aligned with Rahayu et al. (2020), who reported that technological interventions were insufficient without concurrent adjustments in livestock distribution. Therefore, while fermentation enhanced straw quality and CP content, its benefits were limited in districts with extreme imbalances between feed supply and demand.

The disparities in LCC across districts had important implications for livestock management policies. Areas with surplus carrying capacity, such as Samaturu and Wundulako, should be prioritized as centres for livestock expansion under the R-CIS framework. Conversely, districts with chronic deficits, particularly Toari and Watubangga, required complementary feeding strategies, including forage development, concentrate supplementation, or feed transfer from surplus regions. Redistributing cattle populations could also reduce pressure on deficit areas while optimising feed utilisation across the regency. Similar recommendations had been made in studies from Sumatra and East Java, where balanced feed-livestock distribution improved integration outcomes (Mulyono et al., 2021; Hermawan et al., 2022). Ultimately, Kolaka's success in implementing R-CIS depended not only on increasing straw quality through fermentation but also on adopting spatially integrated strategies for livestock and feed resource management.

Table 4. Paddy land carrying capacity in Kolaka Regency

District	Carrying capacity		Additional livestock capacity		FCCI (non-fermented)	Category (non-fermented)	FCCI (fermented)	Category (fermented)
	non-fermented straw (LU)	fermented straw (LU)	non-fermented	fermented				
Baula	1,536	5,077	983	4,524	2.78	Safe	9.18	Safe
Iwoimenda	227	749	-396	127	0.36	Very critical	1.20	Critical
Kolaka	421	1,391	-188	783	0.69	Very critical	2.29	Safe
Latambaga	202	669	-180	287	0.53	Very critical	1.75	Vulnerable
Polinggona	788	2,605	-967	850	0.45	Very critical	1.48	Critical
Pomalaa	956	3,162	259	2,464	1.37	Critical	4.53	Safe
Samaturu	2,210	7,308	1,503	6,601	3.13	Safe	10.34	Safe
Tanggetada	1,184	3,916	-251	2,481	0.83	Very critical	2.73	Safe
Toari	11	37	-3,249	-3,223	0.00	Very critical	0.01	Very critical
Watubangga	1,662	5,494	-4,236	-403	0.28	Very critical	0.93	Very critical
Wolo	1,748	5,778	1,045	5,075	2.49	Safe	8.22	Safe
Wundulako	1,647	5,446	972	4,771	2.44	Safe	8.07	Safe
Total	12,593	41,631	-4,703	24,335	15.35		50.74	

Table 5. Livestock density in Kolaka Regency

Sub-District	Livestock Economic Density	Category	Regional Density	Category
Baula	46.18	Sparse	3.68	Sparse
Iwoimendaa	74.98	Moderate	1.78	Sparse
Kolaka	14.23	Sparse	2.80	Sparse
Latambaga	11.73	Sparse	1.28	Sparse
Polinggona	228.29	Dense	21.79	Dense
Pomalaa	20.91	Sparse	1.87	Sparse
Samaturu	34.70	Sparse	13.38	Moderate
Tanggetada	91.15	Moderate	3.25	Sparse
Toari	309.00	Very Dense	61.71	Very Dense
Watubangga	351.92	Very Dense	60.72	Very Dense
Wolo	28.25	Sparse	1.75	Sparse
Wundulako	30.70	Sparse	1.41	Sparse

Livestock Density

Livestock density was a useful indicator for assessing the pressure of cattle populations on available resources in both social and spatial terms. In this study, density was expressed in two forms: economic density (LU/1,000 inhabitants) and regional density (LU/km²). Table 5 showed that Watubangga and Toari were categorised as very dense, with Watubangga recording 351.92 LU/1,000 inhabitants and 60.72 LU/km², while Toari reached 309 LU/1,000 inhabitants and 61.71 LU/km². These values were well above the thresholds of 300 LU/1,000 inhabitants or 50 LU/km², commonly used to define high livestock pressure. Conversely, Baula recorded only 46.18 LU/1,000 inhabitants and 3.68 LU/km², classifying it as sparse. This contrast illustrated the highly uneven distribution of cattle across Kolaka Regency. This was explained by Meehan et al. (2016), Watuwaya et al. (2020), and Gerhana et al. (2025), who stated that livestock density in a region was strongly influenced by the development of livestock populations, the potential carrying capacity of agricultural land, and the population size of the area.

High livestock density had significant implications for resource use and sustainability. Districts like Toari and Watubangga, with densities above critical levels, were more prone to feed deficits and potential environmental stress. Previous studies had shown that over-concentration of livestock often leads to land degradation and inefficient use of agricultural by-products (Suryani and Haryanto, 2021). In Kolaka, these pressures were aggravated due to high-density areas also had limited local straw production, as shown earlier in Table 2. This mismatch created structural feed deficits that cannot be resolved solely through improvements in straw quality. Instead, additional strategies such as forage development, concentrate supplementation, or inter-district feed transfer were required to maintain sustainability in these regions.

On the other hand, districts with low livestock density, such as Baula, Latambaga, and

Wundulako, presented opportunities for expansion within the Rice–Cattle Integration System (R-CIS). Their relatively low densities mean that available land and straw resources could support additional cattle without creating excessive pressure. Similar findings were reported in Papua Barat, where balanced livestock density facilitated better utilisation of crop residues (Labatar and Wosiri, 2018). For Kolaka, this suggested that policy interventions did not need to be uniform across districts. Instead, high-density areas like Toari and Watubangga were advised to prioritize population control and feed supplementation, while low-density areas can be designated as growth zones for livestock expansion. This differentiated approach helped optimise feed resources, reduce deficits, and enhance the overall sustainability of R-CIS in Kolaka.

Livestock Concentration Index and Feed Concentration Index

The Livestock Concentration Index (LCI) was used to measure the degree of cattle concentration relative to total livestock distribution, while the Feed Concentration Index (FCI) reflected the concentration of feed resources in each district. Together, these indicators identified areas with either excess livestock or surplus feed potential. Table 6 presented the LCI and FCI values across Kolaka Regency, showing marked disparities between districts. Districts with high LCI values are categorised as livestock-concentrated zones, whereas those with high FCI values were considered feed-rich. This dual analysis complemented the feed carrying capacity by revealing mismatches between where livestock were located and where feed resources were produced.

The analysis of Table 6 indicated that Polinggona, Toari, and Watubangga had LCI values greater than 1.0, placing them in the high-concentration category. Specifically, Toari recorded the highest LCI value at 2.26, while Watubangga reached 4.09, These figures suggested that livestock populations in these districts were significantly above the regional average. Such high concentration levels implied intensified pressure on local feed resources and land, often resulting in feed scarcity and competition with other agricultural activities. Similar findings were reported by Rahayu et al. (2020) in East Java, where clustered livestock populations constrained the effectiveness of integration programmes. Thus, high LCI values served as an indicator of over-concentration and potential feed imbalance.

In contrast, FCI values highlight different trends. Districts such as Baula, Samaturu, Wolo, Wundulako, Watubangga, and Tanggetada all record FCI values above 1.0, categorising them as feed-rich areas. For example, Samaturu's FCI is 2.11, the highest among all districts, reflecting its large rice cultivation area and abundant straw production. These values confirm that feed availability in Kolaka is not evenly matched with livestock concentration. A district like Samaturu, with high FCI but low LCI (0.49), represents an underutilised resource for the Rice–Cattle Integration System (R-CIS). Similar mismatches were also noted in Sumatera Utara by Mulyono et al. (2021), who found that feed-rich districts were often not the same as livestock-dense districts. This highlights the importance of aligning feed resources with livestock distribution.

Table 6. Livestock concentration index and feed concentration index

Sub-District	LCI	Category	FCI	Category
Baula	0.38	Low	1.46	High
Iwoimendaa	0.43	Low	0.22	Low
Kolaka	0.42	Low	0.40	Low
Latambaga	0.27	Low	0.19	Low
Polinggona	1.22	High	0.75	Medium
Pomalaa	0.48	Low	0.91	Medium
Samaturu	0.49	Low	2.11	High
Tanggetada	1.00	Medium	1.13	High
Toari	2.26	High	0.01	Low
Watubangga	4.09	High	1.58	High
Wolo	0.49	Low	1.67	High
Wundulako	0.47	Low	1.57	High

The most striking mismatch was observed in Toari, which recorded an LCI of 2.26 but an FCI of only 0.01 (Table 6). This means Toari had a disproportionately high livestock population with almost no corresponding straw resources. The imbalance leads to persistent feed deficits and reliance on external inputs. In contrast, Samaturu had a high FCI and low LCI, making it a potential source of feed redistribution. This type of imbalance had been documented internationally, such as in crop-livestock systems in China, where livestock were often concentrated in areas with limited crop residue, while surplus residues remain underutilised elsewhere (FAO, 2019). Therefore, Toari's case reflects a global challenge of mismatched livestock-feed geographies.

Overall, the LCI and FCI results demonstrated that Kolaka Regency's main challenge was not the absolute scarcity of feed but rather the spatial mismatch between livestock and feed resources. Districts with high LCI but low FCI, such as Toari, required targeted interventions including feed transfer mechanisms and population management. Conversely, feed-rich but livestock-sparse districts such as Samaturu could have served as centres for straw processing and feed banking. Integrating LCI and FCI with carrying capacity (FCCI) provided a comprehensive framework for identifying priority zones for intervention. Studies by (Hermawan et al., 2022) supported this approach, emphasising that aligning livestock populations with feed resources was central to sustainable integration. Thus, policies in Kolaka should have focused on redistributing resources and optimising spatial management to ensure long-term sustainability of the R-CIS.

CONCLUSION

This study highlights pronounced spatial disparities between feed resource availability and livestock distribution across Kolaka Regency. Districts such as Samaturu, Wolo, and Wundulako exhibit a substantial feed surplus, whereas Toari and Watubangga consistently experienced chronic deficits. The critical constraint did not stem from the total quantity of rice straw produced but rather from its uneven spatial allocation. Application of fermentation technology markedly enhances the nutritional quality of feed particularly crude protein content and consequently improves land carrying capacity, enabling the sustenance of an additional 24,335 livestock units (LU), equivalent to approximately 2,028 LU per district per year. Nevertheless, technological advancement alone cannot resolve the imbalance. An integrated approach involving inter-district feed redistribution and spatially informed livestock management policies is imperative to harmonize feed availability with livestock population density. Developing region-specific strategies that promote feed fermentation in deficit areas while facilitating livestock population growth in surplus zones will significantly strengthen the sustainability of the Rice–Cattle Integration System (R-CIS) in Kolaka Regency.

CONFLICT OF INTEREST

The authors declared that all the material presented in this manuscript has no conflict of interest regarding any financial issues.

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