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Optimizing Resource Use in Upland Rice Farming: A Cobb-Douglas Productivity Analysis in Caraga Region, Philippines

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ABSTRACT

Upland rice farming sustains rural livelihoods in geographically constrained areas but remains low-productivity. This study examines the determinants of upland rice productivity in the Caraga Region, Philippines, using cross-sectional data from 239 farmers and estimating a log-linear Cobb-Douglas production function by ordinary least squares. The results show that seed use (β = 0.338), pesticide application (β = 0.214), man labor (β = 0.237), and seedling rate (β = 1.229) significantly and positively influence output, with seedling rate exhibiting the largest elasticity. Farmer age (β = 0.587), years of schooling (β = 0.173), and family labor (β = 0.240) also have positive and significant effects, whereas household size (β = −0.585) has a negative effect on productivity. Fertilizer use (β = 0.005), man-animal labor, and institutional variables such as extension contact were not statistically significant. The model explains a substantial proportion of the variation in output (R^2 = 0.828; Adjusted R^2 = 0.686). The estimated sum of elasticities, 2.165, indicates increasing returns to scale, implying that a 1% increase in all inputs leads to a 2.17% increase in output. Diagnostic tests confirmed no severe multicollinearity and no significant heteroskedasticity. While the findings highlight the importance of coordinated input use and human capital in improving productivity, the analysis relies on cross-sectional survey data and assumes input exogeneity, which may not fully capture technical inefficiency or unobserved biophysical factors. These results provide an empirical basis for understanding input responsiveness in environmentally sensitive upland rice systems.

Introduction

Rice is much more than a staple crop in the Philippines—it represents a vital source of food and income for millions of people, especially those living in rural communities who depend upon rice as an economic engine. Farmers residing in remote, mountainous, or "upland" areas of Caraga (e.g., Cagayan de Oro) plant rain-fed crops, including rice, in small, fragmented plots. There continue to be many challenges facing upland rice growers. Upland rice yields are typically very low (usually less than 2 tons/ha). This can primarily be attributed to the limited availability of high-quality seed, fertilizers, and farm-related services, combined with difficult terrain and variable climatic conditions [1,2]. The continued existence of farming in these environments will likely remain challenged by the same issues; thus, there is a need for unique, science-based solutions.

Unfortunately, very few scientific studies have focused on the upland rice-growing industry in Caraga. Conversely, while lowland irrigation systems have been extensively researched [3,4]. Our knowledge base regarding resource management practices used by upland rice growers in this region remains woefully inadequate. Additionally, the current body of literature has rarely integrated production analyses with ecological factors relevant to agricultural production and/or input utilization when assessing input productivity and sustainability. Soil degradation/erosion and rainfall variability can directly affect input efficiency/productivity and sustainability, respectively.

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As a result, without better data on how specific inputs (seeds, labor, etc.) contribute to rice yield, developing intervention strategies that respond to farmers' identified needs cannot occur. Although production function analysis is broadly used in irrigation and lowland rice systems, it is very rarely used for the rain-fed upland rice environment. This paper improves upon previous studies that have estimated input elasticities and scale characteristics for upland rice producers in Caraga by providing an estimate of these parameters for this unique region. The explicit computation of total elasticities and assessment of the returns-to-scale characteristics also move beyond mere descriptive productivity analyses and provide contributions to production economics by determining whether the farms are operating under increasing, constant, or decreasing returns. Furthermore, using a scale-based approach provides a structural explanation of where productivity constrains may be derived from, either due to insufficient inputs, poor allocation of available resources, or at an inappropriate level of production. Finally, this research will situate production function analysis within larger sustainable intensification and agro-ecological frameworks through connecting the input responsiveness to both long term resource sustainability and efficiency of use of resources by small holder farmers. Thus, this study's perspective on input responsiveness fits into well-established sustainable intensification frameworks developed by organizations such as the Food and Agriculture Organization (FAO) who suggest increasing agricultural production while reducing negative environmental impacts.

Research emerging now on a combination of older production models and new technology, including data analytics, shows that identifying the productive gaps at the farm level using this approach will increase farm performance [5,6]. The Cobb-Douglas production function (CDPF) has been used for years to help researchers understand how different input factors contribute to agricultural output. Although CDPF has been extensively applied to the study of low-lying rice cultivation, its use in upland farming in Caraga remains unexplored. Additionally, there are other potential approaches, including stochastic frontier analysis (SFA) and machine learning approaches such as random forest modeling, which have demonstrated comparable results in previous applications to similar farming systems [7,8].

Many studies support the relevance of input-based analysis in upland rice contexts. Saito et al. [9] and Baron [10] have shown that varietal performance under nutrient-limited conditions significantly affects yield outcomes, especially in the rainfed uplands of Laos. Meanwhile, Hauser and Norgrove [11] emphasized that nutrient cycling under slash-and-burn systems must be managed carefully to avoid soil degradation. In the Philippines, Acierto and Vargas [12] noted that while upland programs offer technological packages, the adoption remains uneven due to knowledge gaps and labor constraints. From a policy lens, cross-country studies in Vietnam [13], Bangladesh [5], and Uganda [14] highlight the broader influence of socio-economic conditions such as access to extension agents, credit services, and farmer group membership. In addition, findings from Nigeria [15,16] emphasizes that institutional support and farmer training directly affect production efficiency. These insights further justify the inclusion of non-traditional variables in the model, such as access to extension services and distance to markets.

Beyond pure production efficiencies, upland rice farming is practiced on land with environmental sensitivities, including sloped terrain, nutrient-poor soils, and variable rainfall. Therefore, these environmental factors are increasing the potential risk of loss of the land's topsoil due to soil erosion, reducing the ability to support a crop due to loss of nutrients (through depletion), and increasing the likelihood of unstable yields from climate-related events [3,11,17]. The resource use decisions made by farmers regarding their fertilizers (composition), seedlings (establishment) and how they prepare their land have both positive effects on current year yields as well as negative impacts on the sustainable nature of the soil over time [18]. Inefficiencies in fertilizer application may be due to an improper nutrient balance, which can "mine" soil nutrients, reducing long-term soil fertility and decreasing the resilience of ecosystems in upland agricultural environments.

An example of this would be rapid land degradation, resulting in increased sedimentation/erosion in watersheds and excessive amounts of nutrients being carried into bodies of water. Understanding how farmers respond to changes in their environment (input responsiveness) in areas where agricultural production has intensified in recent years will help us identify if our current methods of farming are supporting sustainable intensification or contributing to the degradation of our ecosystems. This research provides an integrated perspective on sustainable upland rice production using production elasticity and environmental constraints. Returns to Scale are important in this case as well. Increasing returns to scale indicate that coordinated increases in all inputs result in greater than proportionate outputs; however, those increases should be viewed within the ecological boundaries of the uplands.

If the soils of the upland area are weak and have high potential for erosion, then increased levels of inputs without proper balances of nutrients and management could provide short-term productivity advantages while threatening the long-term sustainability of the farm. By investigating the effect of different inputs on upland rice yields in Caraga through application of the CDPF, this research adds new knowledge to both environmental resource management and production economics. It also seeks to identify which are the most important inputs that contribute to yield growth, provide evidence regarding the statistical importance of these inputs, and make practical suggestions as to how farmers can utilize input resources more efficiently. Specifically, the study aims to (1) estimate input elasticities, (2) assess returns to scale, and (3) evaluate the role of human capital and institutional factors in shaping productivity outcomes. The findings provide a basis for actionable policy recommendations, including balanced nutrient management, strengthened extension delivery, and context-specific sustainable intensification strategies for upland farming systems.

Materials and Methods

Study Area

The research took place in the Caraga region of the Philippines with four municipalities being at the center for their high concentration of upland rice cultivation: specifically, Tandag (Surigao del Sur), Socorro (Surigao del Norte) and Trento and Sibagat (Agusan del Sur). The four municipalities have different elevations and levels of soil fertility as well as different degrees of access to markets. In addition to these factors, Caraga's mountainous terrain and reliance on rainfall present numerous obstacles that constrain the capacity of small-scale farmers to produce rice. A map showing the location of the municipalities studied is shown in figure 1.

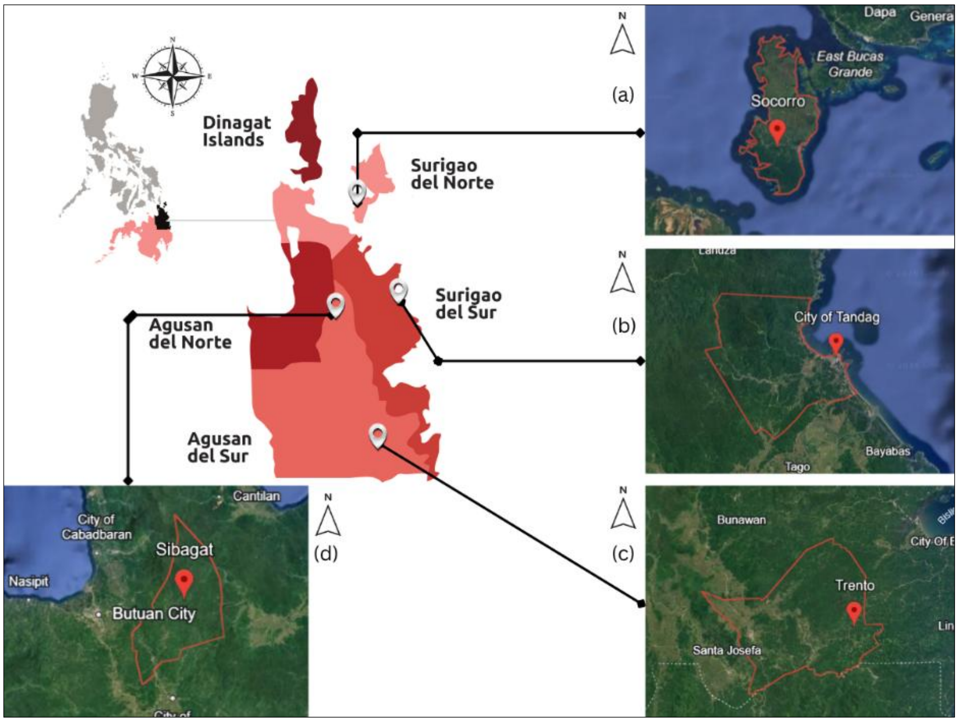

Figure 1. Map of study areas in the Caraga Region. Red dots indicate surveyed municipalities. (a) Socorro, Surigao del Norte; (b) Tandag City, Surigao del Sur; (c) Trento, Agusan del Sur; and (d) Sibagat, Agusan del Sur.

Data Collection Method

Primary data for this study were gathered through field-based surveys conducted among upland rice farmers in the municipalities of Tandag, Socorro, Trento, and Sibagat in the Caraga Region. Respondents totaled 239, sampled using proportionate random sampling to ensure an even distribution of responses across all surveyed municipalities. The sampling frame was comprised of upland rice producers as identified by local agricultural office staff and extension personnel in each municipality. Proportionately, the number of farmers selected in each municipality correlated to the degree to which that municipality contained upland rice farm activity. Although there may have been no consistent and available population figures regarding upland rice farms per municipality, the sampling method employed was intended to identify both spatial and agro-ecosystem variations among the studied locations. The municipalities of Tandag, Socorro, Trento, and Sibagat were selected because they are actively engaged in producing upland rice and represent a range of farming conditions found throughout the Caraga Region. However, due to those constraints, neither the sampling ratio nor the margin of error can be calculated. Nonetheless, using proportional allocation in combination with random selection will enhance the representativeness of the sample. Acknowledging this limitation should not compromise the analytical validity; however, when applying the results generally, it should be considered.

The questionnaire was pre-tested and validated to ensure clarity and consistency in responses. Trained enumerators, many of whom were agricultural extension workers familiar with the local dialects and terrain, conducted face-to-face interviews. This approach ensured accurate and reliable data capture, particularly in geographically isolated and linguistically diverse areas. All interviews were conducted with informed consent, and confidentiality as well as voluntary participation were emphasized throughout the data collection process. The collected data was used to estimate the Cobb-Douglas production function to analyze the relationship between input factors and upland rice productivity. Although suggestions were made to apply SFA or data envelopment analysis (DEA) for technical efficiency estimation, this study focuses solely on production function parameter estimation.

To ensure model validity, diagnostic tests such as variance inflation factor (VIF) for multicollinearity, heteroskedasticity tests, and residual analyses were conducted, with appropriate corrections applied where necessary. The Cobb-Douglas production function was selected due to its parsimonious structure and its ability to directly estimate output elasticities of inputs. This functional form is widely used in agricultural production analysis because it provides stable parameter estimates and facilitates interpretation of returns to scale. Although more flexible functional forms such as the translog model can capture interaction effects among inputs, they require the estimation of a larger number of parameters, which may reduce estimation efficiency and increase multicollinearity concerns in cross-sectional datasets of moderate size (n = 239). Similarly, while SFA is suitable for estimating technical efficiency, this study focuses on input responsiveness and production relationships rather than efficiency decomposition. The Cobb-Douglas specification is therefore appropriate for achieving the study's objective of identifying key productivity determinants and scale properties in upland rice farming systems.

Data Analysis

To estimate productivity, the Cobb-Douglas production function was employed due to its flexibility and ability to capture input elasticity and diminishing returns [4,6]. The functional form is expressed in Equation1.

$$lnYi = \beta_0 + \beta_1 lnX_1 + \beta_2 lnX_2 + ... + \beta_{13} lnX_{13} + \vartheta DS_1 + \varepsilon \quad (1)$$

In this model, upland rice productivity (Yi), measured in kilograms per hectare, is expressed as a function of multiple production inputs and socio-economic factors in logarithmic form. The explanatory variables include seeds used (kg/ha), fertilizer application (kg/ha), pesticides applied (L/ha), total labor input (man-days), man-animal labor (man-animal days), seedling rate (%), distance to the nearest market (km), number of extension contacts, farmer's age (years), years of schooling, household size, family labor participation, and years of farming experience. In addition, a dummy variable representing membership in farmer organizations (DS_1 = 1 if member, 0 otherwise) is included to capture institutional effects. The error term (ε) captures unobserved factors affecting productivity.

Based on production theory, the coefficients of conventional inputs such as seeds, fertilizer, pesticides, labor, and seedling rate are expected to have positive signs, reflecting their contribution to output. Socio-economic variables such as years of schooling and extension contact are also expected to positively influence productivity through improved knowledge and decision-making. Distance to market is expected to have a negative effect due to increased transaction costs, while household size may exhibit a negative or ambiguous relationship depending on labor efficiency and dependency ratios. The Cobb-Douglas model is applied to estimate input elasticities and returns to scale, consistent with the study's objective of analyzing production relationships in upland rice farming systems. Socio-economic factors such as distance to market and extension contacts are included as key determinants influencing productivity, consistent with prior studies linking these variables to access to information, inputs, and market efficiency [9,10,13]. The dummy variable captures the influence of farmers' membership in organizations, which may enhance productivity through collective benefits such as input sharing and knowledge exchange [12].

Ordinary least squares (OLS) estimation was performed using SPSS software to estimate the parameters of the Cobb-Douglas production function. Diagnostic tests for multicollinearity and heteroskedasticity were conducted using VIF and the Breusch-Pagan test, respectively. Summary statistics and correlation matrices were also generated to support model interpretation (see Table 1). All tables and figures include appropriate legends to ensure clarity and self-containment. To assess the robustness of the model, alternative specifications were considered, including comparisons between log-linear and non-log functional forms, as well as sensitivity to the inclusion and exclusion of statistically insignificant variables. The results remained consistent in terms of the direction and significance of key coefficients, indicating stability of the estimated relationships.

However, it is important to note that input variables in cross-sectional farm data may not be strictly exogenous. Farmers' input decisions can be influenced by unobserved factors such as managerial ability, soil quality, and risk preferences, which may introduce potential endogeneity bias. While addressing endogeneity through instrumental variables or panel data approaches is beyond the scope of this study, this limitation is acknowledged and provides direction for future research. While this study relies primarily on survey data, which is a common approach in production function analysis, it acknowledges the limitation of lacking triangulation with complementary data sources such as soil quality metrics, rainfall patterns, and detailed economic cost analysis. Future research could integrate these additional variables to enhance the comprehensiveness and explanatory power of upland rice productivity models.

Table 1. Descriptive statistics of key variables in the Cobb-Douglas Model (N = 239 farmers). Continuous variables are reported as means with standard deviations (SD), while categorical variables are presented as frequencies and percentages. Fertilizer represents the total quantity of inorganic fertilizer applied per hectare, combining urea (46-0-0) and complete fertilizer (14 – 14 – 14), consistent with the variable used in the regression model. Variables were log-transformed in the Cobb-Douglas model estimation.

Variable/indicator	Unit/category	Mean/frequency (n)	Std. Dev./%	Min/remarks	Max/remarks
Production & Inputs					
Rice yield (Y)	kg/ha	2,137.2	746.3	850	4,560
Seed used (X_1)	kg/ha	15.08	17.4	0	—
Fertilizer (X_2)	kg/ha	1.58	1.13	0	2.90
Pesticides/insecticides (X_3)	L/ha	2.1	1.2	0	6
Labor input (X_4)	man-days	154.00	9.3	0	—
Animal labor (X_5)	man-animal-days	13.00	6.5	0	35
Seedling rate (X_6)	%	84.3	5.2	70	95
Farm Characteristics					
Farm size	hectares	2.93 (average)	—	< 1 ha: 20 farmers (8.37%)	> 10 ha: 4 farmers (1.67%)
Tenurial status	—	Owner: 169	70.71	Tenant: 70 (29.29%)	Total: 239
Distance from farm to market	km	2.59 (average)	—	1–2 km: 121 (50.63%)	> 5 km: 8 (3.35%)
Seed type	—	Inbred: 222	92.89	Hybrid: 17 (7.11%)	Total: 239
Institutional Access					
Access to credit	—	Yes: 146	61.1	No: 92 (38.5%)	Total: 238
Seminars/trainings attended	—	Yes: 159	66.5	No: 80 (33.5%)	Total: 239
Membership to farmer association	—	Yes: 178	74.5	No: 61 (25.5%)	Total: 239
Access to government input support	—	Yes: 162	67.8	No: 77 (32.2%)	Total: 239
Access to extension services	—	Yes: 109	45.6	No: 130 (54.4%)	Total: 239
Cultural Management Practices					
Land preparation method	—	Plowing (man-animal): 215	61.42	Slash-and-burn: 135 (38.57%)	Total: 350 (responses)*
Fertilizer application	—	Both organic & inorganic: 162	67.78	None: 21 (8.79%)	Inorganic only: 45 (18.83%)
Type of fertilizer used	—	Urea (46-0-0): 145	40.50	Complete (14-14-14): 140 (39.11%)	Chicken dung: 58 (16.20%)
Weed control method	—	Manual: 230	96.23	Chemical: 7 (2.93%)	None: 2 (0.84%)

Note: kg/ha = kilograms per hectare; L/ha = liters per hectare; km = kilometers; % = percent.

Results and Discussion

Results

Table 1 summarizes the key production inputs, farm characteristics, and institutional conditions shaping upland rice productivity in the Caraga Region. The results indicate moderate average yields (2,137.2 kg/ha) with substantial variability, suggesting uneven productivity across farms. Input use patterns show a labor-intensive production system with active utilization of seeds, pesticides, and labor, while fertilizer use remains relatively imbalanced and dominated by nitrogen-based inputs. These patterns highlight a trade-off between short-term productivity gains and long-term sustainability in fragile upland systems. Table 1 presents continuous variables as means with standard deviations and categorical variables as frequencies and percentages.

Production and Input Use

On average, farmers produced 2,137.2 kg/ha of upland rice, with substantial variability (SD = 746.3 kg/ha), reflecting heterogeneity in farm conditions and input management practices. Seed use averaged 15.08 kg/ha, consistent with broadcast planting systems commonly practiced in upland environments. Fertilizer application consisted of both organic and inorganic inputs applied per hectare, with descriptive evidence indicating greater reliance on nitrogen-based fertilizers, particularly urea. Fertilizer application consisted of combined organic and inorganic inputs as detailed in Table 2. This pattern suggests a nutrient management strategy that emphasizes nitrogen supplementation, which may influence productivity outcomes and soil nutrient balance over time. Labor input was intensive, averaging 154 man-days per hectare, while animal labor averaged 13 man-animal-days. These figures confirm the labor-dependent nature of upland rice production, where mechanization remains limited and farmers rely heavily on household labor for land preparation, crop maintenance, and harvesting. Seedling rate averaged 84.3%, indicating generally strong crop establishment under rainfed upland conditions.

Table 2. Resource use per hectare in upland rice production in the Caraga Region, Philippines. This table presents the average quantities of major production inputs used per hectare by upland rice farmers, including seeds, chemical fertilizers (urea and complete fertilizer), organic inputs (chicken dung and swine waste), and labor components. The values represent mean input application rates derived from survey data collected across selected municipalities in the Caraga Region. These variables correspond to the inputs included in the Cobb-Douglas production function model used in this study. The results highlight a labor-intensive production system with a strong reliance on nitrogen-based fertilizers and supplementary organic inputs, suggesting potential imbalances in nutrient management.

Variables	Usage per hectare
Palay Seed (kgs)	15.08
14 – 14 – 14 (Complete) (kgs)	130.00
46 – 0 – 0 (Urea) (kgs)	188.88
Chicken Dung (kgs)	856.55
Swine Waste (kgs)	833.82
Man Labor (man days)	154.00
Man-Animal labor (man-animal days)	13.00
Thresher use (man-machine hour)	3.74

Farm Characteristics

The average farm size was 2.93 ha, indicating relatively small-scale operations. A majority of farmers (70.7%) owned their land, which may encourage longer-term investment in land management and productivity-enhancing practices. Most farms were located within two kilometers of the nearest market (mean distance = 2.59 km), suggesting relatively favorable physical access to input and output markets. Nearly 93% of farmers planted inbred rice varieties, while only a small proportion adopted hybrid seeds. This limited adoption of hybrid varieties may reflect cost considerations, risk preferences, or limited technical support, and it presents a potential avenue for productivity enhancement if supported by appropriate extension services.

Institutional and Service Access

Access to financial credit was reported by 61.1% of farmers, while 67.8% received government input support. Participation in seminars and trainings reached 66.5%, indicating moderate engagement with formal capacity-building activities. However, only 45.6% of farmers reported access to extension services, suggesting a significant gap in technical advisory support. Limited extension contact may constrain the effective adoption of improved agronomic practices and input optimization strategies, thereby affecting productivity performance.

Cultural Practices

Land preparation predominantly relied on man-animal labor (61.4%), reflecting continued dependence on traditional cultivation methods. A notable proportion of farmers (38.6%) practiced slash-and-burn land preparation, which has implications for soil sustainability and long-term environmental management. Fertilizer application practices varied, with 67.8% of farmers combining organic and inorganic inputs, indicating an integrated nutrient management approach at the farm level. Urea was the most used inorganic fertilizer, reinforcing the nitrogen-focused nutrient strategy observed in the descriptive statistics. Manual weed control was almost universally practiced (96.2%), underscoring the labour-intensive nature of upland rice farming systems.

Table 2 disaggregates fertilizer and labor components to provide detailed insight into input composition per hectare among upland rice farmers in Caraga Region. The average quantity of seeds used was 15.08 kg/ha. For chemical fertilizers, farmers applied an average of 188.88 kg/ha of urea (46 – 0 – 0) and 130.00 kg/ha of complete fertilizer (14 – 14 – 14). Organic fertilizer use was also observed, with chicken dung and swine waste applied at average rates of 856.55 kg/ha and 833.82 kg/ha, respectively. In terms of labor input, upland rice farms required an average of 154 man-days per hectare. Additionally, farmers reported using 13 man-animal days for land preparation. Some farmers also utilized threshers, recording an average of 3.74 man-machine hours, although many still practiced manual threshing using traditional tools.

Table 3 showed eight out of fourteen explanatory variables significantly influenced upland rice productivity. Seeds (0.338), pesticides (0.214), man labor (0.237), seedling rate (1.229), age (0.587), years of schooling (0.173), and family members working on the farm (0.240) had positive and statistically significant effects on output. Household size (–0.585) had a negative and significant effect.

Table 3. Resource productivity analysis of upland rice farming in Caraga Region, Philippines. This table presents the estimated coefficients of the Cobb-Douglas production function using ordinary least squares, where coefficients represent output elasticities of production inputs and socio-economic variables. The model includes physical inputs, farmer characteristics, and institutional variables, with corresponding standard errors and p-values reported to assess statistical significance. These estimates are used to evaluate input responsiveness and returns to scale in upland rice production systems. The results indicate that seedling rate, seeds, pesticides, labor, and human capital variables significantly influence productivity, while fertilizer use is not statistically significant under current conditions.

Variable	Estimated coefficient	Standard Error	p-value
Log Constant	1.372***	0.330	0.000
Log Seeds	0.338***	0.053	0.000
Log Fertilizer	0.005	0.021	0.805
Log Pesticide	0.214**	0.067	0.002
Log Man Labor	0.237***	0.061	0.000
Log Man-Animal Labor	0.142	0.088	0.108
Log Seedling Rate	1.229***	0.285	0.000
Log Distance to Farm to Nearest Market	0.009	0.080	0.906
Log Contact to Extension Agent	0.099	0.062	0.110
Log Age	0.587**	0.183	0.002
Log Years in Schooling	0.173*	0.078	0.028
Log Household Size	–0.585***	0.098	0.000
Log Family Members Working in the Farm	0.24*	0.091	0.009
Log Years in Upland Rice Farming	–0.03	0.049	0.538
Log Membership	0.221	0.218	0.313
R-square	0.828		
Adjusted R-square	0.686		

Note: ***p < 0.01, **p < 0.05, *p < 0.10.

The estimated coefficients represent output elasticities. A 1% increase in seed use increases output by 0.338%, while a 1% increase in pesticide use increases output by 0.214%. A 1% increase in man labor increases output by 0.237%. Seedling rate exhibited the largest elasticity (1.229), indicating strong responsiveness of output to improvements in crop establishment. In this study, seedling rate was measured through field observations conducted by trained enumerators during farm visits, capturing the proportion of successfully established seedlings relative to total planted seeds. This variable reflects the effectiveness of early-stage crop establishment, which is particularly critical in rainfed upland systems where germination and early growth are highly sensitive to soil moisture conditions, seed quality, and initial nutrient availability. The relatively high elasticity suggests that improvements in seedling establishment can generate more than proportional increases in output. This may be explained by the fact that better plant stand density enhances resource utilization efficiency, including light interception, nutrient uptake, and weed competition. In upland environments characterized by fragile soils and rainfall variability, successful establishment reduces early-stage losses and sets the foundation for higher yield potential. Thus, the magnitude of the coefficient reflects the central role of establishment quality as a binding constraint in upland rice productivity. The fertilizer coefficient (0.005) was positive but statistically insignificant, indicating that changes in fertilizer application did not produce a measurable proportional change in output under current conditions.

The sum of the elasticities of the physical production inputs—seeds, fertilizer, pesticides, man labor, man-animal labor, and seedling rate—equals 2.165. Since this value exceeds one, the production process exhibits increasing returns to scale. A proportional 1% increase in all production inputs would increase output by approximately 2.17%, holding other factors constant. The model explains a substantial proportion of output variation (R^2 = 0.828; Adjusted R^2 = 0.686). Diagnostic tests indicated no severe multicollinearity among explanatory variables, as all VIF values were within acceptable thresholds. The Breusch-Pagan test results further indicated that heteroskedasticity was not statistically significant, supporting the reliability and consistency of the estimated coefficients.

Table 4 presents the perceived constraints affecting upland rice production. Lack of capital received the highest severity rating (mean = 4.90), followed by pest and disease incidence (4.69) and unpredictable weather conditions (4.23), all classified as most severe problems. Other constraints, including lack of government support (4.02), high cost of fertilizer (3.88), and low seed quality (3.76), were also identified as severe issues. Meanwhile, lack of technical knowledge (3.25) and limited extension agent visits (2.78) were perceived as moderate problems. These constraints provide contextual insight into the production environment under which the estimated productivity relationships operate.

Table 4. Problems encountered of upland rice farmers in Caraga Region, Philippines. This table presents the perceived constraints affecting upland rice production, measured using mean severity scores and corresponding qualitative descriptions. The variables include production, institutional, and environmental challenges such as seed quality, weather variability, pest and disease incidence, capital access, and extension support. The data were collected from surveyed farmers across selected municipalities in the Caraga Region and reflect their assessment of production limitations. The results show that lack of capital and pest and disease pressures are the most severe constraints, indicating that financial limitations and production risks are the primary challenges faced by farmers.

Problems encountered	Mean	Qualitative description
Low seed quality	3.76	Severe problem
Unpredictable weather condition	4.23	Severe problem
Pest and disease	4.69	Most severe problem
Lack of capital	4.90	Most severe problem
High cost of fertilizer	3.88	Severe problem
Lack of government support	4.02	Severe problem
Lack of technical knowledge	3.25	Moderate problem
Less extension agent visit	2.78	Moderate problem

Discussion

The results indicate that upland rice productivity in Caraga is primarily driven by crop establishment quality, coordinated input use, and human capital. The high elasticity of seedling rate (1.229) suggests that early-stage crop establishment is the most critical determinant of output. This finding is consistent with studies showing that yield gaps in upland rice systems often originate during germination and early vegetative growth stages [9,19]. In rainfed environments characterized by variable moisture and fragile soils, successful establishment improves plant density and enhances resource-use efficiency. This implies that interventions targeting seed quality, planting techniques, and early-stage management can generate substantial productivity gains.

The positive elasticities of seeds, pesticides, and labor confirm that productivity responds to conventional inputs, although at diminishing rates. These results align with prior Cobb-Douglas studies in rice systems, which report inelastic but significant input responses under smallholder conditions [4]. The significance of education further reinforces the role of human capital in improving decision-making and input allocation [3,20]. his suggests that productivity improvements are not solely input-driven but also depend on farmers' capacity to optimize resource use. The estimated elasticity sum of 2.165 indicates increasing returns to scale, suggesting that farms operate below optimal production levels. From a production theory perspective, this reflects underutilization of complementary inputs and constraints in achieving efficient scale [21,22]. However, increasing returns do not necessarily imply technical efficiency. Frontier-based studies using stochastic frontier analysis have demonstrated that scale inefficiency frequently coexists with technical inefficiency in rice systems [7,23]. However, increasing returns must be interpreted within ecological limits. In upland systems, expansion of input use without proper management can intensify pressure on soil resources and accelerate land degradation. This highlights a key sustainability trade-off between short-term productivity gains and long-term environmental stability.

The insignificance of fertilizer use requires careful interpretation. One explanation relates to soil conditions. Upland soils in the Caraga Region are typically nutrient-depleted and erosion-prone, which limits the efficiency of fertilizer uptake [3,24]. Under such conditions, nitrogen-dominated fertilization strategies, particularly the heavy use of urea, may not translate into proportional yield gains due to deficiencies in other essential nutrients. Recent studies emphasize that balanced nutrient management is necessary to improve fertilizer efficiency and crop response in degraded soils (e.g., integrated nutrient strategies combining organic and inorganic inputs) [25,26]. Another explanation relates to farmer behavior and management practices. Farmers may apply fertilizer at suboptimal timing, rates, or combinations, which reduces its effectiveness. Limited access to extension services, as observed in the study, may further constrain farmers' ability to adopt appropriate nutrient management practices [12,27]. In addition, aggregation bias in the measurement of fertilizer use may mask variation in nutrient composition and application efficiency across farms. These findings are consistent with recent evidence showing that fertilizer responsiveness in smallholder systems depends strongly on management quality and local soil conditions rather than quantity alone [28].

These results partially contradict studies that report significant positive effects of fertilizer on rice productivity under controlled or irrigated conditions, where nutrient availability and water management are more stable [5,26]. The divergence suggests that in rainfed upland systems, fertilizer effectiveness is constrained by environmental and institutional factors, rather than being inherently unproductive. This highlights the importance of context-specific nutrient management strategies. From an environmental perspective, the findings point to potential risks of nutrient mining and long-term soil degradation. The reliance on nitrogen-intensive fertilizer, combined with limited replenishment of other nutrients, may lead to gradual depletion of soil fertility. Nutrient mining has been identified as a major constraint in tropical upland systems, where continuous cultivation without balanced nutrient replacement reduces soil productivity over time [24,29]. This process can weaken ecosystem resilience and reduce the sustainability of agricultural production.

The implications extend to upland watershed management. Unsustainable input practices, particularly imbalanced fertilization and slash-and-burn land preparation, can increase soil erosion and nutrient runoff. These processes affect not only farm-level productivity but also downstream water quality and ecosystem services. Recent studies highlight that integrated land and nutrient management approaches are essential for maintaining both agricultural productivity and watershed stability in upland environments [30,31]. This underscores the need to align productivity interventions with broader environmental management objectives. The constraint analysis supports these interpretations. Limited capital restricts farmers' ability to invest in optimal input combinations, while pest and disease pressures increase reliance on pesticides. Climate variability further exacerbates production risks in rainfed systems [9,17]. These constraints interact with input use decisions, reinforcing the importance of institutional support, particularly extension services, in improving farm-level productivity outcomes.

Overall, the results indicate that upland rice productivity is shaped by a combination of agronomic, economic, and institutional factors. While increasing returns to scale suggest unrealized production potential, sustainability concerns related to nutrient imbalance, soil degradation, and watershed impacts must be addressed. Improving productivity in upland systems therefore requires integrated strategies that combine balanced nutrient management, strengthened extension services, and context-specific interventions tailored to fragile agroecosystems.

Conclusions

This study contributes to production economics by applying the Cobb-Douglas production framework to a fragile upland rice system and demonstrating that productivity is strongly shaped by crop establishment quality, coordinated input use, and human capital. The finding of increasing returns to scale (elasticity sum = 2.165) indicates that upland farms operate below optimal production levels, suggesting the presence of scale inefficiencies and underutilized complementarities among inputs. However, this result must be interpreted within the ecological constraints of upland environments, where input intensification without proper management may lead to resource degradation rather than sustainable productivity gains. From a theoretical perspective, the study highlights the importance of integrating production function analysis with agroecological constraints. The results show that input responsiveness in upland systems is not solely determined by input quantity, but also by soil conditions, management practices, and institutional factors. In particular, the insignificance of fertilizer use underscores the limitation of conventional input-output models when nutrient imbalance and environmental constraints are not explicitly considered.

From a policy standpoint, the findings suggest that improving upland rice productivity requires targeted and context-specific interventions. First, promoting balanced nutrient management through integrated use of organic and inorganic fertilizers is essential to enhance fertilizer efficiency and prevent nutrient mining. Second, strengthening extension services is critical to improve farmers' knowledge of proper input timing, composition, and crop management practices. Third, investment in seed quality and crop establishment practices should be prioritized, given the strong influence of seedling rate on productivity. Finally, support mechanisms that enhance farmers' access to credit and technical assistance can facilitate more efficient resource allocation. Future research should move beyond cross-sectional analysis by incorporating panel data and biophysical variables such as soil fertility, rainfall patterns, and topographic conditions to better capture production dynamics in upland systems. The application of frontier-based approaches, such as stochastic frontier analysis, may also provide deeper insights into technical efficiency and input-use gaps. In addition, disaggregating fertilizer use by nutrient composition and application practices would allow for a more precise assessment of nutrient responsiveness and environmental impacts.

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Author Contributions

NSD: Conceptualization, Methodology, Software, Investigation, Writing - Review & Editing.

AI Writing Statement

During the preparation of this work, the authors used ChatGPT, Grammarly, and Scispace to assist with language editing and literature search. These tools were used only to improve the clarity and organization of the manuscript. All scientific interpretations, data analysis, and conclusions were developed solely by the authors. The authors carefully reviewed and edited all outputs and take full responsibility for the content of this publication.

Conflicts of interest

There are no conflicts to declare.

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