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Optimizing Agricultural Inputs and Cropped Area Dynamics: A Decade-Long Analysis in Pakistan

Iqra Nazeer
[1]*University of Education, Lahore
*** Email**: nazeer.iqra64@gmail.com

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This study presents an analysis of agricultural inputs and cropped area dynamics in Pakistan from 2012 to 2022, aiming to understand the relationships between key agricultural parameters. The analysis considers factors such as total cropped area, fertilizer offtake, import of fertilizers, and import of insecticides, utilizing data collected from reliable sources including the National Fertilizer Development Centre and the Pakistan Bureau of Statistics. Descriptive statistics, correlation analysis, and the coefficient of determination were employed to explore these relationships and their implications for agricultural productivity and sustainability. The findings reveal notable fluctuations in total cropped area, fertilizer offtake, and imports of fertilizers and insecticides over the study period. While correlations between cropped area and fertilizer offtake, as well as the import of insecticides, were modest, a negative correlation was observed between cropped area and fertilizer imports. These findings suggest nuanced interactions influenced by various factors beyond fertilizer usage alone, such as soil fertility, climate conditions, and economic considerations. The study underscores the importance of promoting balanced and sustainable agricultural practices, including judicious fertilizer use and integrated pest management strategies, to enhance crop yields, soil fertility, and environmental sustainability. Furthermore, it highlights the need for policymakers, researchers, and agricultural stakeholders to adopt holistic approaches that integrate various parameters to devise effective strategies for enhancing agricultural productivity, sustainability, and resilience in Pakistan. In conclusion, this analysis provides valuable insights into agricultural dynamics in Pakistan and offers recommendations for future research directions and interventions to address systemic challenges and ensure food security and environmental stewardship in the face of a changing world.

Keywords: National Fertilizer Development Centre, Cropped Area, Fertilizer Offtake, And Imports of Fertilizers Cropped Area, Imports of Fertilizers.

Introduction:

Enhancing resource productivity and optimizing the utilization of agricultural inputs are pivotal factors in advancing agriculture within developing nations. Amidst challenges such as population growth, urbanization, and industrial expansion, the availability of cultivable land and water resources in Pakistan is under significant strain due to non-agricultural uses. Consequently, there is a decline in the per capita availability of arable land and irrigation water, while the demand for food and industrial raw materials continues to escalate [1]. This trend is further compounded by soaring prices of agricultural inputs like fertilizers, pesticides, machinery, and fuel, contributing to elevated production costs and consumer dissatisfaction over escalating food prices [2]. Moreover, Pakistan is grappling with climatic changes, including rising temperatures, erratic rainfall patterns, and intensified flooding, which pose additional challenges for farmers and stakeholders involved in agricultural development and food production [3].

The recent shortfall in wheat production, juxtaposed with the burgeoning population's domestic needs, has led to price spikes and strained foreign exchange reserves due to increased imports. Rice exports have traditionally served as a significant source of foreign exchange earnings, amounting to approximately $2 billion annually [4]. The expansion of maize production has bolstered the poultry, livestock, and edible oil industries, contributing significantly to the country's trade balance. Enhancing the production of these crops, particularly through vertical integration and efficiency enhancements, can positively impact the trade balance by substituting imports and boosting exports [5] [6].

Given this context, it becomes imperative to enhance the productivity of agricultural resources and optimize input efficiency. The cultivation area for these key crops, covering an estimated 14 million hectares, represents around 55%-60% of Pakistan's total cropped area, with their annual production contributing 98% to the total food grain output in the country. Therefore, the production and productivity of these crops are vital for ensuring food security, managing food inflation and influencing Pakistan's trade balance. Punjab's significant contribution to the annual food grain production, exceeding 73% based on available data, underscores its pivotal role as the country's primary food grain hub [1] [7].

Soil fertility, defined as the soil's ability to naturally supply plants with adequate nutrients in proper proportions, relies on essential elements such as C, H, O, N, P, K, S, Ca, Mg, Na, Cl, Si, Mo, Zn, B, Fe, Mn, and Co. However, in regions extensively utilized for agriculture over the past two decades, soil fertility loss has emerged as a significant concern [8] [9]. This loss is attributed to increased specialization, concentration, and intensification of crop and livestock production without due consideration of site-specific soil and climate conditions, leading to notable soil degradation and irreversible damage, including compaction, erosion, waterlogging, chemical degradation, and humus loss [10] [11]. In Pakistan, the absence of soil erosion prevention machinery and inadequate post-harvest soil energy replenishment exacerbate soil fertility deterioration. Despite Pakistan's fertile layer being over 6 inches deep, compared to other countries with a 4-inch-thick layer, the average output remains lower. Experts attribute insufficient crop production mainly to low soil fertility and ineffective soil fertility management practices [12]. According to soil specialists, the majority of Pakistani soils lack essential plant nutrients, hindering optimal crop yield. Phosphorus, potassium, and nitrogen are identified as primary nutrients crucial for plant growth, while organic matter, copper, iron, zinc, and boron are required in minimal amounts [13].

At the core of crop agriculture lies the genetic makeup of planting material, crucial for the cultivation of staple crops like maize, rice, wheat, and beans, typically distributed in seed form. Openly pollinated varieties (OPVs) offer seeds that can be saved and replanted, unlike hybrids, which respond more favorably to inputs like fertilizer, leading to higher yields under suitable conditions but necessitating the purchase of new seeds each season to maintain their initial vigor [14]. Conversely, crops such as cassava, banana, potato, and sugarcane rely on vegetative propagation, where farmers use cuttings from mature plants rather than seeds, ensuring genetic consistency across generations as each new plant is a clone of its parent. While this method guarantees the preservation of desired genetic traits, it limits genetic diversity within the population, potentially reducing resilience to new pests or diseases [15].

These differing propagation methods significantly impact adoption and diffusion, particularly among small-scale farmers who often rely on informal sources for planting material. Seeds, if stored properly, can retain viability for extended periods, making them easier to transport and store compared to cuttings, which typically deteriorate more rapidly. Additionally, while cuttings facilitate the preservation and sharing of desired genetics, they can also render production systems vulnerable to new diseases due to limited genetic diversification [16] [17]. Consequently, seed supply chains tend to be more developed and expansive, spanning vast regions, whereas cuttings are usually sourced locally, exchanged informally, and attract less

attention from the private sector. Although small-scale farmers may obtain both seeds and cuttings through informal channels, there's a growing trend towards purchasing branded seeds from established retailers, contrasting with the rare commercialization of cuttings [18] [19].

Unlike fertilizers and pesticides, planting material is a living entity with the potential for evolutionary change over time, introducing complexity to agricultural systems. While synthetic fertilizers differ starkly from organic alternatives like manure, improvements in planting material are often subtle and continuous [20] [21]. Farmers historically acted as informal breeders, selecting and saving seeds based on desired traits, but modern breeding techniques have led to more dramatic genetic enhancements. These improved strains and varieties, compared to traditional landraces, are developed with specific agroecological contexts in mind, reflecting the spatial heterogeneity of growing conditions and emphasizing the importance of quality planting material as a critical input in agriculture [22] [23].

Objective:

This study aimed to analyze the relationships between key agricultural parameters total cropped area, fertilizer offtake, import of fertilizers, and import of insecticides over an eleven-year period (2012-2022) in Pakistan.

Methodology:

Data Collection:

Data spanning eleven years (2012-2022) was gathered from reliable sources such as the National Fertilizer Development Centre, Pakistan Bureau of Statistics, and other relevant agricultural databases. The dataset included information on total cropped area, fertilizer offtake, import of fertilizers, and import of insecticides.

Data Preprocessing:

The collected data was cleaned to remove inconsistencies, missing values, or outliers that could skew the analysis results. Appropriate data-cleaning techniques were employed to ensure the accuracy and reliability of the dataset.

Descriptive Statistics:

Descriptive statistics for each variable (total cropped area, fertilizer offtake, import of fertilizers, import of insecticides) over the eleven-year period. These statistics provided insights into the central tendency, variability, and distribution of the data.

Correlation Analysis:

Correlation analysis was conducted to examine the relationships between different agricultural parameters. Correlation coefficients (such as Pearson's correlation coefficient) were calculated to quantify the strength and direction of the relationships. The focus was on analyzing the correlations between total cropped area and fertilizer offtake, import of fertilizers, and import of insecticides.

Coefficient of Determination (R^2):

The coefficient of determination (R^2) was calculated for each relationship of interest. R^2 indicated the proportion of variability in one variable that could be explained by changes in another variable. The R^2 values were interpreted to assess the strength and significance of the relationships.

Visualization:

Visualizations such as line graphs, scatter plots, and bar charts were created to visualize the trends and patterns in the data. Visual representations enhanced understanding and facilitated communication of the findings. The findings of the analysis were interpreted, discussing the observed relationships between agricultural parameters. The implications of these relationships for agricultural productivity, sustainability, and policy-making were explored. Contextual factors that may have influenced the observed patterns were considered, along with potential implications for future research and practice.

Results and Discussion:

This scrutiny presents data spanning eleven years, from 2012 to 2022, detailing various agricultural parameters. The total cropped area, measured in million hectares, fluctuates moderately over the years, with a peak of 24.10 million hectares recorded in 2020. Fertilizer offtake, representing the quantity of fertilizer utilized in agriculture (measured in thousands of metric tons), shows variability throughout the period, reaching its highest point in 2017 at 5,040,000 metric tons. In contrast, the lowest offtake occurred in 2013, totaling 3,621,000 metric tons. Similarly, the import of fertilizer (also measured in thousands of metric tons) displays fluctuations, peaking in 2018 at 1,191,000 metric tons and dipping to 735,000 metric tons in 2013. Import of insecticides, measured in tons, exhibits less variability compared to fertilizer, with the highest import recorded in 2021 at 37,441 tons and the lowest in 2013 at 17,882 tons. Figure 1 provides insights into the changing trends and dynamics of agricultural inputs over the specified timeframe.

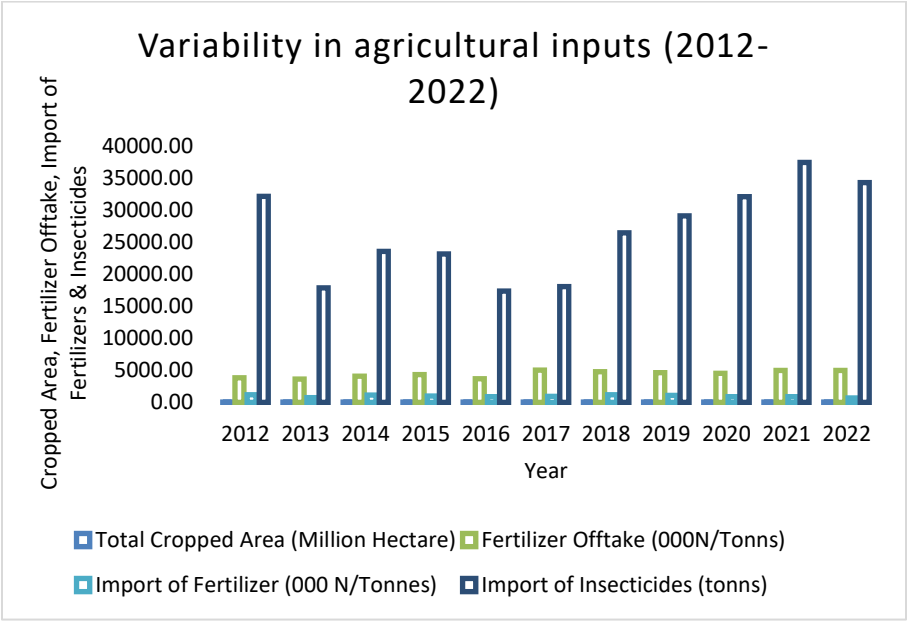


Figure 1: Agricultural Inputs Varying from the Year 2012 to 2022.

Farmers purchase fertilizers as inputs to provide nutrition to plants or alter soil properties. When examining a fertilizer bag, the most prominent feature, aside from the brand name, is a set of three numbers. These numbers indicate the ratio of the three primary macronutrients: nitrogen (N), phosphorus (P), and potassium (K), represented as N-P-K. For instance, the formula 18:46:0 corresponds to Di-Ammonium Phosphate (DAP), a commonly used fertilizer in Pakistan. This formulation signifies that it contains 18% nitrogen (N), 46% phosphorus (P), and 0% potassium (K), measured by the composition of the forms that plants can absorb: phosphorous pentoxide (P_2O_5) for phosphorus and potassium oxide (K_2O) for potassium.

In Pakistan, farmers predominantly utilize Urea (46:0:0) and DAP (18:46:0) fertilizers. However, there is a widespread tendency to under-apply potassium (K) fertilizers, resulting in crop yields significantly below their potential. The primary nutrients in fertilizers are nitrogen (N), phosphorus (P), and potassium (K), often referred to as NPK fertilizers. These nutrients play critical roles in plant growth and development. Nitrogen is essential for leaf and stem growth, phosphorus is vital for root development and flower formation, and potassium helps in overall plant health and disease resistance. In addition to these primary nutrients, fertilizers may also contain secondary nutrients like calcium, magnesium, and sulfur, as well as micronutrients

such as iron, zinc, and manganese, which are required in smaller quantities but are equally important for plant growth.

Insecticides are chemicals or biological agents used to control or eliminate insect pests that damage crops and reduce yields. They target various stages of the insect's life cycle, including eggs, larvae, pupae, and adults, and can be applied to crops through spraying, dusting, or seed treatment. Insecticides work by disrupting the insect's nervous system, interfering with its ability to feed, breed, or reproduce, or by physically suffocating or repelling the insects. There are different types of insecticides, including organophosphates, carbamates, pyrethroids, neonicotinoids, and biological insecticides derived from natural sources such as plants, bacteria, or fungi. The choice of insecticide depends on factors such as the type of pest, the crop being grown, environmental considerations, and regulatory requirements. While insecticides are essential tools for pest management in agriculture, their use should be carefully managed to minimize adverse effects on non-target organisms, human health, and the environment. Integrated pest management (IPM) approaches that combine various pest control strategies, including cultural, biological, and chemical methods, are often recommended for sustainable pest management practices.

Fertilizer offtake refers to the quantity of fertilizer that is withdrawn or taken from storage for use in agricultural activities within a specific period, typically measured in thousands of metric tonnes (N/Tonns). It is a crucial indicator of the demand for fertilizers in the agricultural sector and reflects the amount of nutrients being applied to crops to enhance their growth and productivity. Higher fertilizer offtake often indicates increased agricultural activity and a greater need for nutrients to support crop growth. Import of fertilizers refers to the quantity of fertilizers that are brought into a country from foreign sources within a specified time frame, typically measured in thousands of metric tonnes (N/Tonnes). Countries may import fertilizers to supplement domestic production or to meet specific nutrient requirements for different crops. The import of fertilizers is influenced by factors such as domestic production capacity, agricultural demand, trade agreements, and international market prices. Fluctuations in the import of fertilizers can impact domestic fertilizer availability, agricultural productivity, and food security.

Import of insecticides refers to the quantity of insecticides that are imported into a country from foreign sources within a given period, usually measured in metric tonnes. Insecticides are chemicals used to control or eliminate insect pests that can damage crops and reduce yields. The import of insecticides is influenced by factors such as pest outbreaks, crop planting patterns, pest resistance, regulatory policies, and availability of alternative pest management strategies. Changes in the import of insecticides can affect pest control efforts, crop protection, and ultimately agricultural productivity.

Table 1: Fertilizer Distribution in Farms (Thousand Tonnes)

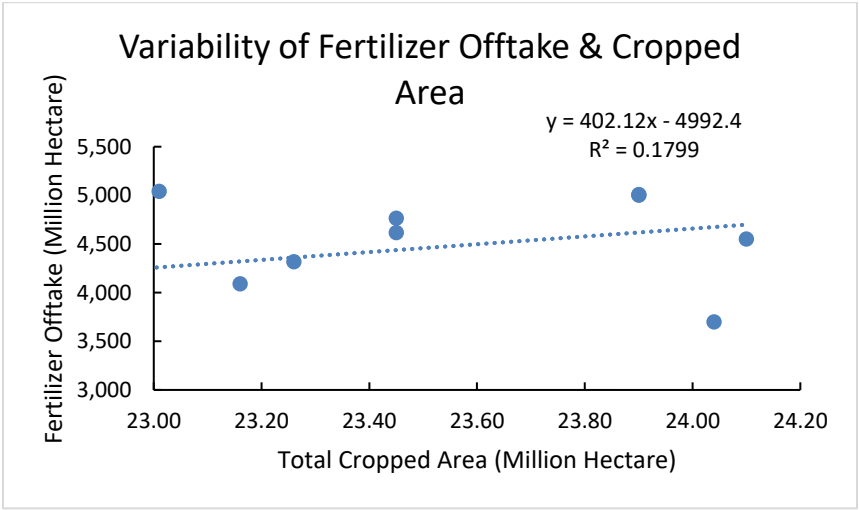
Farm Inputs	Fertilizer	Urea (thousand tonnes)	DAP (thousand tonnes)
Opening Inventory	-	200	276
Domestic Production	-	3,158	451
Imported Supply	-	103	185
Total Availability	-	3,461	912
Offtake	-	3,137	490
Closing Inventory	-	294	460
Opening Inventory	294	-	460
Domestic Production	2,928	-	226
Imported Supply	298	-	302
Total Availability	3,520	-	988

Offtake	3,470	-	702
Closing Inventory	67	-	284

Source: Pakistan Beau rue of Statistics.

Variability of Cropped Area and Fertilizer Offtake:

The relationship between fertilizer offtake and cropped area is a critical aspect of agricultural dynamics, offering insights into resource utilization and productivity. The coefficient of determination, represented by the R^2 value of 0.1799, signifies a modest association between these variables as indicated in figure 2. This suggests that approximately 17.99% of the variability in cropped areas can be explained by changes in fertilizer intake. While fertilizer usage undoubtedly influences cropped areas, it's evident that other factors play significant roles in shaping agricultural outcomes. These factors might include climatic conditions, soil fertility, technological advancements, market forces, and governmental policies. Therefore, while fertilizer offtake serves as an essential indicator of agricultural input usage and potential yield enhancement, its impact is moderated by a multitude of contextual variables. Consequently, a comprehensive understanding of agricultural systems requires considering a broader spectrum of factors beyond fertilizer offtake alone. Policymakers, researchers, and agricultural stakeholders must adopt holistic approaches, integrating various parameters to devise effective strategies for enhancing agricultural productivity, sustainability, and resilience. By acknowledging the complex interplay of factors influencing agricultural outcomes, stakeholders can work towards fostering resilient and sustainable agricultural systems that meet the challenges of a changing world.



Variability of Cropped Area and Import of Fertilizer:

The interplay between fertilizer imports and cropped areas is a pivotal aspect of agricultural productivity and sustainability. Understanding the dynamics of this relationship is crucial for policymakers, agricultural experts, and stakeholders aiming to optimize agricultural practices. In this analysis, we delve into the correlation between fertilizer imports and cropped areas, shedding light on the intricate balance that drives agricultural production. The relationship between fertilizer imports and cropped areas is often regarded as a cornerstone of modern agricultural practices. By supplying essential nutrients to crops, fertilizers play a vital role in enhancing yields and ensuring food security. However, the extent to which fertilizer imports influence cropped areas can vary significantly based on several factors, including soil fertility, climate conditions, and economic considerations.

A statistical analysis of the relationship between fertilizer imports and cropped area reveals a correlation coefficient (R^2) of 0.0966 as shown in figure 3. While this value suggests a negative correlation, it is essential to explore the underlying factors contributing to this relationship.

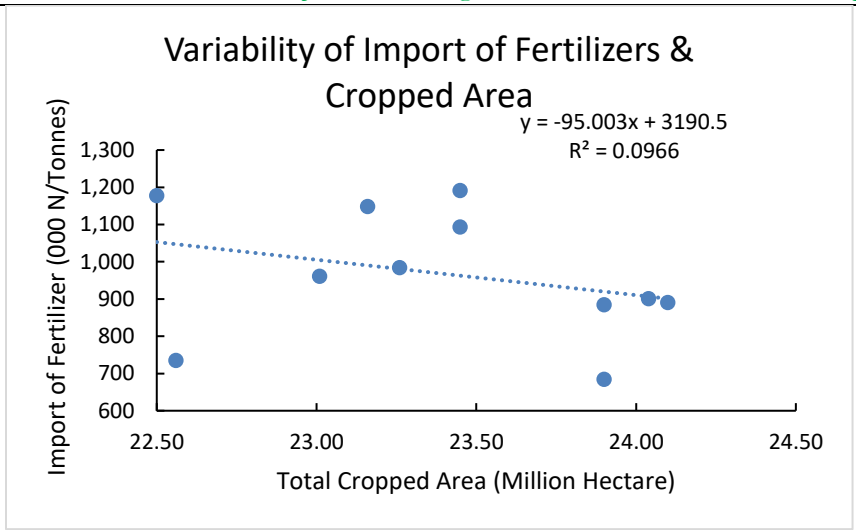


Figure 3: Variability of Import of Fertilizers and Cropped Area.

Variability of Cropped Area and Import of Insecticides:

The relationship between the import of insecticides and cropped areas is a topic of significant interest, particularly in agricultural economics and environmental studies. The coefficient of determination, represented by $R^2 = 0.1283$, indicates the proportion of variability in the import of insecticides that can be explained by changes in cropped area as indicated in figure 4. At $R^2 = 0.1283$, it suggests that approximately 12.83% of the variability in the import of insecticides can be attributed to changes in cropped area. While this percentage may seem relatively low, it still signifies a discernible relationship between these two variables.

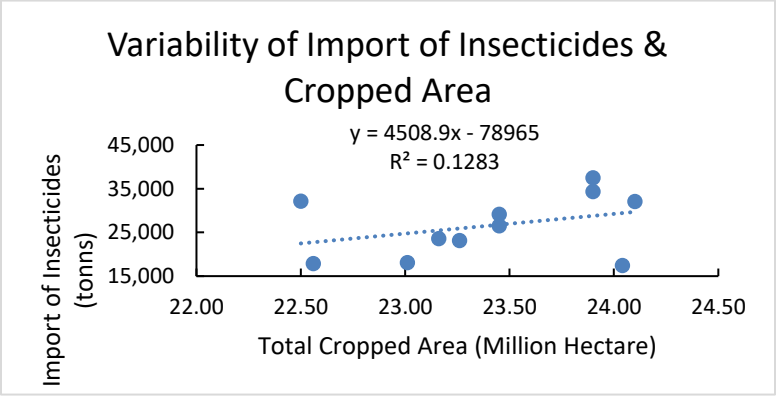


Figure 4: Variability of Import of Insecticides and Cropped Area.

Discussion:

The analysis of agricultural inputs and cropped area dynamics from 2012 to 2022 in Pakistan reveals significant insights into the interplay between various parameters influencing agricultural productivity and sustainability. This analysis reveals notable fluctuations in total cropped area, fertilizer offtake, and imports of fertilizers and insecticides over the eleven-year period. These fluctuations underscore the dynamic nature of agricultural practices influenced by various factors such as market conditions, technological advancements, and policy decisions. Secondly, correlation analysis indicates modest associations between cropped area and fertilizer offtake and import of insecticides, while a negative correlation is observed between cropped area and fertilizer imports. This suggests that while fertilizer usage and pest control efforts may impact cropped areas to some extent, other factors play significant roles in shaping agricultural outcomes. Moreover, the findings emphasize the importance of promoting balanced and sustainable agricultural practices. Encouraging judicious fertilizer use, including potassium fertilizers often under-applied by farmers, can enhance crop yields and soil fertility while

mitigating environmental risks. Similarly, implementing integrated pest management strategies can reduce reliance on chemical insecticides and minimize environmental impact.

The correlation analysis highlighted modest associations between total cropped area and fertilizer offtake, as well as the import of insecticides. However, the relationship between cropped area and fertilizer imports showed a negative correlation, suggesting complex dynamics influenced by multiple factors beyond fertilizer usage alone. The coefficient of determination (R^2) provided further insights, indicating that a proportion of variability in the import of insecticides can be attributed to changes in cropped area, albeit relatively low.

Importantly, the study underscores the importance of considering contextual factors such as soil fertility, climate conditions, technological advancements, and governmental policies in shaping agricultural outcomes. While fertilizer offtake serves as a critical indicator of agricultural input usage, its impact is moderated by a multitude of factors.

In Pakistan, the Mouza Census of 2020 conducted by the Pakistan Bureau of Statistics reveals that out of 44,406 rural populated Mouzas, only 4,204 have a seed shop within their boundaries, accounting for a mere 9% of the total. The average distance to these seed shops in rural areas amounts to a considerable 23 kilometers, a significant figure considering the socio-economic circumstances of the rural populace.

Furthermore, a substantial portion of Mouzas, specifically 21,112, need to travel distances ranging from 1 to 10 kilometers to access a seed shop, constituting 48% of all Mouzas. Additionally, 23% of Mouzas are situated 11 to 25 kilometers away, while 10% and 9% lie at distances of 26 to 50 kilometers and more than 51 kilometers from seed shops, respectively. In numerical terms, this translates to 10,371 Mouzas at distances of 11 to 25 kilometers, 4,507 Mouzas at distances of 26 to 50 kilometers, and 4,212 Mouzas located beyond 51 kilometers from seed shops [24].

It is noteworthy that shops selling seeds also offer fertilizers, herbicides, and other agricultural inputs. Consequently, access in terms of distances to Mouzas is not significantly different when compared to accessing fertilizer or pesticide shops. In Pakistan, 11% of Mouzas have fertilizer shops within their boundaries, while 48% are situated 1 to 10 kilometers away, 22% are located 11 to 25 kilometers away, and 10% and 9% are positioned 26 to 50 kilometers and more than 51 kilometers away from fertilizer shops, respectively. The average distance required to access a fertilizer shop is 22 kilometers. The statistics for pesticide shops mirror those of seed shops, with only a marginal difference of ±1% [25] [26].

Moving forward, it is imperative for policymakers, researchers, and agricultural stakeholders to adopt holistic approaches that integrate various parameters to devise effective strategies for enhancing agricultural productivity, sustainability, and resilience. This includes promoting balanced fertilizer usage, implementing integrated pest management practices, and addressing systemic challenges such as the under-application of potassium fertilizers. By acknowledging the complexity of agricultural systems and leveraging data-driven insights, stakeholders can work towards fostering resilient and sustainable agricultural practices that meet the challenges of a changing world while ensuring food security and environmental stewardship.

Conclusion

The analysis of agricultural inputs and cropped area dynamics in Pakistan from 2012 to 2022 reveals notable trends and associations. Fluctuations in total cropped area, fertilizer offtake, and imports of fertilizers and insecticides were observed. While correlations between cropped area and fertilizer offtake and import of insecticides were modest, a negative correlation was noted between cropped area and fertilizer imports. This suggests nuanced interactions influenced by various factors beyond fertilizer usage alone.

Limitations and Recommendations: Any limitations of the study, such as data constraints or methodological assumptions, were acknowledged. Recommendations for future research directions or interventions were provided based on the study findings.

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