Mini Project Report on

Agricultural Economics/Development Economics

At

"Indian Institute of Technology, Jammu"

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Literature Review: -

Soil degradation and erosion are critical challenges affecting global agricultural sustainability, driven by factors such as land use practices, land tenure systems, and conservation measures. Effective soil conservation is essential for maintaining long-term farm productivity and environmental balance. Assessing eco-efficiency (EE) in agriculture requires integrating technical efficiency (TE) and soil conservation efficiency (SCE) to evaluate sustainable land management. A study analysing Austrian crop farms used the Revised Universal Soil Loss Equation (RUSLE) to quantify soil erosion and Data Envelopment Analysis (DEA) to measure efficiency levels. Findings reveal that tenant farmers achieve higher TE but lower SCE, prioritizing short-term economic benefits over soil conservation. Austria, with one of the highest soil erosion rates in Europe, shows a significant gap in eco-efficiency (EE = 0.16), emphasizing the need for improved land tenure policies, greater participation in Agri-Environmental Schemes (AES), and a shift in agricultural subsidies toward sustainability-focused incentives.[1]

The study, conducted in Brazil (Rio da Prata Basin) and published in 2018, assesses land use and soil erosion trends over 30 years (1986–2016) and predicts future scenarios for 2050 and 2100 using the CA-Markov hybrid model. The results show a significant decrease in soil erosion (59.47%) and sediment export (69.86%) due to improved vegetation cover and conservation practices. However, future projections indicate a 5.78% rise in soil erosion by 2100, mainly due to agricultural expansion. The study underscores the importance of sustainable land management to mitigate environmental degradation and maintain ecosystem balance.[2]

A 2023 study from China systematically reviewed the effects of land use and land cover (LULC) on soil erosion control in the red soil hilly region (RSHR) using a quantitative synthesis approach. Data from 79 studies covering 57 sites were analysed using statistical models like ANOVA and LSD tests. Findings indicate that vegetation coverage above 60% and multi-layer structures significantly reduce soil erosion, with broadleaf and mixed forests being the most effective. Soil erosion declines sharply in the first three years of restoration and stabilizes after 15 years, emphasizing the importance of sustainable land management practices.[3]

The study assesses the adoption of soil and water conservation (SWC) practices in Ethiopia’s Lege-Lafto Watershed. Using a mixed-methods approach, including household surveys, focus group discussions, and logistic regression analysis, the research identifies key factors influencing farmers' adoption decisions. The findings reveal that perception of soil erosion, family labour availability, education level, and membership in local institutions positively affect adoption, while off-farm employment and distance from markets negatively impact it. The study emphasizes the need for training programs and policies that integrate local knowledge with modern conservation techniques.[4]

This research investigates the eco-efficiency of agriculture in EU-27 countries from 2008 to 2017 using a Window Slack-Based Measurement Data Envelopment Analysis (W-SBM-DEA) model. The study considers various inputs such as agricultural land, labor, and costs while accounting for both desirable outputs (crop and livestock production) and undesirable outputs (GHG emissions). The findings highlight significant variations in eco-efficiency across EU countries, with the Netherlands, Belgium, Italy, and Malta ranking as the most eco-efficient. The study concludes that integrating environmental impacts into technical efficiency assessments provides a more realistic understanding of agricultural performance, aiding policymakers in promoting sustainable farming practices.[5]

The study, conducted in Tanzania and published in 2021, explores the relationship between land tenure security, access to agricultural credit, and rice productivity to achieve Sustainable Development Goals (SDGs) by 2030. Using cross-sectional data from 1,188 farm households in eight districts, the research applies descriptive statistics, correlation analysis, and a conditional mixed process model. Findings reveal that only 4% of farmers perceive land tenure security, and just 10% have access to credit, with rice productivity averaging 400 kg/ha. A positive correlation exists between land tenure security, credit access, and rice productivity, with credit access increasing rice yields by 2,645 kg/ha. The study highlights the need for secure land tenure, improved credit access, and sustainable agricultural policies to enhance productivity and food security in Tanzania.[6]

The study, conducted in Malawi and published in 2020, examines the economic impacts of soil erosion on agricultural productivity and welfare. Using a two-year dataset that combines topsoil loss data with socio-economic, agro-ecological, and climatic information at the household and plot level, the study employs an unconditional quantile regression model to assess the heterogeneous effects of soil loss. Findings reveal that soil erosion disproportionately affects the most vulnerable farmers, leading to a 1– 3% reduction in Malawi's GDP under worsening erosion scenarios. The study emphasizes the role of sustainable agricultural practices, such as erosion control measures, in mitigating productivity losses and recommends policy interventions that target the most affected households to enhance agricultural resilience and food security.[7]

The study, conducted in the North-Western Himalayan region of India and published in 2023, examines the impacts of soil erosion on soil quality and agricultural sustainability. By analyzing long-term data from runoff plots with varying erosion severity, the research establishes a quantitative relationship between erosion, soil properties, and wheat productivity. Results show that severe erosion reduces soil organic carbon by 81.4%, water holding capacity by 31%, and cation exchange capacity by 50%. Wheat yield declines significantly in severely eroded soils, with a sustainable yield index dropping from 0.9 (slightly eroded) to 0.6 (severely eroded). The study highlights the urgent need for erosion control measures to maintain soil quality and agricultural productivity in the region.[8]

The study, published in 2020, presents a systematic review of soil erosion control practices in agricultural land across Asia. Using the PRISMA method, the research analyzes 39 studies from the Web of Science and Scopus databases to classify erosion control measures into three main categories: agronomic practices, agrostological practices, and mechanical practices, with a total of 11 sub- themes. The results indicate that tillage operations (22.73%) and mulching (21.21%) are the most frequently studied practices, followed by cover cropping (18.18%) and grass cultivation (15.15%). The review highlights the effectiveness of conservation tillage, vegetative barriers, and contour farming in reducing soil loss and runoff. However, challenges such as economic feasibility and adaptation to different climatic conditions remain. The study underscores the need for region-specific conservation strategies and further research to optimize soil erosion control in Asia.[9]

The study by Mishra et al. (2022), conducted in the Rani Khola watershed of Sikkim, Eastern Himalayas, examines land degradation, overland flow, soil erosion, and nutrient loss to address pressing challenges to food security and sustainable agriculture. Using experimental field data and surveys from 300 households, the research assesses erosion under different land uses, including barren land, terrace cultivation, and agroforestry. Barren lands showed the highest erosion and nutrient loss, while agroforestry and terracing helped minimize degradation. The findings underscore the impact of steep slopes, deforestation, and unregulated land use—often rented or mismanaged—on soil health. The study advocates integrating farmers' knowledge and conservation practices into land policy to combat erosion and ensure long-term productivity in fragile Himalayan ecosystems.[10]

The study by Mekuria et al. (2018), conducted in the Gule watershed of northern Ethiopia, examines the impact of Integrated Watershed Management (IWM) on soil erosion reduction and rural livelihoods. It addresses critical issues of soil degradation driven by poor land use, overgrazing, and deforestation in rented or insecurely held lands. Using household surveys and RUSLE modelling, the study found a 52% reduction in soil erosion and significant improvements in vegetation cover, water availability, and crop yields. Conducted across 269 households, the research reveals how IWM enhances sustainable land use and productivity. It underscores the urgent need for participatory planning and secure land tenure to support long-term conservation goals and community resilience.[11]

The study by Amfo et al. (2021), conducted in Ghana's Ashanti region, explores the role of soil water conservation (SWC) practices in mitigating climate change and improving cocoa productivity. It responds to challenges of declining yields, unsustainable land use, and poor soil fertility often linked to aging farms and limited credit access. Using survey data from 400 farmers and a two-step Tobit model, it found that SWC adopters achieved significantly higher yields (up to 300 kg/ha) compared to non- adopters (215 kg/ha). Mulching and tree retention were the most common practices. The research highlights the need for SWC incentives, farmer training, and stronger agricultural policies to ensure sustainability and food security.[12]

The 2022 study titled *"Soil and Water Conservation Techniques in Tropical and Subtropical Asia: A Review"* systematically examines biological, engineering, and agricultural methods used to control soil and water loss in South and Southeast Asia. Based on data from runoff plot experiments and literature spanning 1980 to 2018, the study finds that most techniques are more effective at reducing sediment loss than runoff. Biological measures like mixed-species afforestation and hedgerow planting with vetiver and alfalfa are particularly effective, while engineering methods such as terracing and slope hydraulics projects show strong performance, especially when combined with vegetation. Agricultural practices including contour tillage, ridge farming, and mulching also demonstrate notable conservation benefits, although results vary with topography and crop type. The review highlights that integrated approaches generally yield better outcomes than single techniques but also notes challenges such as high costs, labor demands, and limited adoption due to technical or economic constraints. It concludes with recommendations for establishing standardized evaluation systems, integrating environmental engineering technologies, and developing cost-effective, low-impact conservation materials to improve soil and water conservation across the region.[13]

This study investigates how land tenure stability influences farmers' adoption intensity of sustainable agricultural practices (SAPs) in banana production in China. The central research question explores whether stable land rights encourage more intensive use of SAPs. Using data from 629 banana farmers across Guangdong, Hainan, and Yunnan provinces, the study employs an Endogenous Switching Regression (ESR) model to account for selection bias. Data were collected via structured field interviews. The analysis reveals that land tenure stability significantly increases SAP adoption intensity by 30.55%, particularly among farmers cultivating more land. The effect varies by farm size and region. Findings also show a positive correlation between SAP use and land productivity. The study concludes that enhancing land tenure stability can substantially improve sustainable farming practices and productivity. It recommends supportive land rental policies and targeted programs to expand SAP adoption in developing countries, contributing to more sustainable and productive agricultural systems.[14]

This study aims to assess the global impact of climate change on soil erosion and evaluate the adaptation potential through land use change and soil conservation. The key research question addresses how climate change and land use dynamics influence soil erosion globally, and how adaptation strategies can mitigate these effects. Data were collected through a systematic review of 224 modelling studies, encompassing 979 projections across various climate zones. The methodology involved statistical analysis of methodological robustness and expert consultations. Key findings reveal a global increase in soil erosion, most significantly in semi-arid zones, mainly due to intensified precipitation and land use change. However, reforestation and conservation practices can counterbalance this trend. The study concludes that robust modelling, climate data correction, and integrated land management are essential to adapt effectively to future soil erosion. The results underline the importance of proactive soil conservation as a vital climate adaptation strategy.[15]

Introduction: -

Soil degradation and erosion present critical threats to global agricultural sustainability, food security, and environmental health. As foundational components of terrestrial ecosystems, soils support plant growth, regulate water cycles, contribute to biodiversity, and play a pivotal role in carbon sequestration and climate resilience. The health of soil directly influences crop yields and ecosystem stability, making its preservation fundamental to the future of sustainable development. However, widespread unsustainable land use practices, insecure land tenure systems, population pressures, and inadequate conservation measures have contributed to the rapid deterioration of soil quality. This degradation is especially pronounced in erosion-prone areas, where poor land management practices strip away fertile topsoil, diminish productivity, and lead to long-term ecological imbalances.

Understanding soil erosion as both a biophysical and socio-economic phenomenon is critical for developing effective interventions. The multifaceted nature of soil erosion requires an integrated approach that not only addresses physical causes such as rainfall, topography, and land cover, but also incorporates socio-economic and institutional dimensions such as land ownership structures, policy frameworks, and community engagement. Numerous studies have highlighted the complex interplay between land management practices and soil conservation outcomes. For instance, research in Austria demonstrates that tenant farmers often achieve higher technical efficiency but lower soil conservation efficiency, prioritizing short-term gains over long-term sustainability[1]. Austria, with one of the highest erosion rates in Europe, exemplifies how land tenure and subsidy policies can shape environmental outcomes.

Similarly, studies across other diverse regions such as Brazil[2], China[3], and Ethiopia[4] have emphasized the importance of vegetation cover, land use changes, and sustainable conservation interventions in mitigating soil loss. In Brazil's Rio da Prata Basin, long-term improvements in vegetation cover have significantly reduced erosion rates over three decades, although future projections warn of erosion resurgence if sustainable practices are not maintained. In China, quantitative syntheses demonstrate that increasing vegetation coverage and restoring multi-layered land cover systems can substantially reduce erosion. In Ethiopia's Lege-Lafto Watershed, adoption of soil and water conservation (SWC) practices is shaped by factors like farmer education, family labor, and access to local institutions, further emphasizing the need for a holistic, context-specific strategy.

The effectiveness of SWC practices also hinges on localized socio-economic conditions, which can either facilitate or hinder their adoption. In regions such as Tanzania[6], Ghana[12], and Malawi[7], critical factors such as land tenure security, access to credit, education, infrastructure, and community involvement play a significant role in determining conservation outcomes. For instance, in Tanzania, secure land tenure and access to agricultural credit are positively correlated with rice productivity and overall land investment, yet only a minority of farmers report having these advantages. In Malawi, soil erosion disproportionately affects economically vulnerable populations, resulting in significant GDP losses and highlighting the importance of targeted policy interventions.

Beyond Africa, regional studies from Asia[9], the Himalayan belt[8], [10], and Sub-Saharan Africa[11] underscore the benefits of integrated watershed management, agroforestry, terracing, and mechanical erosion control techniques in reducing land degradation and enhancing rural livelihoods. In India's Himalayan region, long-term monitoring of erosion-impacted soils has demonstrated severe declines in soil organic carbon and water retention, directly impacting agricultural productivity. Similarly, studies in Sikkim and northern Ethiopia have shown that insecure or rented land tenure often contributes to unregulated and unsustainable land use, reinforcing the need for secure tenure arrangements as a prerequisite for long-term investment in soil conservation.

These varied studies collectively suggest that achieving eco-efficiency in agriculture—a composite metric that incorporates both technical efficiency and environmental sustainability—requires comprehensive, location-specific strategies. Integrating environmental outcomes into performance assessments allows for a more realistic understanding of agricultural sustainability. This approach is particularly relevant in the face of growing environmental challenges such as climate change, land fragmentation, and increasing demand for food production.

Despite this growing body of evidence, significant knowledge gaps remain regarding the influence of ownership structures—especially land tenure types—on the adoption, effectiveness, and long-term sustainability of soil conservation strategies. The existing literature emphasizes outcomes but often lacks data-driven, empirical evaluations that link land tenure systems directly to conservation behaviour and productivity outcomes at the micro (farm) level.

This study seeks to address these gaps by analyzing agricultural data to evaluate the relationship between land ownership methods, soil conservation practices, and farm productivity. By quantifying soil loss and conservation outcomes in relation to different tenure systems, the research aims to provide empirical insights into the eco-efficiency of agricultural systems in erosion-prone areas. Specifically, this work will apply analytical methods to assess the extent to which ownership models— such as owned, rented, or sharecropped land—influence soil conservation behaviour, technical efficiency, and environmental outcomes. The findings will inform conclusions on how ownership structures influence sustainable land use and help shape policies that promote equitable, productive, and climate-resilient agricultural development.

Result and Discussion: -

This section presents the analytical outcomes of the study, including statistical summaries of the key variables, productivity calculation, detailed insights into each plotted graph, and soil loss estimation using the Universal Soil Loss Equation (USLE). The graphs have been interpreted to extract meaningful trends and to support the findings regarding soil erosion and crop productivity.

Productivity Calculation: - In agricultural and rural development studies, ***productivity*** serves as a key indicator of land-use efficiency and economic output. In this project, productivity is used to evaluate how efficiently farmers are utilizing their land resources across various years, ownership patterns, and socio-economic conditions such as education, crop types, and soil quality.

The productivity is computed using the following relationship:

$$\text{Productivity (Rs.)} = \frac{Quantity \times Rate}{Effective\ Area}$$

Where:

- Quantity = Amount of agricultural output produced (kg or Qt)
- Rate = Selling price or value per unit of quantity (Rs.)
- Effective Area = Portion of the plot area that was actually utilized (acres)

$$\text{Effective Area} = Plot\ Area \times \left(\frac{Percentage\ Area}{100}\right)$$

Table 01: - Descriptive Statistics of Key Agricultural Production Variables

Key Variable	Minimum	Maximum	Mean	Standard deviation
Quantity	0.00	2×10^6	2210.83	16410.49
Product Rate	0.00	42000.0	33.27	545.99
Product Revenue	0.00	3.8×10^6	22241.44	66038.42
Plot Area	0.01	25.00	1.33	1.785
Effective Area	0.001	25.00	1.09	1.610
Productivity	0.00	3.13×10^6	20889.20	55682.53

Figure 1: Mean Productivity Across Different Ownership Status

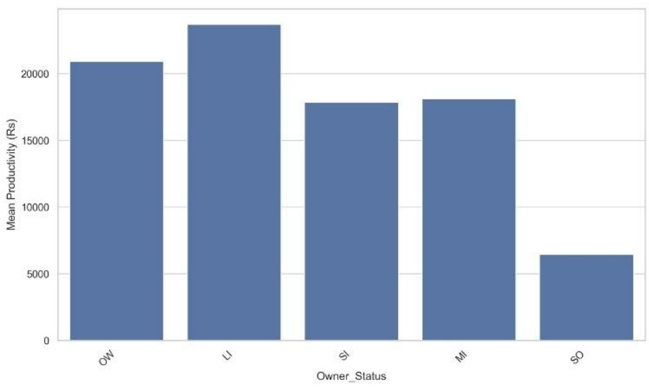

Figure 1 presents the mean productivity across different land ownership categories. The x-axis displays the ownership types—**Owner (OW)**, **Leased-In (LI)**, **Shared-In (SI)**, **Leased-Out (MI)**, and **Shared-Out (SO)**—while the y-axis represents average productivity levels. In the **OW** category, the farmer fully owns the land and has complete control over its use and management. **LI** refers to land that is cultivated by a farmer who rents it from another owner, typically under a lease agreement. In **SI**, the farmer cultivates land under a shared arrangement, where profits or produce are divided between the cultivator and the owner. **MI** represents land that is rented out by the owner to another individual, meaning the owner does not engage in cultivation. Finally, **SO** involves a shared-out arrangement where the landowner allows another farmer to manage the land in exchange for a share of the output.

The results indicate that **LI** and **OW** categories have the highest productivity, suggesting that **direct access and control over land**, whether through ownership or leasing-in, promotes better agricultural performance. **SI** and **MI** show moderate productivity, possibly due to shared responsibilities or the absence of direct involvement by the landowner. The **SO** category shows the lowest productivity, likely due to reduced authority over land use and weaker incentives for investment. Overall, the findings highlight the significance of **secure and active land control** in achieving higher agricultural productivity.

Figure 2: Mean productivity across different crop seasons

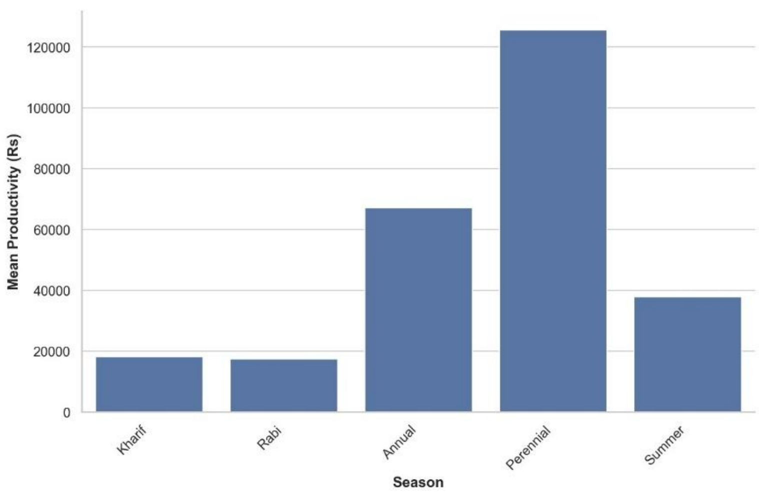

Figure 2 presents the mean productivity across various cropping seasons. The results indicate that **Perennial and Annual crops** exhibit significantly higher productivity compared to **seasonal crops** such as Kharif, Rabi, and Summer. This trend suggests that **longer crop cycles**, which involve sustained land use and continuous farmer engagement, contribute to better agricultural outcomes. Similar to the findings in Fig 1, the results highlight the importance of **consistent control and prolonged investment** in maximizing productivity.

Figure 3: Interaction Between Ownership Status and Season on Mean Productivity

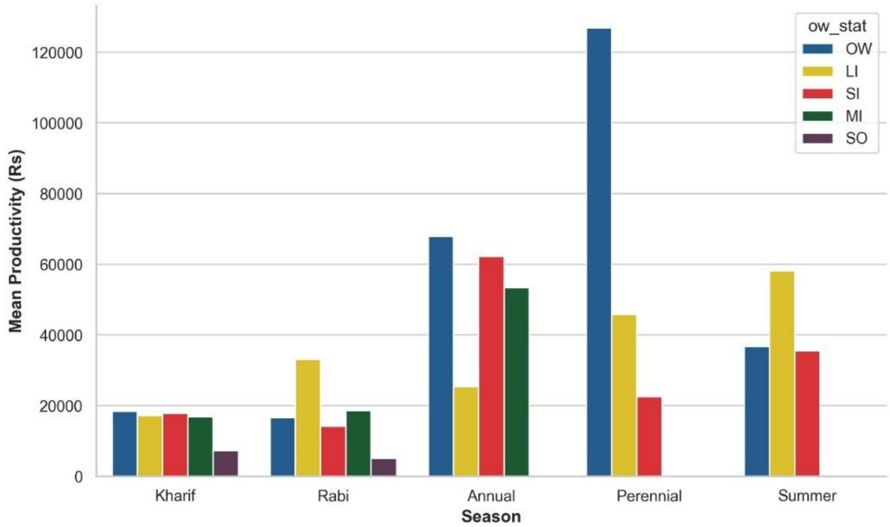

Figure 3 depicts the interaction between land ownership status and cropping season in determining mean agricultural productivity. The x-axis shows the cropping seasons, while the y-axis represents average productivity levels across five ownership categories: **Owner (OW)**, **Leased-In (LI)**, **Shared-In (SI)**, **Leased-Out (MI)**, and **Shared-Out (SO)**.

The figure reveals that **Owner (OW)** and **Leased-In (LI)** categories consistently outperform other ownership types across most seasons, especially in **Perennial** and **Annual** cropping. Notably, **OW in Perennial crops** yields the highest productivity overall, reinforcing the importance of **direct and sustained control** over land. In contrast, **Shared-Out (SO)** productivity remains low across all seasons, indicating that **indirect control and weak incentives** are detrimental regardless of crop cycle.

These findings suggest that the **combined effect of ownership structure and crop duration** plays a critical role in shaping agricultural outcomes. Productivity is maximized when both **secure land tenure** and **long-term cultivation cycles** are present, highlighting the synergy between land control and farming commitment.

Figure 4: Year-wise Mean Agricultural Productivity (2010–2014)

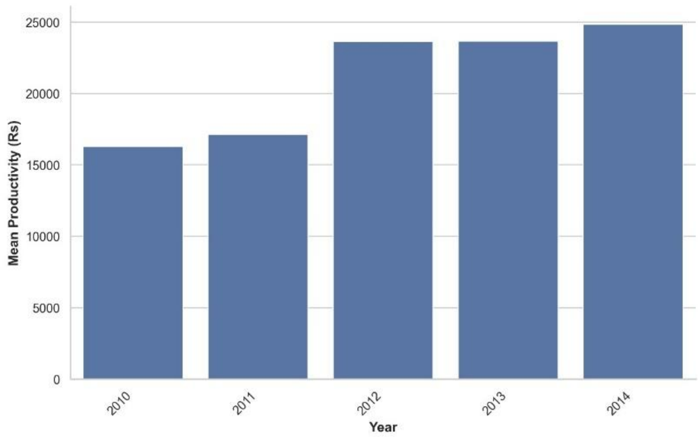

Figure 4 illustrates the trend of mean agricultural productivity over the years 2010 to 2014. The x-axis denotes the year of cultivation, while the y-axis represents the average productivity in Indian Rupees (Rs). This bar chart highlights a steady increase in mean productivity throughout the observed period, with a significant rise beginning in 2012. The average productivity moved from around ₹16,000 in 2010 to nearly ₹25,000 by 2014, indicating a notable enhancement in agricultural output.

This upward trend may reflect improvements in agricultural practices, increased adoption of modern techniques, better access to resources, and possibly favourable climatic conditions during these years. The plateau between 2012 and 2013 suggests a temporary stabilization, followed by continued growth. The pattern emphasizes the importance of sustained investment and consistent support in agriculture to achieve long-term productivity gains.

Figure 5: Year-wise Trends in Mean Agricultural Productivity by Land Ownership Types (2010–2014)

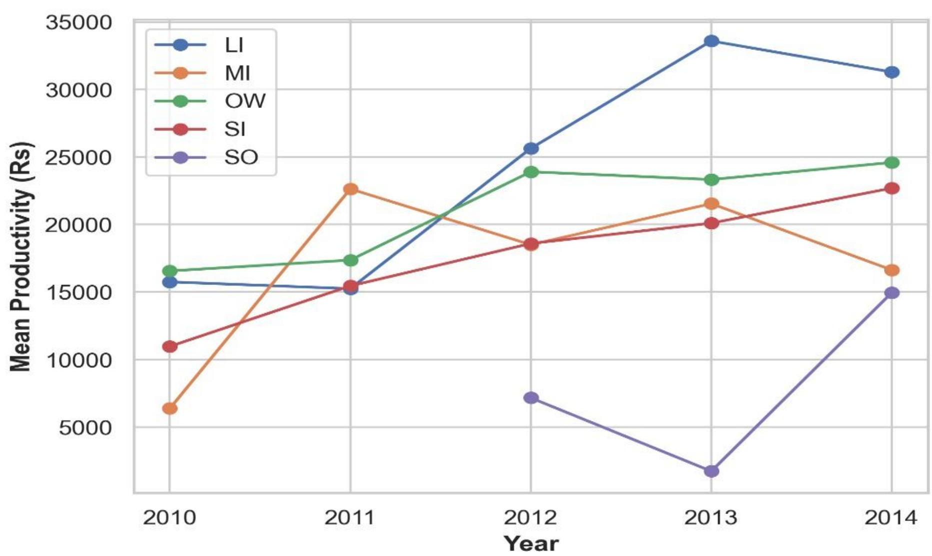

Figure 5 illustrates the trend of mean agricultural productivity from 2010 to 2014 across five land ownership categories: Leased-In (LI), Leased-Out (MI), Owner (OW), Shared-In (SI), and Shared-Out (SO). The graph reveals that **Leased-In (LI)** lands experienced a steady and significant increase in productivity over time, peaking in 2013 and maintaining high levels in 2014. This suggests that lessees may have strong incentives to optimize output during their lease period. The **Owner (OW)** category showed stable and consistently high productivity, reflecting the benefits of secure tenure and long-term land stewardship.

In contrast, **Shared-Out (SO)** lands demonstrated the lowest productivity overall, with sharp fluctuations and a significant dip in 2013, highlighting the inefficiencies associated with indirect or fragmented control. **Leased-Out (MI)** and **Shared-In (SI)** categories showed moderate gains, though MI exhibited a notable decline in 2014. These patterns underscore how land tenure arrangements influence agricultural outcomes, with direct control (as in LI and OW) generally supporting better performance than shared or outsourced arrangements.

Soil Loss Calculation: -

Soil erosion is the process by which the top layer of soil is removed due to water, wind, or tillage. It is a significant environmental concern because it reduces soil fertility, clogs waterways, and causes sedimentation in dams and reservoirs. One of the most widely used methods for estimating soil erosion is the **Universal Soil Loss Equation (USLE)**. This empirical model predicts the average annual rate of soil erosion based on rainfall patterns, soil type, topography, crop system, and management practices.

The USLE is given by the formula:

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

Where:

- **A** = Average annual soil loss (tons/acre/year)
- **R** = Rainfall-runoff erosivity factor
- **K** = Soil erodibility factor
- **LS** = Slope length and steepness factor
- **C** = Cover-management factor
- **P** = Support practice factor

R – Factor:

The rainfall erosivity factor (R) is a key component in soil erosion modeling, representing the erosive force of rainfall in terms of its energy and intensity. In the absence of high-resolution pluviograph data required for the standard EI30-based R estimation (as used in USLE), an alternative empirical approach was developed using available long-term monthly rainfall data.

A modified empirical model was formulated to estimate the R-factor based on total annual rainfall, monsoon rainfall concentration, and average rainfall intensity. The model leverages key rainfall parameters derived from the dataset and incorporates elements of intensity and seasonality that are known to influence erosive potential.

The empirical equation used for R-factor estimation is as follows:

$$R = 50 + 0.3 \times P + 15 \times MRR + 2 \times ARI$$

Where,

- **P** = Total Annual Rainfall (mm) = Sum of monthly rainfall
- **MRR** = Monsoon Rainfall Ratio = **JJAS_rain / P**
- **ARI** = Average Rainfall Intensity = **P / Total Rainy Days (** $\sum_{i=1}^{12} \mathrm{rd}\_i$ where rd_*i* is the number of rainy days in month i)

Table 2: Interpretation of Rainfall Metrics and Their Erosional Significance

Component	What It Measures	Why It's Important
P	Total rainfall volume	Higher rain → more erosion potential
MRR	% of rain in monsoon season	Reflects intensity of seasonal storms
ARI	Rainfall per rainy day	Proxy for splash energy/intensity

The constants employed in the empirical formula were selected to reflect the relative contribution of each parameter to rainfall erosivity, based on both prior empirical models and logical scaling of regional rainfall characteristics. The coefficient **0.3** for annual rainfall (P) is adapted from Lal's (1976) widely cited Indian model R=79+0.363PR = 79 + 0.363P, ensuring that total rainfall remains the dominant contributor to R while allowing flexibility for other dynamic factors. The coefficient **15** for the monsoon rainfall ratio (MRR) amplifies the effect of concentrated seasonal rainfall typical of South Asian monsoon climates, where a large portion of annual precipitation occurs in just a few months, often with high erosive power. The coefficient **2** for average rainfall intensity (ARI) ensures that years with fewer but more intense rainfall events are appropriately represented, capturing splash and kinetic energy effects. Lastly, a constant **intercept of 50** was added to establish a baseline erosivity level, acknowledging that even in years with moderate rainfall, some erosive force is likely present due to background weathering and occasional high-intensity events.

Together, these constants produce a semi-empirical yet interpretable model that aligns with both physical understanding and regional erosion characteristics, offering a practical approach in data-limited contexts.

K – Factor:

- Base K-Value from Soil Texture (***soil_type,*** and ***soil_type_ot*** from datasets):
- Soils are grouped by texture, with typical K-factor ranges:

Table 3: USDA-Based K-Factor Ranges for Various Soil Types and Texture Groups

Soil Type	Texture Group	K-Factor Range by USDA guidelines
Red, Sandy, Murrum	Sandy/Loamy	0.05 – 0.20 (e.g., 0.17)
Medium Black, Deep Black	Clay/Clay Loam	0.20 – 0.35 (e.g., 0.28)
Problematic, Shallow, Saline/Alkaline	Mixed/Degraded	0.15 – 0.30 (e.g., 0.20)
Others / Custom (soil_type_ot)	Case-by-case	Variable

-- *USDA: U.S. Department of Agriculture*

Table 4: K-Factor Adjustment Table Based on Soil Properties

Soil Depth Adjustment	Soil Fertility Adjustment (soil_fert)	Soil Degradation Adjustment (soil_degr)
< 30 cm: Increase K by **+0.02**	**Fertility < 30:** Increase K by **+0.02**	**If degraded:** Increase K by **+0.02**
> 100 cm: Decrease K by **–0.02**	**Fertility > 100:** Decrease K by **–0.02**	**If "No problem":** No adjustment

LS – Factor:

LS Factor (Slope Length C Steepness) reflects how terrain affects soil erosion. When only **slope categories** are available (instead of exact gradients), standard approximate values are assigned:

Table 5: Slope Categories and Corresponding LS Values with Descriptions

Slope Category	LS Value	Description
Levelled	0.1	Flat or nearly flat land
Slight Slope	0.3	Gentle, rolling terrain
Medium Slope	0.5	Moderate incline
High Slope	1.0	Steep terrain

This method ensures practical LS estimation when precise slope data isn't available.

P–Factor: The **P-Factor** in USLE represents the impact of soil conservation practices (like bunding) on reducing erosion. It's estimated using three dataset columns: bunding, ***bund_type***, and ***bund_type_ot***.

P-Factor Assignment Logic:

- **If bunding = 'no' or missing:**
  → **P = 1.0** (no conservation)
- **If bunding= 'yes'**, P is assigned using either:

(a) From ***bund_type*** *(numeric value):*

Table 6: P value for different bund_type

bund_type	Description	P Value
1	Contour Bunding	0.55
2	Graded Bunding	0.60
3	Earthen Bunds	0.70
4	Stone Bunds	0.50

*(b) From **bund_type_ot** (text description):*

- Contains **"CONTOUR"** → 0.55
- Contains **"STONE"** → 0.50
- Contains **"FIELD"**, **"PROP"**, **"SOIL CONS"** → 0.60
- Contains **"EROSION"** or **"SILT"** → 0.60
- Contains **"SMALL"** or **"LOOSE"** → 0.70
- **Else (default)** → 0.65
- If bundingis **yes** but both type fields are **missing** → **P = 0.65** (default for unknown bund)

This logic ensures that the P-factor reffects actual conservation efforts even when detailed bund data is partially missing or mixed (numeric/text).

C – Factor:

The **C-Factor** in USLE/RUSLE measures the impact of vegetation and land management on soil erosion. Lower values indicate better ground cover and less erosion risk.

Estimation approach -
C-values were assigned to crops using:

- Published erosion research
- RUSLE guidelines
- Literature on vegetative cover

Each crop was grouped into categories with standard C-factor ranges reffecting erosion risk.

Table 7: C-Factor Mapping for Different Crop Categories Based on Vegetative Cover and Erosion Risk

Crop Type Category	Examples	C-Factor Range	Erosion Risk
Dense Cover / Perennial	Lucern Grass, Barseem, Orchard, Fodder Grass	0.01 – 0.05	Very Low
Legumes C Cereals	Chickpea, Maize, Sorghum, Blackgram, Pigeonpea	0.2 – 0.3	Moderate
Vegetables C Spices	Tomato, Onion, Chillies, Cucumber	0.3 – 0.5	Moderate–High
Oilseeds C Commercial Crops	Cotton, Groundnut, Sunflower, Sugarcane	0.4 – 0.6	High
Fallow / Low Cover Areas	Fallow, Sparse crops	0.6 – 0.8	Very High

For unlisted crops, values were estimated based on similarity to known crops. This method helps quantify how vegetation affects erosion in each plot.

Table 8: Summary of RUSLE Key Variable Ranges with Mean and Standard Deviation

Key Variable	Minimum	Maximum	Mean	Standard deviation
K-Factor	0.18	0.26	0.20	0.013
R-Factor	166.30	664.99	366.50	105.87
LS-Factor	0.10	1.00	0.25	0.12
P-Factor	0.70	1.00	0.84	0.18
C-Factor	0.30	0.90	0.28	0.20
A-Factor	0.099	47.40	4.34	4.24

Figure 6: Soil Loss Distribution Across Ownership Categories

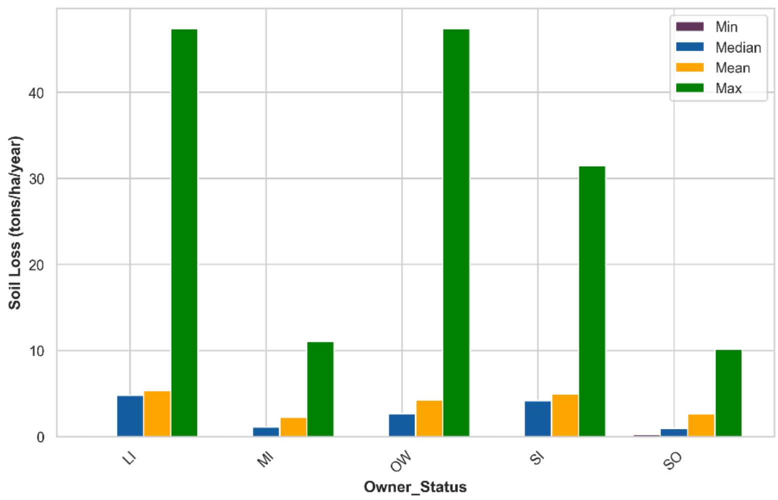

Figure 6 presents the variation in estimated annual soil loss (tons/ha/year) across different land ownership categories: OW (Owner), LI (Leased-In), SI (Shared-In), MI (Leased-Out), and SO (Shared-Out).The chart displays the minimum, median, mean, and maximum soil loss values within each ownership class, allowing for a comparative understanding of erosion severity.

The **maximum soil loss** is highest in *LI (Leased-In)* and *SI (Shared-In)* categories, both exceeding **45 tons/ha/year**, indicating the presence of critically eroding areas under shared or leased management. This may reflect either limited long-term investment in soil conservation or inherently vulnerable land conditions. In contrast, *MI (Leased-Out)* and *SO (Shared-Out)* lands show considerably lower maximum soil loss values, suggesting relatively lower erosion risks or more stable land use.

The **mean and median soil loss values** are substantially lower than the maxima across all categories, suggesting a **right-skewed distribution**—a small number of plots within each ownership type contribute disproportionately to the overall soil erosion. The *MI (Leased-Out)* and *SO (Shared-Out)* categories consistently report the **lowest mean and median values**, indicating relatively effective land management or less erosive conditions in these parcels.

Overall, these findings emphasize the critical need for **focused erosion control measures** in *Leased- In* and *Shared-In* lands, which are likely more prone to neglect or degradation due to fragmented responsibilities or short-term land use strategies.

Conclusion: -

This study investigated the intricate relationship between agricultural productivity and soil erosion across varying land ownership patterns, cropping seasons, and socio-economic contexts using both statistical analysis and the Universal Soil Loss Equation (USLE). The findings highlight several critical insights.

Firstly, productivity was found to be significantly influenced by land ownership structure. Owner-operated and Leased-In plots consistently demonstrated higher productivity, suggesting that secure and direct control over land fosters greater investment and efficiency in agricultural practices. Conversely, Shared-Out plots suffered from lower productivity, likely due to weaker tenure security and reduced incentives for long-term land management.

Secondly, seasonal and perennial cropping patterns played a vital role in determining productivity levels. Perennial and annual crops, with their longer cultivation cycles, exhibited substantially higher returns, underscoring the importance of sustained engagement and consistent land use in maximizing agricultural output.

Temporal analysis revealed a clear upward trend in productivity from 2010 to 2014, indicating positive developments in agricultural practices, possibly supported by technological improvements, better market access, or supportive policy interventions.

From an environmental standpoint, soil erosion risk varied notably across ownership types. Leased-In and Shared-In lands recorded the highest maximum soil loss, indicating hotspots of environmental degradation potentially linked to short-term land use priorities and lack of conservation measures. The USLE-based soil loss analysis reaffirmed the need for tailored soil conservation strategies, especially in plots with high LS and C factors and limited bunding practices.

Overall, the research emphasizes that both agricultural performance and environmental sustainability are deeply rooted in land tenure systems, crop planning, and soil management practices. Future agricultural policy should prioritize secure land tenure, promote conservation-compatible cropping systems, and support investment in soil erosion control—especially in leased and shared farming arrangements. Such integrated strategies are vital for ensuring long-term productivity, ecological stability, and rural resilience.

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