Investigating the Drivers of Crop Yield in Under Developing Economy: Recent Evidence from Pakistan's Agricultural Sector

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Abstract

The present research is organised to investigate the reasons behind the changing pattern of crop yields in a labour-rich and underdeveloped economy, where agriculture plays a primary role in economic activity. The cropping sector alone contributes around 33.95% to the total output of the agriculture sector, which was recorded at 8975069 million during the fiscal year 2022-23. The livestock and cropping sectors jointly contribute 96.32% to the agricultural sector's output [Pakistan Economic Survey, 2023–2024]. This highlights the importance of the cropping sector, which is crucial in determining the performance of the agricultural industry. After utilising the ARDL bounds test on the data series from 1972 to 2022, this research reveals an inverted U-shaped relationship between fertiliser consumption and crop yield, while urban population, agricultural machinery, and rents from natural resources significantly accelerate the yield of the cropping sector. These results emphasise the need to utilise environmentally sustainable and scientifically advanced fertilisers to the extent that crop production reaches its maximum potential. This research further proposes that the adoption of advanced and ecologically supportive technology is encouraged among farmers to boost crop yields. This research further recommends promoting the size of rents from natural resources by increasing investments in natural resources to stimulate crop production in Pakistan. This study also suggests transferring the surplus workforce from the rural sector to cities, so that the burden in terms of production costs on agriculture should decrease. This will enhance profits for farmers, which will be reinvested to increase crop yields further.

Keywords: Fertiliser Consumption; Agriculture Machinery; Natural Resource Rent.

Introduction

The cropping sector plays a crucial role in ensuring food supply, providing raw materials to industries, and providing livelihoods to the workforce employed in the agricultural sector. This is the second-largest sector, contributing approximately 35.19% to the total agricultural industry production as of FY 2023-24. This provisional share was recorded as 32.78% during FY 2024-25. In FY 2023-2024, the agriculture share of GDP was 22.73%, and the cropping sector share of

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GDP was recorded at 8.00% during the same fiscal year. This provisional share of agriculture in GDP was 21.81%, while the share of the cropping sector decreased to 7.15% during FY 2024-25. The provisional rates are lower, which reveals information about the first three quarters approximately. The agricultural sector is crucial because it employs over one-third of Pakistan's workforce. In the recent FY 2025, the provisional rate of workforce absorption is provided as 37%. [Pakistan Economic Survey (Various Issues and Volumes)].

The present research aims to investigate the significant factors that impact the performance of the cropping sector in Pakistan. The proposed indicators are fertiliser consumption, agricultural machinery, urban population, and natural resource rent. These indicators are among the most critical ones that may help change the pattern of production in the cropping sector. To ensure sustainable economic health and address food security challenges, it is crucial to understand the indicators of crop yield. The use of fertilisers impacts soil fertility and helps in maximising crop yield. However, excessive utilisation of fertilisers can result in decreasing returns, which may reduce the productivity of the cropping sector. This can result in an inverted U-shaped relationship between fertiliser consumption and crop yield. Technology in the agricultural industry can lead to increasing returns for farmers. This may help modernise the cropping sector to reap outputs at a faster rate.

The urban population share of the total population can also play a significant role in reducing the burden of a surplus labour supply in the agricultural sector. As the share of the urban population grows, it becomes clear that more people from rural areas are moving to cities in search of better value-added services. The excessive labour will be adjusted in cities, and the excessive cost for farmers will be reduced. Natural resource rents can also help in improving the production of the cropping sector in Pakistan. The rents from minerals, forests, and water resources can provide farmers with the necessary funds, which may boost their investments. This will result in an expansion of the overall production in the cropping sector. This research is vital because it will investigate the nonlinear impact of fertiliser consumption on crop yield. The literature has explored the linear functions of agricultural productivity; however, the nonlinear effect of any agricultural inputs on agrarian productivity is rarely available in the literature. As. As of our exploration, we have found hardly any research that inquiries into this idea. Therefore, this research will add value to the literature through its unique functional form. Another feature of this research is that it incorporates the role of natural resources in targeting crop yield. This evidence on the connection is also limited.

The rest of the study is organised in a way that the literature section will be shared in part 2. Data and Methods will be discussed in part 3. Results and their interpretation will be demonstrated in part 4. The final section will highlight the conclusion and policy implications.

Literature Review

This section presents a discussion of recent studies on the determinants of agricultural value-added productivity, as well as its disaggregated indicators. For instance, greenhouse gas emissions, carbon, as well as energy and consumption, were considered independent factors affecting the value added of agriculture, including cotton, wheat, rice, and sugarcane production in Pakistan's economy, as noted by Qureshi et al. (2016). The study highlighted that carbon emissions were enhancing the value added in agriculture, particularly in wheat and sugarcane production. Still, greenhouse gas emissions were significantly reducing the production of cotton, wheat, and rice. The results also highlighted that energy consumption was considerably increasing cotton, wheat, and rice production. At the same time, fossil fuels were reported to have a negative and significant impact on overall agricultural value added, but showed positive and significant effects on cotton and sugarcane production. Carbon emissions, fertiliser consumption, temperature, and area under rice production were explored as determining factors of rice production by Chandio et al. (2020) in their research. Their findings suggested that the area under rice production, carbon emissions, and fertiliser consumption were significantly accelerating rice production in Pakistan.

Financial development, agricultural machinery, agricultural land, employment, and interest rates were obtained as explanatory indicators of agricultural productivity in Nigeria by Raifu and Aminu (2020). The findings reported that agricultural machinery, land, employment in the farming sector, and financial development were all significantly contributing to increased agricultural productivity. In a study, Akhtar and Masud (2022) examined the impact of rainfall, temperature, energy consumption, carbon emissions, fossil fuel consumption, and humidity on rice, cereal, vegetable, and coffee production, as well as overall agricultural value added. The empirical results highlighted that carbon emissions enhanced both rice and cereal productions while reducing coffee production. Temperature was decreasing rice production and the value added, in agriculture, while energy consumption and fossil fuels were showing a negative impact on the value added in agriculture. The results also highlighted that temperature, fossil fuels, and humidity were significantly contributing to the escalation of coffee production in Malaysia. After this, Mbingui (2022) conducted research examining rainfall, temperature, and economic growth as factors influencing agricultural productivity in the Democratic Republic of the Congo. The study revealed that both temperature and economic growth stimulated long-term agrarian growth, while having short-term effects. Chandio et al. (2022) conducted research targeting the agricultural sector. In their study, the researchers identified the average annual temperature, average annual rainfall, rural labour force, area under cereal production, carbon emissions, financial development, and energy use as key indicators of cereal production in Bangladesh. Empirical findings highlighted the significantly encouraging role of economic growth, area under cereal production, and average annual rainfall in extending cereal production, while carbon emissions significantly deteriorated cereal production.

Agriculture credit, farm size, mechanical farming rate, labour force employed in the agricultural sector, temperature, and rainfall were identified by He et al. (2022) as key indicators of cereal production in their research. The findings suggested that agricultural credits, rainfall, and the labour force were significantly boosting cereal production. Gul et al. (2022) utilised fertilisers, agricultural machinery, area under rice production, carbon emissions, average temperature, water availability, and labour force as determinants of rice production for the Pakistani economy. The estimates of the bounds test revealed that the labour force and the use of fertilisers significantly enhanced rice production. At the same time, the average temperature was reported to have adverse and significant effects on rice production.

Internet, mobile phone, and telephone users, as well as agricultural labourers and the agrarian labour force in the farming and fertiliser sectors, were examined by Hasan et al. (2023) in their research to identify agrarian output. The findings revealed that mobile phone and internet users, as well as agriculture land and fertiliser consumption, were significantly increasing agricultural production, while telephone users and the labour force employed in the farm sector were decreasing agrarian productivity in Bangladesh. Afterwards, we witnessed another study in which Chandio et al. (2025) found that harvested area and fertilisers significantly enhanced the production of potatoes, tomatoes, and chillies. Meanwhile, temperature-stimulated potato production and rain-enhanced tomato production. Surprisingly, carbon emissions were found to be increasing in the production of both tomatoes and chillies. During the same time, Ishfaq and Khalid (2025) obtained data on land use, area under cultivation, pesticides, fertilisers, employment, income, agricultural credit, urban population, and population growth to determine agrarian productivity for the Pakistani economy. Their proposed model revealed many conceptual and theoretical weaknesses. The empirical results disclosed an insignificant impact of all the indicators on agricultural productivity. Yadav and Goyari (2025) considered arable land, capital formation, financial development, per capita GDP, trade openness and rural population as determining indicators of crop production in India. They applied the bounds test and reported significantly accelerating effects of financial development, trade openness, per capita GDP and capital formation on crop production. After discussing several empirical studies on the determinants of agricultural value added, the next section will outline the sources and methods used to present the empirical results.

Methodology

This section outlines information about the sample and possible methods for obtaining empirical results. This research takes into account some of the key indicators of crop production, such as fertiliser usage, agricultural machinery, the share of the urban population to the total population, and natural resources rents. The sample is extracted for all these indicators using the World Development Indicators database of the World Bank (2025). The annual frequency of the sample is considered, as the sample range spans from 1972 to 2022. The indicators are further converted into natural log form. The proposed function is provided as follows:

$$\ln CP_t = f(\ln FRC_t, \ln FRC_t^2, \ln MAC_t, \ln UBP_t, \ln NR_t)$$

Table 1: Detail about the Variables

Variables	Composition	Sample Period
$\ln CP_t$	Natural Log of Crop Production Index	1972-2022
$\ln FRC_t$	Natural Log of Fertilizer Consumption as share of Fertilizer Production	1972-2022
$\ln FRC_t^2$	Squared Term of Natural Log of Fertilizer Consumption as share of Fertilizer Production	1972-2022
$\ln MAC_t$	Natural Log of Agricultural Machinery, Tractors Per 100 sq. km of Arable Land	1972-2022
$\ln UBP_t$	Natural Log of Urban Population as share of Total Population	1972-2022
$\ln NR_t$	Natural Log of Total Natural Resources Rents as share of Gross Domestic Product	1972-2022

The analysis part will start with a table of summary statistics in order to assess whether the conditions of normal distribution are satisfied by the selected indicators or not. In the next step, to examine whether the independent indicators are significantly correlated or not, the VIF - Variance Inflation Factor test will be used. Later on, KPSS (1992) unit root test will be applied to evaluate whether the data series report any trend over the selected period or not? Based on the findings of this test, order of integrated series will be reported and then any suitable method will be applied to find long run cointegrating relation between crop production and its indicators. In case if the data series provides mixed integrated order, then we will consider Pesaran et al.

(2001)'s proposed method ARDL bounds test. This methodology will confirm presence of long run cointegrating relation between outcome and explanatory indicators if the upper critical bound remains less than the estimated value of F-test. The results will further report the impact of independent indicators on crop production in long and short run. Afterwards, possible diagnostic tests will be used to assess whether the estimated coefficients during the proposed time are reliable and efficient or not. If all the diagnostics confirm the reliability of the results, then on the basis of such results, certain policy implications will be proposed.

Results and Discussion

This part starts by sharing the summary stats to highlight whether the variables taken in this research meet the assumptions of normal distribution or not. The Jarque-Bera test is utilized to find this result. The results highlight that the probabilities of Jarque-Bera test for the natural logarithm of fertilizer consumption, its squared term, agriculture machinery and natural resource rents are statistically significant. This confirms that all these indicators do not satisfy the assumptions of a normal distribution while crop production and urban population are satisfying the required assumptions hence both are normally distributed. These results are provided as under in Table 2:

Table 2: Descriptive Stats

Variables	Mean	Std. Dev.	Jarque-Bera	Probability	Observations
$\ln CP_t$	4.1691	0.4000	4.0876	0.1295	51
$\ln FRC_t$	4.9418	0.1629	39.8535	0.0000	51
$\ln FRC_t^2$	24.4472	1.6538	46.6058	0.0000	51
$\ln MAC_t$	4.2873	0.8045	14.7473	0.0006	51
$\ln UBP_t$	3.4591	0.1116	3.1708	0.2049	51
$\ln NR_t$	0.5334	0.5586	8.5411	0.0140	51

Besides discussing the estimates of Table 2, the presence of multicollinearity is tested by applying the variance inflation factor (VIF) matrix. This matrix shows that all the computed values for the determinants of crop production are not exceeding or equal to the threshold 10. This confirms that the explanatory variables of crop yield are having insignificant correlation between them. This highlights that multicollinearity is not relevant between the selected determinants of crop yield in this research. The estimates of the VIF matrix are reported as below in Table 3:

Table 3: VIF Matrix

Variables	$\ln FRC_t$	$\ln MAC_t$	$\ln UBP_t$	$\ln NR_t$
$\ln FRC_t$	-	1.3450	1.4103	1.5484
$\ln MAC_t$		-	7.5005	1.0836
$\ln UBP_t$			-	1.0425
$\ln NR_t$				-

Besides sharing insights upon the VIF analysis, the outcomes of the KPSS (1992) unit root test are reported in Table 4. The estimates of this test suggest that crop production, agriculture machinery and urban population have LM stats 2.5487, 1.1240 and 1.3556 respectively. All these are exceeding 0.739 which is 10% critical value of KPSS test. This confirms that all these three indicators fall in the critical region where we reject the null hypothesis of stationary series. Therefore, we conclude that these three indicators are non-stationary at level specification. Following these indicators, fertilizer consumption, its squared term, and natural resources rent report LM stats equal to 0.6244, 0.5300 and 0.2019 respectively. All these are less than the 10% critical value of KPSS test. This confirms that all these three indicators are stationary at level as these indicators fall in the acceptance zone of null hypothesis. The LM stats for all the selected variables confirms that these indicators are stationary at first difference. On the basis of these findings, we sum up the discussion that some indicators are stationary at level and some are at first difference. Therefore, the order of integration for the data series of this research is mixed. This provides motivation to apply Pesaran et al. (2001)'s approach of cointegration to obtain long run equilibrium link between crop yield and its determining factors. The findings of unit root test are reported in the below given Table 4 while the findings of Pesaran et al. (2001)'s approach are shared in Table 5:

Table 4: Unit Root

at Level			**at First Difference**		
Variables	**LM-Test**	**Conclusion**	**Variables**	**LM- Test**	**Conclusion**
$\ln CP_t$	2.5487	Non-Stationary	$\Delta \ln CP_t$	0.2273	Stationary
$\ln FRC_t$	0.6244	Stationary	$\Delta \ln FRC_t$	0.0296	Stationary
$\ln FRC_t^2$	0.5300	Stationary	$\Delta \ln FRC_t^2$	0.0308	Stationary
$\ln MAC_t$	1.1240	Non-Stationary	$\Delta \ln MAC_t$	0.6287	Stationary
$\ln UBP_t$	1.3556	Non-Stationary	$\Delta \ln UBP_t$	0.5451	Stationary
$\ln NR_t$	0.2019	Stationary	$\Delta \ln NR_t$	0.0830	Stationary

Note: The KPSS (1992) asymptotic critical values are 0.739 at 1%, 0.463 at 5% and 0.347 at 10% percent levels of significance.

Table 5: Cointegration Test

Estimated Models	$\ln CP_t = f(\ln FRC_t, \ln FRC_t^2, \ln MAC_t, \ln UBP_t, \ln NR_t)$
Optimal lags	(1 , 0 , 0 , 0, 0 , 0)
F – statistics	4.9205
DIAGNOSTIC TESTS	
Serial Correlation	0.2044 [0.647]
Functional Form	2.5363 [0.119]
Normality	1.2658 [0.531]
Heteroscedasticity	0.9857 [0.320]

Note: For F-Statistics; Lower Critical Bound is 2.9016 while Upper Critical Bound is 4.2277 at 5 percent significance level. Also the values within [] represents Probability Values.

The analysis extends to the discussion of cointegration results. Bounds test reports 4.9205 as value of F-test which is exceeding the 5% upper critical value which is 4.2277. This confirms that crop yield has long run equilibrium association with its determining factors like fertilizer consumption, its squared term, agriculture machinery, urban population and natural resource rent. The analysis also highlights that the error term has constant variance, it is not serially correlated, it is normally distributed and it is well specified. The insignificant probabilities of all these tests allow us to draw this conclusion. Besides shedding light upon cointegrating linkage, the long-run impacts of fertilizer consumption, its squared term, agriculture machinery, urban population and natural resource rent upon crop yield is going to be captured and shared in the Table 6. The long-run effects of the determinants of crop yield demonstrate that linear term of fertilizer consumption is significantly encouraging crop yield while its squared or non-linear term is significantly deteriorating it. This shows that fertilizer consumption poses an inverted U-shaped influence on crop yield. The magnitude suggests that by increasing 1% linear term of fertilizer usage significantly stimulates crop yield by 4.5398 percent while due to 1% expansion in squared term of fertilizer usage, crop yield significantly declines 0.4583 percent. As fertilizer an important input to crop yield but if it is excessively utilized beyond a threshold then it will reveal its adverse impact on crop yield. These findings are shared in the below provided Table 6:

Table 6: Long Run Coefficients

Dependent Variable: $\ln CP_t$

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
$\ln FRC_t$	4.5398	2.0403	2.2251	0.031
$\ln FRC_t^2$	-0.4583	0.2013	-2.2761	0.028
$\ln MAC_t$	0.7479	0.2829	2.6433	0.011
$\ln UBP_t$	0.3038	0.0204	14.8701	0.000
$\ln NR_t$	0.3964	0.1830	2.1670	0.036
C	-17.9084	5.3151	-3.3694	0.002

The analysis also highlights the encouraging effects of agriculture machinery, urban population and natural resources rent on crop yield. Due to one percent increase into these indicators, crop yield significantly accelerates by 0.7479%, 0.3038% and 0.3964% respectively. These three indicators also play their imperative roles to escalate crop yield. Adapting modern technology in the agriculture sector is important because the results are supporting its positive effects. Moreover, the surplus labor force is required to transfer to the cities, it will reduce the burden of agriculture sector and helps in reaping positive effects. Investments in natural resources can boost the earnings from natural resources, which may help in expanding crop yield. Out of these three highlighted indicators, we may witness agriculture machinery which is appearing as the most impactful indicator to enhance crop yield. Additionally, the study demonstrates the short run effects of fertilizer consumption, its squared term, agriculture machinery, urban population and natural resource rents on crop yield. The results are reported in Table 7 which is provided as under:

Table 7: Short Run Coefficients

Dependent Variable: $\Delta \ln CP_t$

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
$\Delta \ln FRC_t$	3.7729	1.8309	2.0607	0.045
$\Delta \ln FRC_t^2$	-0.3809	0.1811	-2.1032	0.041
$\Delta \ln MAC_t$	0.6216	0.2353	2.6417	0.011
$\Delta \ln UBP_t$	0.2524	0.0468	5.3941	0.000
$\Delta \ln NR_t$	0.3295	0.1557	2.1166	0.040
ECM_{t-1}	-0.8311	0.1301	-6.3878	0.0000
Diagnostics				
Adjusted R-Square			0.4389	
F-Stats [P. Value]			7.3892 [0.000]	
DW-statistic			2.0048	
Akaike Info. Criterion			84.7031	
Schwarz Bayesian Criterion			78.0110	

The results reveal that use of fertilizer beyond a certain threshold value is not encouraging for crop yield. The linear term is escalating crop yield while its squared term is reducing crop yield. Unlike long run, the effect of use of fertilizer remains U-shaped on crop yield. As agriculture machinery appears as the most prominent input as compared with urban population and natural resource rent in long run, the results support this finding even in the short run span as well. Due to one percent increase in agriculture machinery, urban population and natural resources rent, crop yield will significantly follow an upward trend by 0.6216%, 0.2524% and 0.3295% respectively. The results also reveal that the coefficient of speed of adjustment is -0.8311 and it is significant as well. This confirms the convergence hypothesis which states if long run equilibrium instable in response to any external or internal shock then the present proposed model has the strength to retrieve long run and stable equilibrium again with the 83.11% speed of adjustment each year. The instability will be corrected in about 1.2032 years or in about 14.44 months.

The results further provide insights about the structural stability of the estimated coefficients for the selected sample by considering two graphs like CUSUM and CUSUM Squares plots. These plots are used to assess whether mean and variance of error term remains stable over time or not. As the graphs disclose that mean and variance of residual term are found to be inside their corresponding critical ranges. Therefore, mean and variance of error term are stable during the selected time span. This provides confirmation of stability of long and short run effects of the determinants of crop yield on crop yield. The stability graphs are shared as under:

Figure 1: CUSUM Graphs

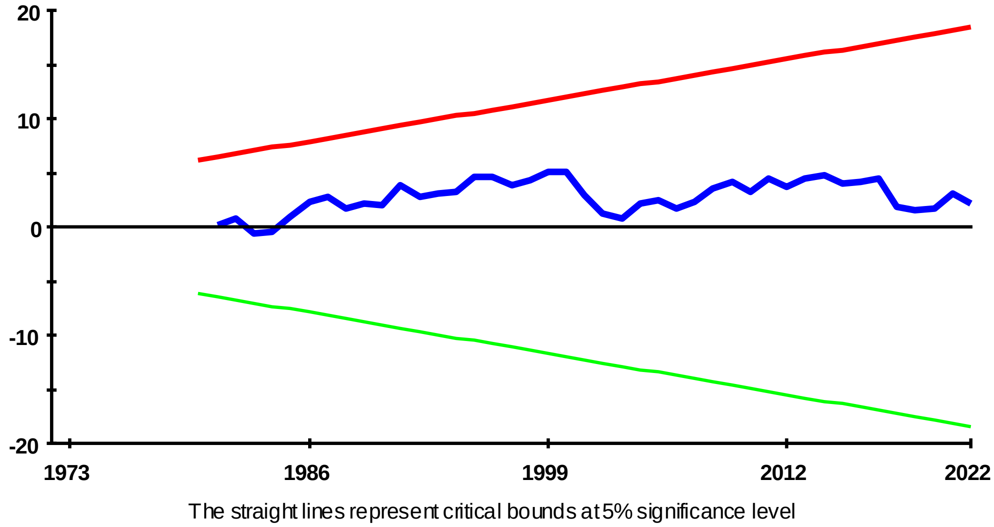
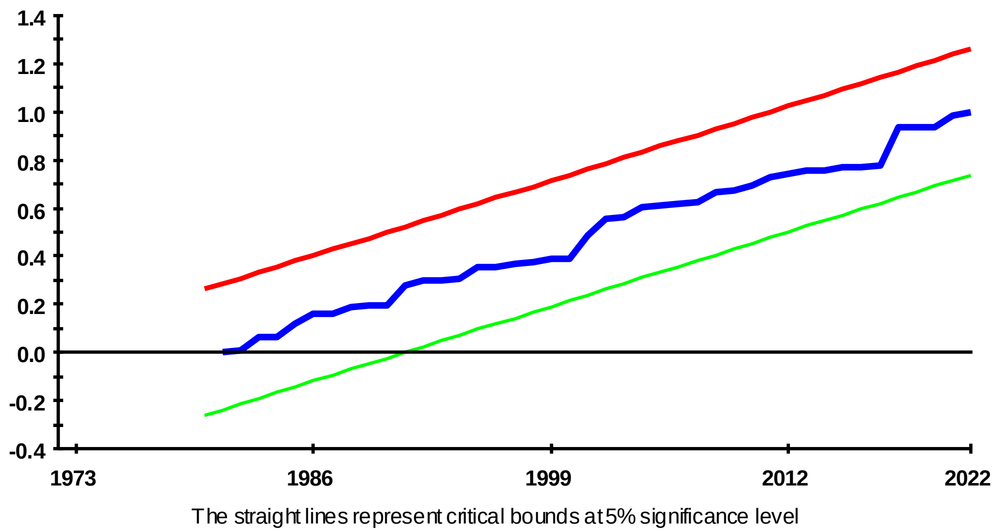


Figure 2: CUSUM Square Graphs



Conclusion

This study examines the effects of fertilizer consumption, its squared term, agriculture machinery, urban population share and rents from natural resources on crop yield in Pakistan. To obtain empirical results, this research covers annual data series from 1972 to 2022, applies ARDL bounds test and confirms presence of long run equilibrium between crop yield and its determining indicators. Empirical result suggests that fertilizer usage initially expand crop yield but beyond a certain threshold it is declining it. Fertilizer usage is forming an inverted U-shaped

impact on crop yield. The findings further uncover that adapting technological equipment and expanding investments on natural resources during cultivation is helpful in boosting yield of the cropping sector while transforming surplus supply of labor from rural to urban sector is also stimulating crop yield. Among the three indicators like agriculture machinery, urban population and natural resources, this study confirms that agriculture machinery is most important input to expand crop yield.
On the basis of these results, this research suggests that farmers should be given more awareness on soil structure and soil health so that he may rationally apply both organic and inorganic fertilizers in a way that it may improve crop yield. The farmers should not go beyond a certain threshold point where fertilizers start harming crop production. It is further suggested that more subsidized and more advanced technology with hands on practice are made accessible to farmers for cultivation. This will bring further extension in crop yield. Moreover, it is proposed that more investments should be encouraged in natural resources so that more rents are earned. These rents may further be allocated to farmers transparently and on merit basis for R & D activities and for farmer training purposes. This will make farmer more skillful and it will translate in expansion in cultivation. Lastly, surplus workforce from agriculture sector should be transferred to cities or industrial sector so that burden on agriculture sector may come down which will reduce cost of production and improve profit margins. The increased profits will further be reinvested and help in escalating agriculture productivity in the country.

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