

Article

One Cow, Two Gains: Welfare Improvement and Chemical Fertilizer Reduction from an Incentive-Based Cattle Support Program Among Poor Smallholders in Guangxi, China

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Abstract

Under binding resource constraints and rising environmental pressures, enabling poor smallholders to raise incomes while reducing chemical input use remains a key policy challenge in many developing economies. Drawing on two waves of household survey data from Guangxi, China, this study evaluates the impacts of small-scale beef cattle rearing promoted through an incentive-based subsidy scheme (Yijiang Daibu). Exploiting quasi-experimental variation in household participation, we combine Coarsened Exact Matching (CEM) with household fixed-effects models to address selection bias and time-invariant unobserved heterogeneity. The results show that participation in dispersed cattle rearing significantly increases household welfare (measured by per capita consumption expenditure) while simultaneously reducing chemical fertilizer application, indicating clear economic and environmental co-benefits. Mechanism evidence suggests that substituting cattle manure for chemical fertilizer plays a central role in driving fertilizer reduction. Moreover, access to credit, participation in farmer cooperatives, and internet access further reinforce both welfare gains and manure–fertilizer substitution effects. Overall, incentive-based support for small-scale livestock production, when aligned with local resource endowments, can deliver both welfare gains and greener production outcomes. This study provides micro-level evidence on how well-designed industrial support policies can jointly promote inclusive growth and agricultural sustainability in smallholder-dominated regions.

Keywords: smallholder agriculture; incentive-based subsidies; crop–livestock integration; welfare improvement; chemical fertilizer reduction



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1. Introduction

Smallholder agriculture remains the backbone of rural livelihoods across developing economies, accounting for a substantial share of agricultural employment, food production, and poverty incidence [1]. Despite persistent constraints—such as fragmented landholdings, limited access to capital, and high exposure to production and market risks—smallholders remain central to food systems and rural development [2]. A fundamental challenge facing policymakers and researchers is how smallholder-based production systems can simultaneously generate sustained welfare improvement while contributing to environmentally sustainable agricultural transitions [3]. While policy debates often emphasize large-scale, specialized, and capital-intensive farming models [4], a growing body

of research suggests that smallholder-oriented and resource-efficient strategies may offer more inclusive and context-appropriate pathways toward poverty reduction and green development [5].

China provides a particularly relevant setting to examine this issue. Over the past decade, the country has implemented large-scale poverty alleviation programs targeting rural households, with a strong emphasis on promoting locally adapted agricultural activities [6]. Within this policy context, incentive-based industrial support schemes—commonly referred to as Yijiang Daibu (reward-based subsidies)—have been widely adopted to stimulate household participation in income-generating activities [7]. These schemes provide ex post payments conditional on verified production outcomes, aiming to strengthen households' self-development incentives and reduce the risk of falling back into poverty. Among the supported activities, small-scale livestock production, especially cattle rearing, has emerged as a priority. While broadly characterized by the symbolic “one cow” entry level, the policy in practice encourages households to expand herd sizes beyond a single animal to generate stable income under land constraints [8,9].

At the same time, China's rural development strategy has increasingly incorporated environmental objectives, notably the reduction in chemical fertilizer use and the mitigation of agricultural non-point source pollution [10]. This dual policy orientation—combining welfare improvement with environmental improvement—has positioned crop–livestock integration as a potentially effective mechanism for achieving multiple development goals. Through on-farm nutrient recycling, livestock manure can partially substitute for chemical fertilizers, thereby reducing input intensity while improving soil fertility [11]. For resource-constrained smallholders, such complementarities between crop and livestock production may enable a transition toward more sustainable input use without compromising livelihoods [12]. However, whether these synergies materialize at the household level, and at what magnitude, remains empirically unclear.

From a household decision-making perspective, small-scale dispersed livestock rearing can be a rational response to local resource endowments in land-scarce mountainous regions [13,14]. Compared with scale-intensive livestock operations, dispersed systems rely primarily on household labor, locally available feed resources, and simple infrastructure, lowering entry barriers for poor households [15]. Moreover, when livestock production is embedded within mixed farming systems, manure use creates complementarities between livestock and crop production, potentially reducing reliance on chemical fertilizers [16]. Nevertheless, dominant narratives of agricultural modernization—favoring specialization, mechanization, and economies of scale—have often marginalized such smallholder-based mixed farming systems [17]. As a result, their economic and environmental contributions remain underexplored in empirical research, particularly using micro-level household data.

Existing studies provide substantial evidence that livestock-oriented poverty alleviation programs can enhance household income, reduce vulnerability to shocks, and improve welfare outcomes relative to crop-based interventions alone [18]. Livestock ownership has also been associated with improved dietary diversity, nutritional intake, and livelihood resilience in developing economies [19,20]. However, much of the existing literature focuses on program-level impacts or relatively concentrated livestock interventions, with limited attention to dispersed, household-level livestock rearing among poor smallholders [21]. More importantly, few studies explicitly examine whether such small-scale livestock engagement can deliver dual dividends—income growth and reductions in chemical fertilizer use—under severe land constraints. This gap is particularly salient in regions such as Guangxi, where fragmented landholdings, fragile agro-ecological conditions, and long-standing incentive-based livestock support policies jointly shape household production decisions.

This study addresses these gaps by providing micro-level evidence on the income and environmental effects of scattered Cattle rearing among poor smallholders in Guangxi, China. Exploiting quasi-experimental variation in household participation in small-scale livestock production induced by incentive-based subsidy policies, we examine whether and to what extent livestock engagement increases household income while reducing chemical fertilizer application through crop–livestock integration. By jointly analyzing economic and environmental outcomes, this paper makes three main contributions. First, it shifts attention from scale-oriented livestock programs to household-level adoption decisions, clarifying the economic rationale and sustainability of dispersed cattle rearing under resource constraints. Second, it provides direct empirical evidence on crop–livestock complementarities by linking cattle adoption to changes in chemical fertilizer use. Third, by studying an incentive-based policy targeting poor smallholders, it sheds light on how industrial support programs can align welfare objectives with environmental goals in smallholder-dominated agricultural systems.

The remainder of the paper is organized as follows. Section 2 introduces the policy background and the theoretical framework. Section 3 describes the data sources, variable selection, and the quasi-experimental identification strategy. Section 4 presents the empirical results, including baseline estimates, robustness checks, and endogeneity tests. Section 5 discusses the underlying mechanisms and the broader validity of the findings. Finally, Section 6 concludes the study and offers policy implications.

2. Policy Background and Theoretical Framework

2.1. Policy Origins and Institutional Features

Within China’s poverty alleviation and rural revitalization framework, Guangxi has adopted an incentive-based industrial support mechanism known as Yijiang Daibu (reward-based subsidies) to promote income-generating activities among poor rural households. As a less-developed region characterized by fragmented landholdings and mountainous terrain, Guangxi introduced this policy to encourage locally appropriate production choices under binding resource constraints.

A defining feature of the Yijiang Daibu scheme is its *ex post*, performance-based design. Subsidies are provided only after households complete predefined production activities and pass official verification (“build first, subsidize later”), aiming to reduce moral hazard and strengthen household responsibility. This mechanism ensures that every household receiving the subsidy has effectively engaged in the production activity, thereby eliminating the possibility of including non-adopters in the program beneficiaries. Pilot programs began in several counties around 2016 and were subsequently institutionalized. In 2021–2022, the policy was formally incorporated into the regional fiscal framework for rural revitalization and standardized across counties in terms of eligible industries, target groups, and implementation principles.

2.2. Cattle-Based Support and Local Resource Endowments

Within the Yijiang Daibu framework, livestock production—particularly cattle rearing—was identified as a priority supported activity. This reflects its suitability to Guangxi’s hilly terrain, relatively stable market demand, and its compatibility with small and fragmented landholdings. Moreover, cattle rearing exhibits strong complementarities with crop production, providing a practical basis for promoting crop–livestock integration.

Policy implementation follows a unified regional framework combined with county-level discretion. Local governments formulate annual implementation plans specifying subsidy standards, application procedures, and verification requirements. Households may participate through self-managed production, cooperative arrangements, or entrusted

feeding models. Subsidies are typically granted on a per-head basis ranging from RMB 300 to 1500 for households lifted out of poverty and RMB 1500 to 5000 for those remaining in poverty (contingent on poverty severity and breeding scale), subject to a cumulative *Yijiang Daibu* subsidy ceiling of RMB 5000 per household.

The prioritization of cattle production is further supported by Guangxi's favorable feed resource base. As a major sugarcane-producing region, Guangxi generates abundant agricultural by-products such as sugarcane leaves and tops, alongside widely available maize and natural grass resources. The use of locally sourced feed reduces reliance on commercial inputs, lowers production costs, and enhances the feasibility of small-scale cattle rearing for resource-constrained households.

2.3. Targeting, Coverage, and Complementary Measures

The *Yijiang Daibu* scheme explicitly targets households registered in the national poverty monitoring system, including formerly poor households and those at risk of poverty relapse. Some counties apply differentiated subsidy intensities across household categories to balance equity and incentives. Following policy standardization, cattle-based *Yijiang Daibu* programs have been implemented in most counties of Guangxi. While operational details vary across locations and over time, the core incentive structure and targeting principles remain consistent, generating meaningful variation in household exposure to livestock incentives.

In addition to financial rewards, cattle-based *Yijiang Daibu* policies are typically accompanied by complementary services, including technical extension, veterinary support, and guidance on manure management. In some areas, basic requirements for manure recycling are incorporated into verification procedures, strengthening linkages between livestock and crop production. By lowering entry barriers to livestock production and encouraging crop–livestock integration, the policy provides an institutional context in which welfare improvement and reductions in chemical fertilizer use may occur simultaneously.

2.4. Theoretical Framework and Research Hypotheses

Based on the policy features and agricultural household models [22], this study conceptualizes the impact of the *Yijiang Daibu* policy through two primary channels: the income effect on household welfare and the resource substitution effect on production inputs. Furthermore, we posit that these effects are moderated by external facilitating conditions.

2.4.1. The Welfare Effect: Asset Accumulation and Cost Savings

The impact on household welfare, measured by per capita consumption, operates through both revenue and cost channels. First, the *Yijiang Daibu* policy lowers the entry barrier for acquiring productive assets. Unlike simple cash transfers, cattle rearing generates distinct income streams: the direct policy reward and the capital gains from selling mature cattle. Second, the “cost-saving effect” derived from input substitution (using manure instead of expensive fertilizer) effectively increases net agricultural profits. According to the Permanent Income Hypothesis [23] and theories on asset-based coping strategies [24], the accumulation of productive assets and the diversification of income sources improve households' expectations of future earnings, thereby encouraging the smoothing and elevation of current consumption levels [25].

2.4.2. The Resource Substitution Effect: Internalizing Nutrient Supply

The core mechanism linking cattle rearing to fertilizer reduction is the substitution between internal biological resources and external commercial inputs in mixed farming systems [26]. For resource-constrained smallholders, chemical fertilizer represents a significant cash expenditure. The adoption of cattle rearing introduces a stable supply of organic

manure. Drawing on the theory of induced innovation [27] and input substitution, households rationally adjust their input mix to minimize costs when relative factor prices change. Since manure is an “internally generated” by-product with a shadow price significantly lower than the market price of commercial fertilizer, rational households are incentivized to substitute manure for chemical fertilizers to maintain soil fertility while minimizing cash outlays.

2.4.3. Moderating Factors: Financial and Information Enablers

Finally, consistent with the mechanisms highlighted in the distinction between potential and realized gains, we argue that the magnitude of the above effects depends on complementary endowments. Access to credit eases liquidity constraints for complementary investments (e.g., feed, housing); cooperative membership reduces transaction costs and technical barriers [28]; and internet access alleviates information asymmetry regarding prices and technologies. These factors are hypothesized to amplify the positive impacts of cattle rearing.

3. Data and Empirical Strategy

3.1. Data Source and Quasi-Experimental Design

In recent years, with the gradual phase-out of backyard pig production and the sustained growth in beef demand, cattle rearing has become an increasingly important livelihood option in many less-developed regions of China. Since around 2017, local governments across Guangxi have incorporated beef cattle production into the Yijiang Daibu (reward-based subsidy) industrial support program, providing targeted financial incentives, technical assistance, and complementary services to encourage poor households to engage in cattle rearing. Compared with the pre-policy period, cattle production experienced a marked expansion in policy support intensity, geographic coverage, and household participation.

Prior to 2017, cattle rearing was not widely promoted as a poverty alleviation activity in Guangxi, and participation among poor households was limited. Following the policy rollout, however, cattle rearing was systematically encouraged in most poor counties and became a key supported livelihood option. This institutional shift generated a clear distinction between households that adopted cattle rearing after the policy implementation and those that did not. Crucially, the policy operates on a “Build First, Subsidize Later” basis, meaning subsidies were granted strictly after households verified their production activities. Leveraging this policy-induced variation, this study treats households that actually engaged in cattle rearing after 2017 as the treatment group, and those that did not as the control group. This strict definition ensures that all households in the treatment group were fully exposed to the intervention, thereby creating a quasi-experimental setting to identify the economic and environmental effects of small-scale cattle rearing among poor smallholders.

The empirical analysis is based on two rounds of household survey data collected in Guangxi in 2017 and 2020. The first round was conducted between January and June 2017, and the second round between June and December 2020. Both surveys collected detailed information on household demographics, agricultural production activities, income sources, and input use. To ensure data accuracy and minimize potential recall bias often associated with self-reported data, the surveys were administered through one on one, face-to-face interviews by a trained research team comprising faculty members and graduate students. Crucially, we implemented a strict cross-check protocol regarding logical consistency during the field investigation. Enumerators simultaneously recorded total expenditure, physical quantity, and unit price for key inputs like fertilizers, verifying logical consistency

on-site (i.e., Quantity $\times$ Price = Total Expenditure) to identify and correct any discrepancies immediately. The study area covers 10 counties across six prefecture-level cities in Guangxi (Hechi, Baise, Nanning, Laibin, Yulin, and Guigang), comprising five nationally designated poor counties, four provincially designated poor counties, and one non-poor county.

To accurately represent the target population of the Yijiang Daibu policy, a stratified multi-stage random sampling strategy was employed in the first wave. The stratification criteria were strictly based on administrative poverty designations: At the village level, the sampling frame was restricted to officially designated poor villages. Four such villages were randomly selected from each county. At the household level, the sampling frame focused on registered poor households (including both formerly and currently poor households listed in the national poverty database). From each village, approximately 12 households were randomly selected. This procedure yielded an initial sample of 480 households from 40 villages. Due to attrition driven by labor migration, production exits, or household shocks, a balanced panel of 392 households was retained for the two-wave analysis.

Crucially, the data captures a significant policy-induced shift. In the baseline wave (2017), participation in beef cattle rearing was negligible. By contrast, in the follow-up wave (2020), approximately half of the sampled households had adopted small-scale cattle rearing under the policy incentives. This substantial temporal variation in adoption status within the same households provides the necessary identification variation to examine the welfare and environmental effects of cattle-based crop–livestock integration.

3.2. Empirical Strategy

3.2.1. Coarsened Exact Matching

Imbalances between treated and control groups are a major source of bias in causal effect estimation. Although the household surveys were designed to approximate random sampling, participation in cattle rearing ultimately reflects households' voluntary production decisions, which may be influenced by observable and unobservable factors such as asset endowments, risk preferences, policy awareness, and local implementation intensity. Estimating treatment effects directly from the raw sample may therefore yield biased results due to selection concerns.

To address this issue, this study employs Coarsened Exact Matching (CEM) to preprocess the data prior to outcome estimation. CEM reduces covariate imbalance by temporarily coarsening key covariates and matching treated and control households within the same strata, thereby improving comparability between groups [29]. Compared with alternative matching approaches such as propensity score matching, CEM imposes fewer modeling assumptions, offers greater transparency, and retains a larger share of the sample while effectively controlling for observable differences [30]. Specifically, households that participated in cattle rearing are matched with non-participating households based on a set of pre-treatment household and village characteristics. CEM is implemented prior to the fixed-effects estimation to ensure covariate balance between treated and control households. Accordingly, the average treatment effect on the treated (ATT) of cattle rearing among poor households can be expressed as:

$$ATT = E(y_1 - y_0 | X, T = 1) = E(y_1 | X, T = 1) - E(y_0 | X, T = 1) \quad (1)$$

Here, y_1 and y_0 denote potential outcomes with and without treatment, X is a vector of covariates, and T indicates participation.

3.2.2. Fixed-Effects Models

Using the matched and weighted sample, we estimate fixed-effects models to identify the net effects of cattle rearing on household welfare and chemical fertilizer application

while controlling for time-invariant unobserved heterogeneity [31]. Based on two-wave panel data, the baseline specification is:

$$y_{it} = \beta_0 + \gamma_0 d_{2t} + \beta_1 T_{it} + \beta_2 X_{it} + Z_i + \varepsilon_{it} \quad (2)$$

In the above specification, y_{it} denotes the outcome for household i in period t (with $t = 1$ for 2017 and $t = 2$ for 2020). T_{it} equals 1 if household i participated in the cattle component of *Yijiang Daibu* and engaged in commercial beef cattle production in period t , and 0 otherwise. X_{it} is a vector of time-varying controls. d_{2t} is a time dummy, Z_i household fixed effects and ε_{it} is an idiosyncratic error term. With two waves, the fixed-effects model is equivalent to first differencing:

$$y_{i2} - y_{i1} = \gamma_0 + \beta_1 (T_{i2} - T_{i1}) + \beta_2 (X_{i2} - X_{i1}) + (\varepsilon_{i2} - \varepsilon_{i1}) \quad (3)$$

Equation (3) explicitly demonstrates how the time-invariant unobserved heterogeneity (Z_i) is mathematically eliminated through differencing. To simplify the notation for the final estimation, we define the difference operator Δ such that $\Delta y_i = y_{i2} - y_{i1}$, $\Delta T_i = T_{i2} - T_{i1}$, and $\Delta X_i = X_{i2} - X_{i1}$. Consequently, the model can be rewritten in its compact form as:

$$\Delta y_i = \gamma_0 + \beta_1 \Delta T_i + \beta_2 \Delta X_i + \Delta \varepsilon_i \quad (4)$$

In the first-difference specification, ΔT_i equals 1 if the household adopted cattle rearing between 2017 and 2020 and 0 otherwise. Because estimation is conducted after CEM, the weighted first-difference model is:

$$\Delta y'_i = \gamma'_0 + \beta_1 \Delta T'_i + \beta_2 \Delta X'_i + \Delta \varepsilon'_i \quad (5)$$

where the prime symbol (') indicates variables weighted by the CEM weights.

3.2.3. Variable Selection

We use annual per capita household consumption expenditure and chemical fertilizer input per hectare of cultivated land as the main outcome variables to capture welfare improvement and fertilizer reduction effects of cattle rearing among poor households. Consumption expenditure is a widely used proxy for household welfare and living standards [32]. Under China's targeted poverty alleviation framework, measuring income precisely can be difficult because some earnings are informal or volatile (e.g., temporary wages, transfers or support from family members). For poor households in less-developed areas, reported income may therefore be a noisy measure of economic well-being, whereas consumption expenditure can better reflect changes in living standards and household welfare [9].

As the second outcome, chemical fertilizer input in crop production captures changes in input structure associated with manure substitution following cattle adoption—i.e., whether cattle rearing contributes to reducing chemical fertilizer use through crop–livestock integration. To reduce skewness and account for scale differences, the two dependent variables are log-transformed in the empirical analysis.

Based on the survey and related literature, we control for household head characteristics (age and education) [33], household labor force size, cultivated land area [34], productive fixed assets excluding housing [9], total crop-production input expenditure, household credit balance [35], internet access [36], cooperative membership [37], engagement in other commercial livestock activities, and the share of non-farm income in total household income, among other variables [38].

For CEM, we match on five pre-treatment covariates reflecting eligibility and capacity to participate in the cattle component of Yijiang Daibu: poverty status, whether the household is located in a nationally designated poor county, education, prior cattle-rearing experience, and access to forage resources (e.g., crop residues or forage crops). After matching, the L1 statistic decreases from 0.548 to 0.217, indicating improved overall balance [30].

Table 1 reports descriptive statistics for outcomes and controls based on the 2020 survey, as well as group means after CEM. The table shows significant differences in the two outcomes between cattle-rearing and non-rearing households: cattle-rearing households apply significantly less chemical fertilizer per hectare and have higher per capita consumption expenditure.

Table 1. Descriptive statistics before and after CEM.

Variable	Definition	Unmatched Sample		CEM-Matched Sample	
		Control Mean	Treated Mean	Control Mean	Treated Mean
Fertilizer	Chemical fertilizer application in crop production (kg/ha)	481.5	384.2	516.1	367.5
Consumption	Per capita consumption expenditure (USD/year)	769.6	925.3	773.1	912.3
Cattle rearing	Participated in cattle rearing during 2017–2020 (1 = yes, 0 = no)	0	1	0	1
Age	Age of the household head (years)	54.3	53.5	54.6	53.9
Education	Years of schooling of the household head (years)	4.74	5.31	4.91	5.18
Labor force	Number of household laborers	1.95	1.86	1.94	1.87
Household size	Total household members (persons)	3.47	3.44	3.45	3.44
Land size	Cultivated land area (ha)	0.322	0.346	0.319	0.341
Fixed assets	Productive fixed assets excluding housing (USD)	2895.2	3066.5	2876.4	3007.6
Inputs	Crop input expenditure (USD/ha/Year)	4239.8	4142.2	4320.3	4127.7
Credit	Total outstanding household credit (USD)	2699.5	2641.2	2685.1	2772.3
Internet access	Broadband access or smartphone use (1 = yes, 0 = no)	0.65	0.66	0.65	0.67
Cooperation	Member of a farmers' cooperative (1 = yes, 0 = no)	0.35	0.46	0.34	0.47
Other livestock	Other livestock production excluding beef cattle (1 = yes, 0 = no)	0.42	0.37	0.49	0.37
Non-farm	Share of non-farm income in total household income (%)	0.44	0.39	0.43	0.39

Note: The 2020 exchange rate is 1 USD = 6.89 RMB. Fertilizer input is measured on a nutrient-content basis (pure nutrient). Control = non-cattle-rearing households; Treated = cattle-rearing households.

4. Results

4.1. Baseline Regression Results

Table 2 reports regression estimates of the impacts of cattle rearing on per capita household consumption expenditure and chemical fertilizer application in crop production, before and after applying CEM. As shown in Table 2, regressions are jointly significant, with F-statistics significant at the 1% level. The estimated effect of cattle rearing remains statistically significant and of similar magnitude in both the unmatched and CEM-matched samples. Because CEM improves balance on observed covariates, post-matching estimates are based on better-balanced samples and are therefore more credible. Below we discuss the estimated effects on welfare and fertilizer use.

Table 2. Impacts of cattle rearing on household consumption expenditure and chemical fertilizer.

Variables	Consumption Expenditure		Chemical Fertilizer Application	
	Unweighted	CEM-Weighted	Unweighted	CEM-Weighted
Cattle rearing	0.058 *** (0.019)	0.052 *** (0.018)	−0.147 ** (0.063)	−0.158 *** (0.061)
Labor force	−0.004 (0.023)	−0.005 (0.020)	−0.012 * (0.007)	−0.022 ** (0.010)
Household size	−0.067 (0.057)	−0.079 ** (0.039)	0.157 (0.189)	0.151 (0.174)
Land size	0.006 ** (0.003)	0.007 ** (0.003)	−0.002 ** (0.001)	−0.002 ** (0.001)
Fixed assets	0.126 *** (0.046)	0.138 *** (0.034)	0.186 (0.141)	0.187 (0.154)
Inputs	−0.083 (0.094)	0.079 (0.067)	0.280 * (0.156)	0.285 ** (0.141)
Credit	0.005 ** (0.002)	0.005 ** (0.002)	0.147 (0.110)	0.134 (0.108)
Internet access	0.012 * (0.006)	0.016 ** (0.007)	−0.083 (0.110)	−0.053 * (0.031)
Cooperation	0.042 ** (0.019)	0.051 ** (0.023)	−0.007 * (0.004)	−0.010 ** (0.005)
Other livestock	0.032 * (0.018)	0.033 * (0.018)	−0.004 ** (0.002)	−0.007 ** (0.003)
Non-farm	0.559 *** (0.116)	0.661 *** (0.092)	0.249 (0.354)	0.237 (0.311)
Constant	6.662 *** (0.687)	6.617 *** (0.431)	7.496 *** (2.091)	9.723 *** (1.498)
Observations	548		548	
R square	0.326	0.453	0.237	0.298
F-statistic	16.09 *** (0.00)	17.84 *** (0.00)	5.62 *** (0.00)	5.43 *** (0.00)

Notes: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Standard errors are reported in parentheses. Dependent variables are in logs and crop input expenditure, productive fixed assets, and credit are also log-transformed. Observations are household-year; the matched estimation sample contains 548 observations.

On the welfare side, cattle rearing is associated with a significant increase in per capita household consumption expenditure. Columns (1) and (2) of Table 2 show that the coefficient on cattle rearing is positive and statistically significant at the 1% level in both samples. This suggests that cattle rearing improves household welfare and purchasing power among poor households, for whom baseline consumption is typically low.

On the environmental side, cattle rearing significantly reduces chemical fertilizer application in crop production. Columns (3) and (4) report fixed-effects estimates before and after CEM. In both cases, cattle rearing has a statistically significant negative association with chemical fertilizer use. This aligns with the descriptive statistics in Table 1: fertilizer input per hectare is 384.2 kg/ha for cattle-rearing households compared with 481.5 kg/ha for non-rearing households in the unmatched sample.

Several complementary factors are also associated with welfare improvement and fertilizer reduction. In Table 2, covariates such as land size, household credit, internet access, cooperative membership, and engagement in other livestock activities are significantly related to household consumption and/or fertilizer use. Larger land size is associated with higher consumption and lower fertilizer intensity, consistent with the idea that moderate scale can support both welfare gains and greener production. Access to credit and digital connectivity is positively related to consumption, underscoring the role of inclusive finance and rural infrastructure. Cooperative membership and internet access are also linked to

reduced fertilizer use, suggesting that organization and information can facilitate input substitution and improved management. Diversification into other commercial livestock activities is positively associated with consumption and may further support greener production. Finally, non-farm income plays an important role in household welfare.

4.2. Robustness Tests

Although baseline results are stable across unmatched and CEM-matched samples, we further examine robustness by (i) adding interaction terms, (ii) including county-by-year fixed effects, and (iii) using alternative dependent variables. First, because cattle rearing may depend on land availability (e.g., for forage) and may be correlated with other livestock activities, we include interactions between cattle rearing and land size, and between cattle rearing and other livestock activities. Second, to account for heterogeneity in local economic development and policy resources, we add county-by-year fixed effects. Third, following the literature [3,9], we replace outcomes with meat expenditure (as an alternative welfare proxy) and organic fertilizer use (to capture manure-related input substitution). In the study context, meat expenditure accounts for a sizable share of food spending among poor households and can serve as an alternative proxy for household welfare.

Tables 3 and 4 present results from these checks. Across specifications, cattle rearing remains significantly associated with higher consumption (or meat expenditure) and lower chemical fertilizer use (and higher organic fertilizer use). Notably, consistent with the substitution channel, Table 4 confirms that cattle rearing significantly increases organic fertilizer application. Although we lack soil test data, this significant increase quantitatively corroborates the replacement mechanism: cattle manure effectively substitutes for synthetic inputs by maintaining soil fertility, particularly in sloping lands dominant in the region [39]. The interaction between cattle rearing and land size is positive and significant for consumption, suggesting that land resources partly shape the returns to crop–livestock integration. The interaction between cattle rearing and other livestock activities is significant for both welfare and fertilizer outcomes, consistent with complementary effects of diversified livestock-based production. Overall, these robustness checks support the baseline conclusion that small-scale cattle rearing delivers both welfare gains and fertilizer reduction among poor smallholders.

Table 3. Robustness checks: interaction terms with county-by-year fixed effects (household fixed effects).

Variables	Consumption Expenditure		Chemical Fertilizer Application	
Cattle rearing	0.046 *** (0.013)	0.067 *** (0.021)	−0.166 ** (0.083)	−0.189 *** (0.052)
Cattle rearing × Land size	0.002 ** (0.001)	—	0.015 (0.016)	—
Cattle rearing × Livestock	—	0.042 ** (0.023)	—	−0.011 ** (0.006)
Controls	YES	YES	YES	YES
County-by-year FE	YES	YES	YES	YES
R square	0.48	0.47	0.211	0.214
F-statistic	16.59 *** (0.00)	16.85 *** (0.00)	11.97 *** (0.00)	10.93 *** (0.00)

Notes: All specifications are estimated with household fixed effects. County-by-year fixed effects are included in all columns. *** and ** denote significance at the 1% and 5% levels, respectively. Standard errors are in parentheses. "—" denotes that the variable was not included in the model.

Table 4. Robustness checks using alternative outcome variables (household fixed effects).

Variables	Meat Expenditure		Organic Fertilizer Application	
Cattle rearing	0.006 ** (0.003)	0.018 *** (0.004)	0.281 ** (0.127)	0.289 *** (0.063)
Cattle rearing × Land size	0.004 ** (0.002)	—	0.022 (0.025)	—
Cattle rearing × Livestock	—	0.017 *** (0.006)	—	0.044 ** (0.021)
Controls	YES	YES	YES	YES
County-by-year FE	YES	YES	YES	YES
R square	0.43	0.42	0.23	0.24
F-statistic	32.10 *** (0.00)	32.22 *** (0.00)	10.89 *** (0.00)	12.64 *** (0.00)

Notes: All specifications are estimated with household fixed effects and include county-by-year fixed effects. *** and ** denote significance at the 1% and 5% levels, respectively. Standard errors are in parentheses. "—" denotes that the variable was not included in the model.

To verify that our results are not sensitive to the specific choice of the matching algorithm, we re-estimated the treatment effects using Propensity Score Matching (PSM). We calculated propensity scores based on household characteristics in the baseline year (2017) to match adopters in 2020 with non-adopters, employing the k-nearest neighbor algorithm ($k = 4$). The PSM-weighted regression results, reported in Table 5, are highly consistent with our baseline CEM estimates. Specifically, cattle rearing continues to show a significant positive effect on consumption expenditure and a significant negative effect on chemical fertilizer application intensity, confirming that our main findings are robust across different matching specifications.

Table 5. Robustness Check using Propensity Score Matching (PSM).

Variables	Consumption Expenditure	Chemical Fertilizer Application
	PSM-Weighted	PSM-Weighted
Cattle rearing	0.057 ** (0.028)	−0.148 ** (0.064)
Controls	YES	YES
County-by-year FE	YES	YES
Observations	632	632
R square	0.313	0.245
F-statistic	17.22 *** (0.00)	5.84 *** (0.00)

Notes: *** and ** denote statistical significance at the 1% and 5% levels, respectively. Standard errors are reported in parentheses. Observations are household-year; the matched estimation sample contains 632 observations.

4.3. Endogeneity Test

Although two-wave fixed-effects models and CEM effectively mitigate bias from observable characteristics, concerns regarding reverse causality and omitted time-varying unobservables may still persist. To further address potential endogeneity of cattle adoption, we estimate an instrumental-variable fixed-effects (IV-FE) model.

Following the standard approach in social network and technology adoption literature [28,40,41], we select an indicator for whether neighbors or close relatives engage in cattle rearing as an instrument for household cattle adoption. Fieldwork and theory confirm the relevance of this instrument: households' adoption decisions are influenced by local demonstration and peer effects, where cattle rearing by neighbors or close relatives increases exposure to information, learning opportunities, and perceived feasibility, thereby encouraging adoption. Regarding the exclusion restriction, conditional on controls and fixed effects, we assume that the decision of neighbors or close relatives to rear cattle does not directly alter the focal household's budget constraints or agricultural production

environment; it affects the outcomes primarily through the channel of influencing the household's own cattle adoption decision.

Table 6 reports IV-FE results. The bottom panel presents the validity tests for the instrument. First-stage statistics indicate that the instrument is strongly correlated with the endogenous adoption variable. Regarding the estimation results, the impact of cattle rearing on per capita consumption stays positive and significant (0.027), confirming that welfare gains persist even after accounting for endogeneity. After instrumenting, the coefficient for chemical fertilizer application represents a legitimate reduction effect of -0.309 . Notably, this reduction is larger in magnitude than the baseline estimate (-0.158). This result aligns with the sociological perspective of 'peer effects' and social learning [40,42]. It suggests that households adopting cattle rearing through social networks (influenced by neighbors) benefit from knowledge spillovers, enabling them to implement manure-fertilizer substitution more effectively than the average population.

Table 6. IV-FE estimates addressing endogeneity in cattle rearing.

Variables	Consumption Expenditure		Chemical Fertilizer Application	
	NO	YES	NO	YES
Cattle rearing	0.027 *** (0.005)	0.039 *** (0.014)	-0.309 *** (0.055)	-0.124 *** (0.047)
Controls				
F-statistic	25.17 *** (0.00)	18.31 *** (0.00)	16.52 *** (0.00)	14.31 *** (0.00)
F-stat (1st stage)	78.47 *** (0.00)	18.31 *** (0.00)	76.52 *** (0.00)	31.53 *** (0.00)

Notes: *** denote significance at the 1% levels, respectively. Standard errors are in parentheses.

5. Discussion

Using two-wave household panel data from Guangxi, this study identifies the welfare and environmental effects of small-scale cattle rearing among poor smallholders under the Yijiang Daibu policy framework. Combining CEM with household fixed effects in a quasi-experimental setting, we find that cattle adoption significantly increases per capita consumption expenditure while reducing chemical fertilizer application per hectare. These results indicate dual benefits in terms of welfare improvement and greener production. They also suggest that, in underdeveloped regions characterized by tight resource constraints, fragmented landholdings, and ecological pressure, small-scale livestock production does not necessarily imply low efficiency or high pollution. Under incentive-compatible policies and within household-managed crop–livestock systems, smallholders can pursue a development pathway that balances welfare improvement with green production.

Welfare effects: We use per capita consumption expenditure to capture changes in household welfare. This approach is preferred because income measurement among poor households can be noisy: income sources are often informal and volatile, and transfers are difficult to observe precisely in surveys. Results indicate that households participating in cattle rearing experience significant increases in consumption, consistent with cattle functioning as both a source of cash income and an asset with value-appreciation potential. Livestock can also serve as a buffer stock that can be liquidated during periods of major expenditures (e.g., education and healthcare), improving resilience and enabling consumption smoothing [43]. In addition, the ex post verification and payment design of Yijiang Daibu can strengthen production incentives and reduce reliance on unconditional transfers, increasing the likelihood that cattle rearing develops into a sustainable livelihood activity rather than a short-term project response [44,45]. Consistent with our field observations, even small increases in herd size can generate meaningful increments to household income, thereby improving welfare and allowing broader upgrading of consumption across categories [9,15].

Input substitution effects and nutrient cycling: The primary mechanism through which cattle rearing reduces chemical fertilizer intensity is input substitution driven by nutrient cycling in crop–livestock integration. For cash-constrained smallholders, chemical fertilizer is a typical purchased input, whereas manure from cattle provides an internal, low-cost nutrient source within the household. As a result, manure can substitute for chemical fertilizers [46]. Robustness checks show that cattle rearing significantly increases organic fertilizer use, consistent with a manure-to-fertilizer substitution channel [47]. Importantly, reduced chemical fertilizer use does not necessarily imply lower output; rather, it reflects a shift toward greener production through input substitution. Although our survey did not measure soil nutrients directly, agronomic literature affirms that cattle manure is rich in essential nutrients (N, P, K). Recent studies on similar sloping lands demonstrate that partial organic substitution significantly improves soil physicochemical properties and nutrient availability [39]. This suggests that the observed fertilizer reduction is supported by a scientifically sound agronomic basis, improving long-term soil health while maintaining productivity. These results further indicate that livestock and crops can be synergistic rather than merely substitutable within smallholder systems [48].

Validation with macro-level statistics: Regarding the validity of these self-reported findings, while survey data inherently faces recall risks, our rigorous cross-verification method (detailed in Section 3.1) minimizes measurement error. Furthermore, our micro-level evidence is strongly corroborated by official regional administrative data. According to the Guangxi Statistical Yearbook, the usage of chemical fertilizers (pure volume) in all six prefecture-level cities covered by our study (Nanning, Guigang, Yulin, Baise, Hechi, and Laibin) decreased from 1.42 million tons in 2017 to 1.32 million tons in 2020, representing a total reduction of approximately 7.5%. This consistent downward trend, observed in both specific major agricultural cities (e.g., Nanning dropping from 538,300 to 471,700 tons; Laibin dropping from 262,800 tons to 248,900 tons) and the region as a whole, aligns perfectly with our household survey data. This reinforcement from macro-level statistics confirms that the observed reduction is a genuine systemic shift rather than an artifact of self-reporting bias. (Source: Guangxi Statistical Yearbook, 2018–2021. Available online: <http://tjj.gxzf.gov.cn/tjsj/tjnj/> (accessed on 25 January 2026). Statistics represent the "Consumption of Chemical Fertilizers (Pure Content)" for the respective cities in 2017 and 2020).

Complementary conditions and amplification mechanisms: We also find that credit access, cooperative participation, and internet access are associated with stronger welfare improvements and fertilizer reduction, suggesting that the dual benefits of cattle rearing depend on complementary enabling conditions. Cattle rearing requires upfront investment and involves relatively long production cycles; credit can ease liquidity constraints related to calf purchase, housing, and veterinary care, reducing underinvestment and premature exit [49]. Cooperatives can reduce transaction costs and strengthen organizational capacity by providing technical training, disease prevention services, input procurement, and marketing support [50]. Digital connectivity improves information access and decision-making by facilitating price discovery, technical learning, and social linkages [51]. Together, these factors help explain heterogeneity in program effectiveness across households.

Long-term sustainability and policy exit: Furthermore, a critical consideration for the Yijiang Daibu program is its long-term sustainability and exit strategy, specifically regarding whether the “two gains” can persist after the subsidy is phased out. Our analysis suggests that the policy is designed to foster capacity building rather than dependency, a goal that aligns precisely with the original design intent of “award in lieu of subsidy” and “construct first, subsidize later.” From an economic perspective, the subsidy serves as a “kick-start” mechanism that helps resource-constrained poor households overcome the high initial

capital barriers to livestock entry, particularly the significant upfront costs required for calf acquisition [52]. Unlike consumable transfer payments, cattle are productive biological assets capable of growth and reproduction, meaning that the revenue generated from the first cycle of subsidized rearing typically provides households with sufficient internal capital to finance subsequent cycles and enables a transition from subsidy-reliance to self-sustaining production [53]. From an environmental perspective, as corroborated by our fieldwork, the substitution of manure for chemical fertilizer is driven by the rational motive of cost minimization. Once farmers adopt this practice and witness the tangible cost savings alongside potential improvements in soil quality, the economic rationale for utilizing manure remains robust even in the absence of external incentives. This implies that the policy has the potential to induce a lasting behavioral shift toward greener agriculture that outlives the duration of the financial support [54].

Boundary conditions and generalizability: While our findings highlight the success of the Yijiang Daibu program, generalizing these results requires careful consideration of local contexts. The program's effectiveness is partly underpinned by Guangxi's specific resource endowments—namely, the abundance of crop residues (e.g., sugarcane leaves) in a humid, hilly region where large-scale mechanization is difficult, making household-level cattle rearing a comparative advantage. Thus, the “dual gains” model is most applicable to regions with similar fragmented landholdings and available fodder resources, such as parts of Southeast Asia or mountainous areas in Southwest China. Conversely, in flat, arid regions suitable for industrial-scale monoculture, the efficiency of such smallholder crop-livestock integration may diminish. However, the core policy mechanism—“award in lieu of subsidy”—holds broader relevance. The design of linking fiscal transfers to verified productive asset accumulation (rather than unconditional cash handouts) provides a replicable template for other developing regions aiming to sustain poverty reduction incentives while avoiding welfare dependency.

Relative to existing literature, this study not only documents welfare gains from livestock-oriented poverty alleviation at the micro level [18], but also clarifies a pathway through which dispersed smallholder cattle rearing can generate environmental improvements through nutrient recycling and input substitution. In regions with fragmented landholdings and tight resource constraints, small-scale cattle rearing need not follow a “high-input, high-pollution” trajectory. With incentive-compatible policy design and locally available feed resources, smallholder-led crop–livestock integration can be a viable pathway toward inclusive growth and green transformation.

6. Conclusions and Policy Implications

6.1. Conclusions

Using two-wave panel data from poor households in Guangxi's ethnic minority areas, this study exploits quasi-experimental variation induced by the implementation of the Yijiang Daibu (reward-based subsidy) program. Combining Coarsened Exact Matching with household fixed-effects models, and further supported by robustness checks and an IV-FE endogeneity test, we evaluate the welfare and environmental effects of dispersed cattle rearing. Results indicate that participation in cattle rearing significantly increases per capita household consumption expenditure while substantially reducing chemical fertilizer input intensity per hectare in crop production. These findings remain robust under various specifications. Overall, dispersed cattle rearing serves as a viable pathway for poverty reduction and green transformation in smallholder production environments characterized by tight resource constraints.

6.2. Policy Implications

Based on our empirical findings and the specific context of the Yijiang Daibu program, we offer three actionable policy recommendations for China's Rural Revitalization strategy:

First, leverage local resource endowments for precision targeting. Our heterogeneity analysis suggests that cattle rearing is most beneficial in specific contexts. Policymakers should prioritize support for small-scale cattle rearing in regions where it holds a comparative advantage—specifically in hilly or mountainous areas with abundant crop residues (e.g., sugarcane by-products) and fragmented land where large-scale mechanization is costly. Instead of a “one-size-fits-all” promotion, local governments should map resource endowments to identify villages where crop-livestock integration is naturally feasible, avoiding inefficient subsidy allocation in unsuitable flatland regions dominated by monoculture.

Second, reinforce the “award in lieu of subsidy” mechanism to foster endogenous development. The positive welfare effects identified in this study validate the effectiveness of the Yijiang Daibu design. Unlike unconditional cash transfers, this program links fiscal support to verified asset accumulation. We recommend that future rural policies continue to shift from passive relief (giving cash) to active capacity building. Specifically, the government should maintain high verification standards for subsidy disbursement, ensuring that funds are used to build sustainable productive capacity rather than for immediate consumption, thereby reducing long-term welfare dependency.

Third, explicitly compel green complementarities through conditional support. Our results show a significant reduction in chemical fertilizer use, representing a “win-win” for income and ecology. To maximize this co-benefit, policy support should not treat cattle rearing and crop planting as separate silos. Subsidy verification should be strictly tied to manure management standards. For instance, receiving the full cattle subsidy could be made conditional on the household demonstrating the utilization of manure in their own fields or its trade within the village. Integrating technical guidance on crop-livestock cycling into the subsidy application process can transform potential pollution sources into valuable agronomic inputs, ensuring the dual goals of welfare improvement and greener production are met simultaneously.

6.3. Limitations and Future Research

Several limitations should be noted. First, with only two survey waves, we cannot fully characterize dynamic trajectories or long-run sustainability of policy impacts and cattle-rearing benefits. Second, data on chemical and organic fertilizer inputs rely primarily on self-reports and may be subject to measurement error. Third, because the study area has specific resource endowments (e.g., sugarcane intercropping) and ethnic characteristics, external validity should be interpreted cautiously when extrapolating to other agricultural zones. Finally, while multiple methods are used to mitigate endogeneity, unobserved time-varying shocks may remain. Future research could utilize multi-wave longitudinal data over longer periods, incorporate more objective measures of ecological impacts (e.g., soil testing), and conduct cross-regional comparative analyses to evaluate the long-term productivity and net environmental effects of dispersed small-scale cattle rearing.

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