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Dynamics and Determinants of Organic Farming across Indian States: A Panel Data Analysis

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Abstract

The present study examines the key factors that influence organic farming production in India. It uses panel data from the top ten organic-producing states during the period between 2012 and 2022. The analysis uses the Panel ARDL model. The long-run results show that organic area and rainfall have a positive effect on organic output. In contrast, bio fertilizer production and irrigation intensity have a negative impact. The negative impact of bio fertilizer production points to poor infrastructure and low farmer awareness. Likewise, the adverse effect of irrigation shows the dominance of conventional farming in irrigated regions. In addition, the error correction term is negative and statistically significant, which suggests that short-run adjustments are moving toward long-run equilibrium. At the state level, trends indicate that states with a larger organic farming area and adequate rainfall report higher organic output. On the other hand, states with high irrigation intensity or increased bio fertilizer production show lower yields. This reflects structural dependence on conventional methods and limited use of organic inputs. Overall, the findings emphasize the need to expand organic farming in rainfed areas, strengthen the supply of organic inputs, and reduce dependence on chemical farming. This study provides useful evidence to guide policies aimed at promoting sustainable organic agriculture in India.

Keywords: Organic Farming, Panel ARDL, Regional Disparities, Sustainable Farming.

Introduction

Organic farming in India has evolved from a marginal activity into a mainstream agricultural approach, primarily due to growing environmental concerns and the implementation of supportive policy frameworks. As a result, India now has the world's highest number of organic producers and ranks among the leading countries in terms of certified organic area. By 2020–21, the total area under organic cultivation reached 4.34 million hectares. This figure subsequently increased to approximately 10 million hectares by 2022–23, including wild harvest zones, with an estimated output of 2.9 million metric tons of organic produce annually (1). The advancement of organic farming in India has relied heavily on institutional mechanisms and policy support. For instance, the National Programme for Organic Production (NPOP), launched in 2001, established national standards, accredited certification agencies, and facilitated market access and farmer training (2). Additionally, the Participatory Guarantee System (PGS-India) offered a cost-effective certification model for small and marginal farmers (3). Despite these efforts, the high cost and complexity of certification remain key constraints, especially for farmers in remote regions (4, 5). To address such limitations, the Indian government introduced targeted programs such as the Paramparagat Krishi Vikas Yojana (PKVY) and the National Mission for Sustainable Agriculture (NMSA) (6). The National Project on Organic Farming (NPOF) and PKVY have significantly expanded organic cultivation, particularly in areas like the Ganga River basin (7). These programs provide financial assistance, training, and market access to organic farmers (8). However, inconsistencies in implementation, delays in disbursal, and limited awareness among farmers have hindered the full realization of policy goals (9, 10). As of 2020, only about 2% of India's net sown area had organic certification, and certified organic farmers represented just 1.3% of the total farming population (11). These figures reveal a substantial scope for further expansion, which necessitates interventions grounded in robust empirical evidence. To achieve a deeper understanding of

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organic production trends, it is crucial to focus on state-level growth in organic output and cultivated area. Variations in agronomic conditions and adoption patterns across states demand an examination of the underlying drivers of production. Factors such as land availability, water access, rainfall, and organic input usage are critical determinants. While quantifying all these factors at scale remains impractical, the present study identifies a set of supply-side determinants with high empirical relevance and consistent state-level data coverage. The four key variables selected for this study are organic cultivation area, annual rainfall, bio fertilizer production, and gross irrigated area. These factors capture the structural and climatic conditions that directly influence organic farming outcomes. Organic area, for instance, reflects not only the extent of adoption but also the level of institutional facilitation. Larger organic areas tend to yield higher outputs when supported by effective soil management (12). In Turkey a study found that organic cultivation area explained over 66% of the variance in organic production between 2003 and 2018 thus reinforcing its centrality in shaping organic output (13). Bio fertilizers are another essential component of organic farming, as they replace synthetic inputs. As organic farming prohibits the use of synthetic fertilizers, farmers must rely on compost, vermicomposting, and microbial inoculants to maintain soil health (14, 15). Empirical studies show that increased use of bio fertilizers improves soil fertility and crop productivity (16). Their effectiveness in leguminous crops has been well-documented, and they also provide broader benefits for soil microbial health (17, 18). However, their efficacy is influenced by environmental factors such as rainfall and microbial activity (19). Additional barriers such as limited commercialization, lack of farmer training, and logistical challenges continue to restrict their widespread adoption (20, 21). India depends on the monsoon, so fluctuations in annual rainfall directly affect agricultural production. Rainfall variability holds particular importance in monsoon-dependent systems. Organic farms depend on natural nutrient cycles and soil moisture retention. However, inconsistent rainfall increases the vulnerability of these systems (7, 22). Although organic practices reduce water requirements, stable production still relies on consistent rainfall or adequate irrigation facilities (23). In this context, irrigation infrastructure serves as a crucial buffer against rainfall variability. A higher gross irrigated area increases farming resilience by ensuring consistent water supply through canals, tube wells, or micro-irrigation systems. Further, irrigated lands contribute nearly 40% of the global food supply despite accounting for only 20% of agricultural land (24). Advanced irrigation systems can increase crop yields by more than 100% compared to rainfed agriculture (25). Although organic farms often require less water due to improved soil health, maintaining yield stability in water-scarce regions depends significantly on access to reliable irrigation systems (23). Moreover, studies have shown that the benefits of organic farming are amplified when combined with drip or sprinkler irrigation, as these systems reduce both water stress and input costs. The focus on these variables is grounded in their direct relevance to organic production and the availability of reliable, state-level time-series data. To ensure analytical tractability and methodological robustness, the study concentrates on supply-side drivers—land, inputs, and water—that fall within the purview of policy influence and farm-level management. Notably, demand-side variables such as consumer preferences, export demand, and price premiums are not included. While such factors undeniably shape the organic farming landscape, they are difficult to measure uniformly across states and years. Moreover, they often represent outcomes of successful organic production rather than immediate determinants. In light of the above, it can be said that most existing studies rely on single-variable analyses and fail to capture the heterogeneity in adoption patterns across states, leaving a critical gap in the literature. This study addresses that gap by applying advanced econometric methods to assess both the combined and state-specific effects of key supply-side variables across ten major organic farming states in India. The findings provide a more comprehensive empirical foundation to guide policy decisions and strengthen future efforts in the organic farming sector.

Methodology

This study tries to investigate the key determinants of organic farming production in

India. The analysis is based on panel data from the top ten organic-producing states over the period 2012 to 2022. Organic production (OP), excluding wild harvest, is taken as the dependent variable. To explain its variation across states, four explanatory variables have been considered: organic area excluding wild harvest (OA), bio fertilizer production (BP) in both carrier and liquid forms, annual rainfall (AR), and Gross irrigated area (GIA), expressed in hectares. The selection of variables in this study is based on both their theoretical relevance and practical importance in explaining organic production with the assumptions that OA represents the extent of land devoted to organic cultivation, as a larger area is generally expected to result in higher production levels. In addition, BP captures the availability of essential organic inputs, which play a crucial role in improving soil fertility and enhancing crop productivity within organic farming systems. Moreover, AR reflects climatic conditions, which significantly influence agricultural output, particularly in regions where farming largely depends on rainfall. Lastly, GIA measured in hectares indicates the availability of irrigation facilities, which not only stabilize production but also reduce the risks associated with rainfall variability across states. The information related to OP and OA has been obtained from the Agricultural and Processed Food Products Export Development Authority (APEDA). Similarly, data on BP has been collected from Lok Sabha Unstarred Questions. Besides this, AR figures have been sourced from the Indian Meteorological Department (IMD). Lastly, data about GIA has been taken from the Ministry of Earth Sciences, Government of India and the India-Stat. To understand the dynamics of organic agriculture in India, Figures 1 and 2 present the trends in organic production and organic area across top ten states, namely Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Sikkim, Uttar Pradesh, and Uttarakhand, over the period 2012 to 2022. This analysis highlights regional disparities and evolving patterns in the adoption of organic farming practices. Figure 1 illustrates the area under organic cultivation (measured in hectares), while Figure 2 shows the corresponding organic output (measured in metric tons). In both figures, actual data points are marked with red dots connected by a blue line, with a green dashed line representing the fitted linear trend.

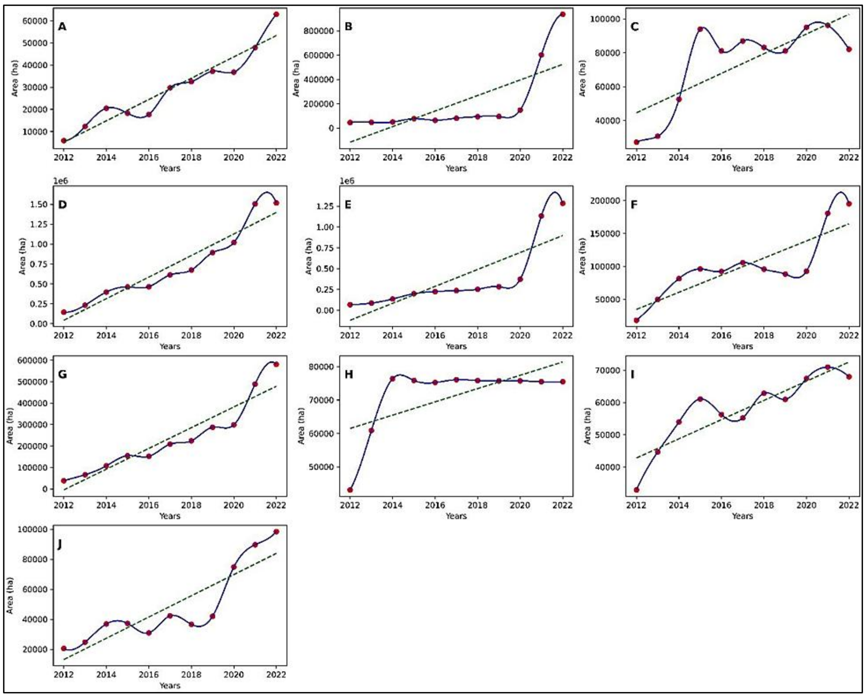

Figure 1: State-wise Analysis of Organic Area Trends A) Andhra Pradesh B) Gujarat C) Karnataka D) Madhya Pradesh E) Maharashtra F) Odisha G) Rajasthan H) Sikkim I) Uttar Pradesh J) Uttarakhand

Madhya Pradesh exhibits the most significant and steady growth in organic cultivation area, expanding from approximately 250,000 hectares in 2012 to over 1.5 million hectares by 2022. This growth results from strong institutional support and widespread adoption among farmers.

Similarly, Maharashtra and Rajasthan show notable upward trends, particularly after 2016, likely driven by the intensified implementation of PKVY and state-level organic initiatives. In contrast, Gujarat experiences a sharp increase in area post-2017, while Sikkim stabilizes following its full transition to organic farming in 2016. On the other hand, states such as Karnataka, Uttar Pradesh, and Uttarakhand show moderate growth with occasional fluctuations, reflecting the influence of region-specific challenges or inconsistent program execution.

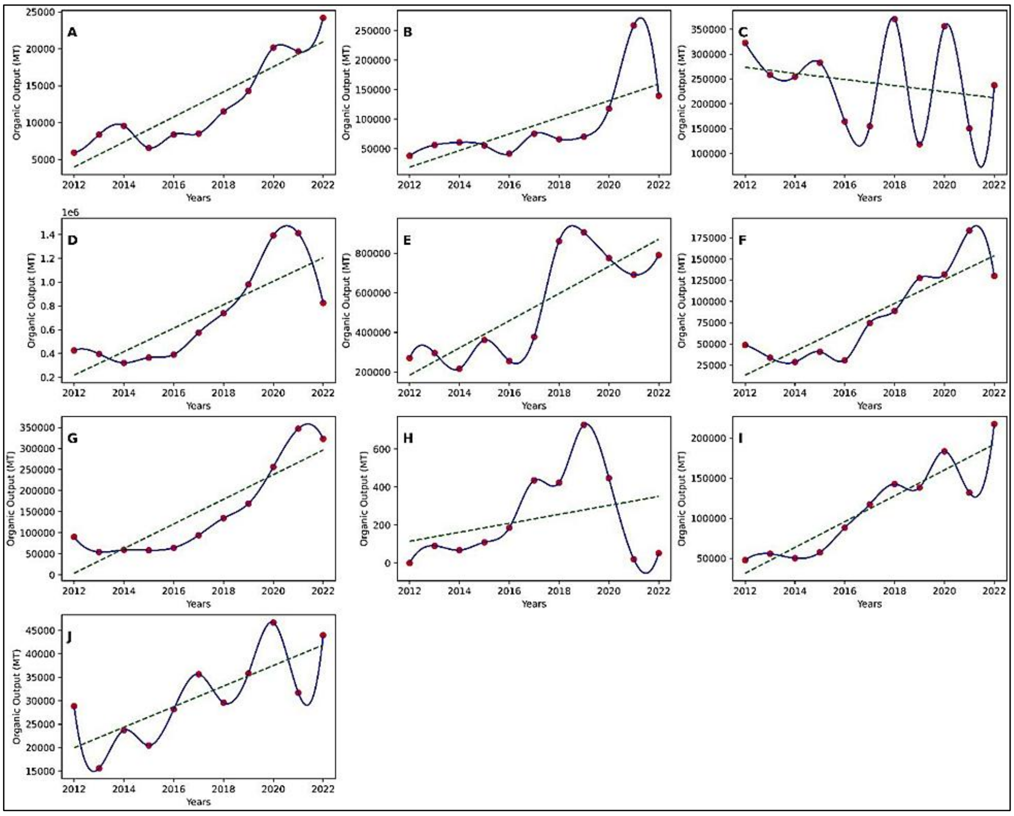

Figure 2: State-wise Analysis of Organic Production Trends A) Andhra Pradesh B) Gujarat C) Karnataka D) Madhya Pradesh E) Maharashtra F) Odisha G) Rajasthan H) Sikkim I) Uttar Pradesh J) Uttarakhand

Figure 2 depicts changes in organic output over time, though these trends do not always align with the expansion in cultivated area. Madhya Pradesh leads once again, demonstrating significant output gains, rising from under 0.4 million metric tons in 2012 to nearly 1.4 million metric tons by 2021-22. This growth closely correlates with the increase in cultivated area. States such as Maharashtra, Rajasthan, and Gujarat also show a positive relationship between cultivated area and production. However, in states like Karnataka and Sikkim, substantial fluctuations in output occur despite relatively stable cultivated areas. This suggests possible yield instability due to factors such as rainfall variability, soil conditions, or market dynamics. In contrast, Andhra Pradesh, Odisha, and Uttarakhand exhibit more stable increases in both area and output, indicating a well-supported and gradual transition. These figures collectively emphasize that increasing the area under organic cultivation is crucial, but it does not always result in proportional increases in output. The differences across states highlight the significance of complementary factors, such as irrigation infrastructure, climatic stability, and biofertilizer adoption, in affecting productivity. A strong correlation between area and output, as observed in Madhya Pradesh and Rajasthan, indicates effective organic farming systems, while inconsistencies in other states point to the need for more targeted support and localized interventions.

Table 1: State-Level Variations in Organic Farming Area and Production in India between 2012 and 2022

States	Movement in Area (%)	Movement in Production (%)
Madhya Pradesh	28.14 - 38.98	27.36 - 41.37
Maharashtra	11.37 - 23.99	19.81 - 33.4
Rajasthan	7.60 - 12.55	4.38 - 10.94
Gujarat	4.16 - 17.36	2.54 - 7.59
Odisha	3.49 - 6.90	2.60 - 5.38
Uttarakhand	1.82 - 4.08	0.93 - 2.39
Karnataka	1.52 - 6.31	4.39 - 24.26
Sikkim	1.40 - 8.56	0.00 - 0.03
Uttar Pradesh	1.26 - 6.53	3.59 - 7.47
Andhra Pradesh	1.01 - 1.74	0.44 - 0.87

Table 1 presents the percentage share of organic farming area and production across states from 2012 to 2022, highlighting temporal fluctuations and each state's relative contribution to India's organic agriculture environment. Madhya Pradesh consistently leads, with its share of organic farming area ranging from 28.14% to 38.98% and its share of production ranging from 27.36% to 41.37%. This dominance underscores its central role in both organic cultivation and output. Maharashtra ranks second, exhibiting notable year-on-year variation. Its share of organic area fluctuates between 11.37% and 23.99%, while production varies from 19.81% to 33.40%, indicating large-scale adoption and significant productivity in organic farming. Rajasthan and Gujarat also make significant contributions; however, their production shares are lower than their area shares, which suggest inefficiencies in output per unit of area.

Karnataka stands out due to its production efficiency. Although its area under organic cultivation ranges from 1.52% to 6.31%, its production fluctuates between 4.39% and 24.26%. This variation points to high output intensity, possibly driven by better agronomic practices or favorable agro-climatic conditions. Sikkim, despite being the first state in India to achieve 100% organic certification, contributes minimally to national organic output, with production levels remaining virtually negligible throughout the period (0.00% to 0.03%). On the other hand, states like Uttarakhand and Uttar Pradesh display a more balanced relationship between area and production. Uttarakhand share of organic area ranges from 1.82% to 4.08%, while its production share fluctuates between 0.93% and 2.39%. Similarly, Uttar Pradesh maintains a moderate area share of 1.26% to 6.53% and a production range of 3.59% to 7.47%, reflecting consistent growth and relatively stable output trends. These patterns suggest that output is influenced not only by land area but also by factors such as input use, crop choice, climate conditions, and irrigation access.

Model Selection

After data collection the study proceeds to examine the stationarity properties of the variables. To test for unit roots in the panel data four standard tests were applied considering their suitability for the sample size and the asymptotic characteristics of each test (26). The panel unit root tests were conducted under the null hypothesis that the variables in all panel series contain a unit root (27–30). The results of the stationarity tests show that the variables exhibit a mixed order of integration. This outcome provides a basis to apply the panel ARDL model. The panel ARDL approach provides several advantages over other dynamic panel estimation techniques such as fixed effects instrumental variables and GMM estimators (31–35). In other words these methods often fail to produce consistent estimates when slope coefficients vary across cross-sectional units. In this context, the panel ARDL model emerges as a more appropriate and reliable estimation technique. However, before applied the panel ARDL model, the study also conducts the Hausman test to assess the suitability of the Pooled Mean Group (PMG) estimator over the Mean Group (MG) estimator. The PMG estimator assumes homogeneity in long-run coefficients across cross-sectional units but allows heterogeneity in short-run coefficients. In contrast, the MG estimator allows heterogeneity in both short-run and long-run coefficients across cross-sections. The Hausman test provides a statistical criterion for selecting the appropriate estimator and establishes the reliability of the empirical results (26). The test result supports the PMG estimator and justifies the estimation of the model within the ARDL framework. This approach enables the interpretation of the coefficients of the variables in levels as representing the long-run impact on the dependent variable with the help of following equation:

$$\Delta OP_{t-1} = \rho^0 + \sum_{i=0}^{n} \rho^1 \Delta OP_{t-1} + \sum_{i=0}^{n} \rho^2 \Delta OA_{t-1} + \sum_{i=0}^{n} \rho^3 \Delta AR_{t-1} + \sum_{i=0}^{n} \rho^4 \Delta BP_{t-1} + \sum_{i=0}^{n} \rho^5 \Delta GIA_{t-1} + \delta^1 OP_{t-1} + \delta^2 OA_{t-1} + \delta^3 AR_{t-1} + \delta^4 BP_{t-1} + \delta^5 GIA_{t-1} + \varepsilon_t \quad [1]$$

Where ρ and σ are the white-noise, ε_t is the error term, OP_{t-1} OA_{t-1} AR_{t-1} BP_{t-1} and GIA_{t-1} are the short run and the long run coefficients of the model, respectively, and Δ is the 1st difference operator; 't' denotes time period, and 'n' is the maximum number of lags in the model, based on the AIC (Akaike Information Criterion).

Results and Discussion

The empirical analysis has been carried out using the econometric model discussed above. The summary statistics related to Equation 1 are reported in Table 4, while the results of the stationarity tests are reported in Table 2, and the result of the Hausman test is presented in Table 3.

Table 2: Stationarity Tests of the Variables

	LLC		IPS		ADF - Fisher		PP - Fisher	
At Level								
	Constant	Trend	Constant	Trend	Constant	Trend	Constant	Trend
OP	0.13939 (0.5554)	1.12430 (0.8696)	1.31183 (0.9052)	0.49846 (0.6909)	11.1855 (0.9413)	12.5986 (0.8939)	**35.2747** **(0.0187)**	**61.3391** **(0.0000)**
OA	**-21.0094** **(0.0000)**	---	**-8.08022** **(0.0000)**	----	**34.9773** **(0.0202)**	----	**58.7518** **(0.0000)**	**----**
AR	-2.49181 (0.0064)	**-8.19818** **(0.0000)**	-0.79838 (0.2123)	**-2.18998** **(0.0143)**	24.0355 (0.2408)	**47.6565** **(0.0005)**	47.9405 (0.0004)	**57.5426** **(0.0000)**
BP	**-3.17071** **(0.0008)**	**-4.65755** **(0.0000)**	-1.51603 (0.0648)	-1.00604 (0.1572)	31.3955 (0.0502)	**31.6231** **(0.0475)**	**39.2921** **(0.0061)**	**51.7.38** **(0.0001)**
GIA	1.00022 (0.8414)	**-2.26583** **(0.0117)**	1.58527 (0.9435)	0.03772 (0.5150)	9.87753 (0.9703)	20.5084 (0.4266)	**33.5299** **(0.0295)**	**46.9427** **(0.0006)**
At First Difference								
OP	0.08224 (0.5328)		**-1.99026** **(0.0233)**		**35.7205** **(0.0166)**		**108.552** **(0.0000)**	
GIA	**-1.90755** **(0.0282)**	----	**-1.72791** **(0.0420)**	----	**32.9698** **(0.0340)**	----	**84.4062** **(0.0000)**	**----**

Note: Probability values are given in parentheses. Bold values indicate that the variable is stationary at the 5% significance level

The results of the stationarity tests based on four different methods are reported in Table 2. In the context of panel data analysis, a variable attains the status of stationarity when at least three out of the four tests produce significant results at the 5 percent level. This criterion provides a more reliable basis to determine the integration order of the variables. Based on this approach, the variables OA, AR, and BP satisfy the condition of stationarity at level, which confirms their integration at I (0). On the other hand, the variables OP and GIA achieve stationarity at their first difference, which confirms their integration at I (1). The existence of both I (0) and I (1) variables in the model confirms the presence of a mixed order of integration across variables. This condition justifies the selection of the ARDL model for estimation because the ARDL approach remains suitable when variables possess different orders of integration. To further establish the appropriateness of this model, the Hausman test is applied. The result of the Hausman test, presented in Table 3, confirms the preference for the PMG estimator over the MG estimator, which validates the application of the ARDL framework in the present study.

Table 3: Hausman Result

Test Summary	Chi-sq. Statistic	Chi-sq	Prob
Cross-section random	2.064532	4	0.7239

The Hausman test results presented in Table 3 show that the probability value is greater than the 0.05 level of significance, which indicates the existence of homogeneity in the long run and heterogeneity in the short run. Therefore, the PMG estimator proves to be more appropriate than the MG estimator in this context. The outcomes of the PMG estimation are reported below.

Table 4: Panel ARDL long-Run PMG Estimation

Selected Model (ARDL 1, 1, 1, 1, 1)				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
OA	0.576373	0.021727	26.52774	0.0000
AR	0.822717	0.059686	13.78416	0.0000
BP	-0.118207	0.007239	-16.32906	0.0000
GIA	-0.716267	0.087019	-8.231161	0.0000
ECM	-0.585699	0.180677	-3.241685	0.0022

The long-run results of the Panel ARDL model are presented in Table 4. The results indicate that OA, AR, BP, and GIA significantly influence organic production (OP) in India. Among these, OA and AR show a positive relationship with OP, whereas BP and GIA exhibit a negative relationship. The coefficients of OA and AR are 0.567 and 0.82, which indicate that a one percent increase in OA and AR leads to an increase in OP by 0.57 percent and 0.82 percent, respectively. This highlights the crucial role of the expansion of organic farming areas and the availability of adequate rainfall in promoting organic production. As far as BP and GIA are concerned, their impact on OP is negative in India during the study period. The negative impact of BP on OP may result from a lack of consumer awareness and the absence of adequate infrastructure for organic inputs (36). On the other hand, the negative association between GIA and OP can be attributed to the structural characteristics of irrigated regions in India. Areas with a higher proportion of irrigated land are generally associated with conventional farming systems, which rely heavily on chemical fertilizers, pesticides, and intensive monoculture practices. These practices deteriorate soil quality, reduce organic content, and create difficulties in shifting towards organic farming (37). Moreover, irrigated regions often encourage crop specialization and chemical-dependent productivity, which directly contradict the diverse and sustainable practices required in organic agriculture. Farmers operating in these regions face additional challenges in adopting organic methods due to their dependency on conventional input subsidies, lower short-term returns, and limited availability of organic alternatives. This finding also aligns with a previous study, which reported that food production under the large-scale organic scenario remained higher in rainfed conditions but was lower in irrigated areas (38). Finally, the error correction term appears negative and statistically significant, which indicates that the short-run disequilibrium adjusts towards the long-run equilibrium at a speed of 59 percent per year.

Conclusion

This study identifies the major determinants of organic farming production in India based on panel data from the top ten organic-producing states during 2012 to 2022. The results confirm that organic area and rainfall have a positive and significant impact on organic production. In contrast, bio fertilizer production and gross irrigated area exhibit a negative relationship with organic output. The positive coefficients of organic area and rainfall reflect the importance of land expansion and favorable climatic conditions in raising organic production. However, the negative influence of bio fertilizer production indicates the existence of infrastructural limitations and a lack of awareness regarding organic inputs. Similarly, the negative impact of gross irrigated area suggests a higher dependence on conventional farming methods in irrigated regions, which creates barriers to the adoption of organic farming practices.

Policy Suggestions

These findings provide important policy directions. First, the government should increase the area under certified organic farming, particularly in rainfed regions where organic methods are more suitable. Second, there is a need to strengthen the supply of organic inputs such as bio fertilizers and promote awareness programmes to improve their usage. Third, policy measures should reduce the dependence on chemical-based farming in irrigated areas by encouraging crop diversification and providing financial incentives for organic farming. Fourth, institutional support for organic certification, marketing, and infrastructure must be improved to ensure better price realization and market access for organic farmers. Finally, a region-specific approach is necessary to promote organic farming in India based on local resources, climatic conditions, and farming practices. The inclusion of demand-side variables to understand their impact on organic production can be one of the areas for future studies.

Limitation of the Study

In examining the determinants of organic farming in India, the study faced some limitations. The main limitation is the unavailability of comprehensive data. As a result, the study focused only on the top 10 organic-producing states in India. This approach may not represent the full diversity of agricultural conditions across the country. Therefore, the findings may not apply to regions with different climates or farming practices. Furthermore, the study focuses solely on supply-side factors, such as organic cultivation area, bio fertilizer production, rainfall, and irrigation intensity. Demand-side factors, such as consumer preferences, market prices, and export demand, were not included, even though they also influence organic farming.

Abbreviations

All abbreviations and their expanded forms are provided in the main body of the manuscript.

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Author Contributions

Irshad Ahmad: Conceptualization, Literature Review, Manuscript drafting, Data Collection, Rizwan Qasim: Methodology, interpretation findings Dastgir Alam: Review, Final manuscript.

Conflict of Interest

The authors declared that there are no conflicts of interest.

Ethics Approval

Not applicable.

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