Virtual Nutrients Trade in Selected Agricultural Commodities of Pakistan

Sidra Majeed (Corresponding Author)
Senior Scientific Officer, Social Science Research Institute, National Agriculture Research Center, Park Road Islamabad
Email: sidramajeed72@gmail.com
Dr. Nadeem Akmal
Principal Scientific Officer, Social Science Research Institute, National Agriculture Research Center, Park Road, Islamabad
Email: nadeemakmal@gmail.com
Dr. Muhammad Azam Niazi
Principal Scientific Officer, Social Science Research Institute, National Agriculture Research Center, Park Road Islamabad
Email: mazamniazi@gmail.com

Abstract
Virtual nutrient trade refers to the transmission of nutrients across regions or countries through the trade of agricultural products. When a region imports food, it also imports the nutrients embedded in that food, affecting local nutrient cycles and agricultural practices. This nutrient flow can have significant implications for sustainability and food security, with potential benefits for nutrient-deficient regions but risks of nutrient depletion in exporting areas. This study estimates the amounts of Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Sulfur (S), and Gypsum embodied in selected agricultural commodities i.e. wheat, rice, maize, cotton, and sugarcane across the provinces of Pakistan. By analyzing production and consumption data for the 2021-22 period, the study calculates the net virtual nutrient flows between provinces. Regions with a negative balance are identified as net importers of nutrients, while those with a positive balance are net exporters. Results indicate that Punjab is a major nutrient-exporting province, particularly for rice, while Khyber Pakhtunkhwa and Baluchistan are primarily net importers of virtual nutrients. The study recommends promoting sustainable agricultural practices in nutrient-deficient regions to enhance local nutrient availability and reduce dependence on imports.
Keywords: Virtual Nutrient flow, Agricultural commodities, Major crops, economic dependency, importing region, exporting region

Introduction

Nutrient flow refers to the movement of essential nutrients from one location to another, influenced by various operational and management strategies. On farms, nutrients can flow in multiple directions entering,

leaving, or circulating within the farm system. The importance of these flows varies, with direction of nutrient flows being more critical for the regions (Ragan and Massey, 2019).

Research shows that the growing disparity between urban and rural populations, combined with global trade in agricultural products, has led to an imbalance in nutrient distribution. Nutrients tend to accumulate in urban centers where food is consumed, while rural farming areas experience nutrient depletion (Cordell et al., 2009; Manning, 2015; Razon, 2018). This linear nutrient flow creates challenges on both the supply and demand sides, necessitating the continued production of synthetic fertilizers to maintain agricultural output and ensure nutrient security.

Chen et al. (2023) introduced the concept of "virtual nutrients," referring to nutrients embedded in traded agricultural goods. In trade networks, nutrients move from regions with higher nutrient-use efficiency to those with lower efficiency, resulting in a "nutrient-saving" effect. Efficient trade flows conserve nutrient resources, whereas inefficient flows lead to nutrient loss.

Nutrient flow studies have been conducted across various scales, from farms and cities to entire ecosystems and global systems (Chowdhury et al., 2014; Jedelhauser and Binder, 2015). These studies use different approaches, such as territorial analysis, which focuses on nutrient movement within and beyond a specific area's borders, or footprint analysis, which assesses nutrient circularity based on local demand and supply.

Global agricultural trade has significantly altered nutrient cycles, with trade playing a major role in the movement of key nutrients like nitrogen (N) and phosphorus (P). Studies have highlighted how these nutrients flow through international agricultural product trade. For example, research shows that phosphorus flows in global trade have surged by 750% between 1961 and 2011 (Nesme et al., 2018).

Mahjabin et al. (2021) examined virtual nitrogen (N) flows in the U.S. food trade network, focusing on nitrogen embedded in cereal grains, agricultural products, and meat/seafood traded among states in 2012. The study revealed that approximately 8.2 trillion grams of virtual nitrogen moved through U.S. food trade, with a national average footprint of 25 kg N per capita per year. Meat and seafood had particularly high nitrogen footprints. Major net importers of virtual nutrient trade were more populous states like Texas and California, while key agricultural states like Nebraska, Kansas, and Iowa were primary exporters. Significant nitrogen flows were noted between Kansas and Texas for grains and between Louisiana and Mississippi for fruits and vegetables. The study highlighted the environmental impact of nitrogen trade flows but focused only on nitrogen embedded in food trade.

Drechsel et al. (2007) examined the movement of virtual nutrients embedded in food, in several West African cities. Study focused on the flow

of food through traditional marketing channels, the consumption patterns in urban areas, and the resulting urban virtual nutrient footprints. The study highlighted significant nutrient transfers from rural areas to urban centers, particularly in staple crops like cassava, yam, cocoyam, plantain, maize, sorghum, millet, and rice, which caused nutrient depletion in rural regions and nutrient accumulation in cities. For Kumasi, the annual inflow of nitrogen (9,810 tons) and phosphorus (1,400 tons) through food and forestry products. This rural-urban nutrient flow had an economic value of approximately $10 million per year. However, the study did not consider analyzing other essential nutrients such as potassium (K), calcium (Ca).

Xiuzhi (2023) analyzed global flows of nitrogen (N) and phosphorus (P) in agricultural trade networks from 1997 to 2016, quantifying nutrient exchanges across 320 products in 221 countries and categorizing them into eight groups, including cereals, beans, fruits, and animal products. In 2016, beef and processed cow products accounted for 12.4% of virtual N and 16.8% of virtual P flows, mainly due to high nutrient inputs for feed. The U.S.-China soybean trade emerged as the largest physical nitrogen exchange, highlighting the significance of staple crops in nutrient redistribution. The study found that just 10% of countries were responsible for 90% of nutrient exports, with Africa importing 0.37 teragrams of virtual P, which increased reliance on imported nutrients while adding environmental burdens like nitrogen contamination in exporting regions (e.g., U.S. poultry exports to Japan). Notably, some products, like lentils and coconuts, had virtual nutrient flows up to 100 times higher than their physical counterparts. The study does not address nutrients beyond N and P or consider environmental impacts such as soil degradation, nor does it examine how policy changes might influence nutrient flows over time.

Mungcharoen and Suwanmanee (2021) assessed virtual nitrogen factors (VNFs) and nitrogen footprints (NFs) for eight primary food categories in Thailand rice, vegetables, fruits, chicken, pork, beef, milk, and eggs considering both domestic consumption and international trade. Using a nitrogen flow model, they analyzed nitrogen inputs (e.g., fertilizers, animal feed) and outputs (e.g., emissions, wastewater). The findings indicated an annual per capita nitrogen footprint of 19.07–19.33 kg N, with food consumption making up the largest share (11.08–11.35 kg N). Key contributors to the nitrogen footprint were rice (34.97–35.26%) and poultry (32.65–33.13%), with rice particularly high due to high domestic consumption and trade. The study highlights opportunities to broaden the scope by including other nutrients (like phosphorus and potassium) and to examine regional variations in nitrogen management.

Matsubae and Kajiyama (2011) estimated Japan's virtual phosphorus ore requirements by analyzing phosphorus flows across sectors like agriculture, chemical manufacturing, and animal production, which were identified as the largest phosphorus consumers. The study found that Japan’s

phosphorus ore demand was twice what was needed solely for fertilizer, with only 12% of the VPOR tied to agricultural products, highlighting a substantial reliance on phosphorus for industrial use.

Nesme et al. (2018) examined global phosphorus (P) flows in agricultural trade from 1961 to 2011 by calculating the phosphorus content in 397 traded agricultural products listed in FAOSTAT. They categorized these products into eight groups, including cereals, soybeans, pulses, fruits, and animal products. The study found an almost eightfold increase in phosphorus trade flows, from 0.4 teragrams (Tg) in 1961 to 3.0 Tg in 2011. This rise boosted the proportion of exported phosphorus absorbed by crops from 9% to 20% over the same period, with traded phosphorus representing 27% of global mineral fertilizer flows by 2011. Cereals, soybeans, and feed cakes were the primary phosphorus carriers, with 44% of phosphorus used for animal feed, 28% for human food, and 28% for other crop uses. A significant finding was the directional flow of phosphorus, mainly from the America to Western Europe and Asia, diverging from mineral fertilizer trade patterns. This dependency on trade impacted the internal phosphorus cycles of exporting nations, increasing their vulnerability to changes in the global fertilizer market. While the study highlights the vulnerabilities of phosphorus exporters, it does not address the food security implications for importing nations or recent shifts in global phosphorus trade.

Ren et al. (2021) studied the virtual flows of nitrogen (N) and phosphorus (P) in interprovincial agricultural trade within China and their influence on grey water stress between 2008 and 2012, focusing on wheat, rice, and maize. Using Ecological Network Analysis (ENA), the researchers mapped virtual nutrient flows across provinces, finding that southern regions were major virtual nutrient exporters to Northern provinces. This imbalance worsened environmental issues in northern China, where intense agriculture and limited water resources increased grey water stress relative to the south. The study highlights the need for further research beyond 2012 to track current nutrient trends and suggests that additional nutrients like potassium should be considered for a fuller environmental impact assessment.

Lun (2021) examined the impact of international agricultural trade on global phosphorus (P) cycle using data from the Global Trade Analysis Project (GTAP). The study calculated virtual phosphorus flows in traded agricultural products, identifying the United States, Brazil, and the European Union as the largest phosphorus exporters, while China held the highest import share at 5% of global phosphorus trade in 2014. The total phosphorus traded globally represented 16% of harvested crop phosphorus, with a third of these flows attributed to soybean trade. The study also found that phosphorus use efficiency (PUE) was lower in tropical regions than in temperate ones, pointing to differences in nutrient management. Despite global phosphorus trade saving an estimated 0.2 teragrams (Tg) of P annually, trade contributed to a buildup of over 0.5 Tg of phosphorus in

soils and freshwater, raising concerns about eutrophication risks. Extending the study to include recent years and additional nutrients like nitrogen (N) and potassium (K) would provide a fuller picture of nutrient flows and environmental impacts, especially as trade patterns and agricultural practices evolve.

While several studies focus on nitrogen and phosphorus flows in agricultural trade (e.g., Mahjabin et al., 2021; Xiuzhi, 2023; Nesme et al., 2018), many fail to integrate other essential nutrients, which are critical to understanding full nutrient dynamics and their implications. While the role of nutrient exporters (e.g., U.S., Brazil, China) is often emphasized, less attention is given to the nutrient needs and vulnerabilities of importing nations**.** Studies like those by Nesme et al. (2018) focus on the trade patterns and the impact on exporters, but the food security and sustainability implications for importing and exporting regions remain underexplored. More research is needed to understand how nutrient trade impacts food security, agricultural sustainability, and the reliance on imports in nutrient-scarce regions. Research could expand on existing studies by incorporating multiple essential nutrients (N, P, K, Ca, Sulpher, Gypsum) helping to identify trade-offs between nutrient types and their consequences on food security, soil health, and sustainability of agricultural systems particularly in regions heavily reliant on import of agricultural trade.

However, estimates based on agricultural production and consumption data can quantify the virtual flow of nutrients like N, P, K, calcium, sulfur, and gypsum. These analyses can reveal nutrient-deficient regions that import nutrients and surplus regions that export them. Understanding localized perspectives of nutrient flow analysis; these dynamics are crucial for improving nutrient management and sustainability in agriculture.

Materials and Methods

Data and computations

To estimate the interprovincial transfer of virtual nutrients through agricultural commodities in Pakistan, five major crops wheat, rice, maize, cotton, and sugarcane were selected for analysis. These crops were chosen based on the availability of comprehensive data for all provinces in year 2021–22. Data on crop area, production, and yield were obtained from the district-Wise Crop Area and Production Statistics published by the Ministry of National Food Security and Research for 2021–22. Data on the consumption of these commodities and their derived products were sourced from the *Household Integrated Economic Survey (HIES) 2018–19*. Per capita consumption was converted to annual consumption and multiplied by provincial population figures from the Pakistan Bureau of Statistics (2022–23) to calculate total consumption per province. Fertilizer usage data for the selected crops was taken from the *Agriculture Policy Institute (API)*

publications, while the nutrient content of each fertilizer type was sourced from fertilizer companies. The macro-nutrients considered in the study included nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulfur (S), and gypsum. However micro-nutrients were out of the scope of the analysis. The total nutrient availability for each province was calculated by aggregating nutrient contributions from all fertilizers used.

Data analysis

The analysis aimed to quantify the virtual nutrient flow between provinces based on crop production and consumption patterns. All crop-related data (nutrient content, production, yield, area, and consumption) were standardized into uniform units to facilitate the analysis. The percentage of nutrients available in a 50 kg bag of respective fertilizer was used to calculate the amount of nutrients available in a 50 kg bag shown in table 1

Table 1: Nutrients available in 50 kg bag of fertilizer

Fertilizer	N (%)	P (%)	K (%)	Calcium (%)	Sulfur (%)	Gypsum (%)
DAP	18	46	0	0	0	0
Urea	46	0	0	0	0	0
SOP	0	0	25	0	9	0
SSP	0	9	0	9	6	23
CAN	13	0	0	5	0	0
Source: FFC, Engro Fertilizers Limited, Fatima Fertilizer Company Limited (2023).						

Virtual nutrients used in production

The total nutrients required for crop production were calculated by multiplying the total crop production by the nutrient content used to produce each crop as per the following equation:

$$N_P(i,t,p) = F_P(i,t)W_F(i) \dots\dots\dots (1)$$

Where:

- NP (i,t,p) represents the nutrients used for the production of crop *i* in year *t* for province *p*.
- FP (i,t) is the nutrient content used to produce crop *i*.
- WF (i) is the total production of crop *i* in tons.

Virtual Nutrient used in Consumption

The nutrients consumed per province were calculated by multiplying the per capita consumption of each commodity by the population of the province. The equation used was:

$$N_C(i,t,p) = F_{CP}(i,t) * P_P(i) \dots\dots\dots (2)$$

Where:

- N_C (i,t,p) represents the virtual nutrients consumed by province *p* in year *t* for crop *i*.
- F_{CP} (i,t) is the per capita consumption of crop *i* in year *t* for province *p*.
- P_P (i) represents the population of province *p*.

Net Virtual Nutrient Availability

Net nutrient availability in each province was determined by subtracting the nutrient consumption from the nutrient production using equation:

$$N_N(i,t,p) = N_P(i,t,p) - N_C(i,t,p) \dots\dots\dots (3)$$

Where:

- N_N (i,t,p) is the net nutrient availability for crop *i* in year *t* for province *p*.

A positive value indicates a net export or outflow of virtual nutrients, while a negative value indicates a net import or inflow of virtual nutrients.

Results and Discussion

Virtual Nutrient flow for wheat

Region	Area (000 acres)	Production (000 tons)	Per capita consumption (Kg)	Total consumption (000 tons)	Nutrients used in production (000 tons)	Nutrients used in consumption (000 tons)
Punjab	16202	20031	84.48	10787	1423	766
Sindh	2918	3556	72.96	4063	221	253
KP	1878	1362	93.6	3824	150	420
Baluchistan	1172	1257	95.16	1417	94	106
Pakistan	22172	26208	84	20092	1799	1379
	(MNFSR 2022)		(HIES 2019)			

Table 2: Province wise nutrient use for wheat crop in Pakistan

Province-wise area, production, consumption nutrients use in production and consumption in wheat crop are given in Table 2. The result revealed that per capita consumption was highest in Baluchistan followed by KP, Punjab, and Sindh. Nutrients used in production are highest in Punjab i.e. 1423, thousand tons and lowest in Baluchistan (94 thousand tons, indicating significant resource input differences. Meanwhile, nutrient used in consumption also varies, reflecting consumption needs based on population size and dietary habits. In contrast, Sindh, KP, and Baluchistan exhibit nutrient deficits and are net importers of virtual nutrients, especially nitrogen and phosphorus, which are critical for wheat production. This pattern indicates a reliance on nutrient transfers from Punjab to sustain wheat cultivation across Pakistan. Results in table 3 revealed that the KPK is having highest inflow of virtual nutrients in the province i.e. -271 thousand tons, followed by Sindh -32 thousand tons and Baluchistan -12 thousand tons. Punjab's nutrient surplus enables it to support the nutrient needs of other provinces for wheat production. N and P being the major nutrients being imported in Sindh, KPK and Baluchistan.

Table 3: Net virtual nutrients for wheat crop

	Net flow of virtual nutrients for wheat (000 tons)						
	N	**P**	**K**	**Calcium**	**Sulfur**	**Gypsum**	**Net Virtual Nutrients Flow**
Punjab	441	206	0	9	0	0	657
Sindh	-22	-9	0	0	0	0	-32
KPK	-189	-81	0	0	0	0	-271
Baluchistan	-8	-4	0	0	0	0	-12

Virtual Nutrient Flow for sugarcane

Province-wise area, production, consumption nutrient use in production and nutrient use in consumption in sugar production in Pakistan are given in Table 4. The result revealed that per capita consumption was highest in Baluchistan to the tune of 21.72 Kg/ annum followed by KP 19.9 Sindh 15.96 and Punjab 14.5 Kg/ annum. Baluchistan province import around 19 thousand tons of nutrients in total for sugar consumption followed by KPK province that use to import 18 thousand tons of virtual nutrients from other provinces and the international market as shown in table 5. On the other hand Punjab province has highest outflow or exports of nutrients virtually i.e. 190 thousand tons followed by Sindh i.e. 49 thousand tons. Key nutrient exports include nitrogen and phosphorus signifying the status as a nutrient-supplying regions.

Table 4: Province wise nutrient use for sugarcane crop in Pakistan

Region	**Area (000 acres)**	**Productin (000 tons)**	**Per capita consumption (Kg)**	**Total consumption (000 tons)**	**Nutrients used in production (000 tons)**	**Nutrients used in consumption (000 tons)**
Punjab	2147	64245	14.52	18540	PK268	77
Sindh	729	19461	15.96	8889	91	41
KP	235	4910	19.92	8139	28	47
Baluchistan	2	35	21.72	3235	0.21	20
Pakistan	3113	88650	16.2	38740	385	168
	(MNFSR 2022)		(HIES 2019)			

Punjab and Sindh are nutrient surplus provinces for sugarcane, particularly rich in nitrogen and phosphorus, which allows them to export these nutrients to other provinces. In contrast, KP and Baluchistan are nutrient-deficient, relying on virtual nutrient imports from other regions or international sources to support their sugarcane consumption needs. Punjab's dominance in sugarcane production makes it a critical provider of virtual nutrients for this crop across Pakistan.

Table 5: Net virtual nutrients for sugarcane crop

	Net flow of virtual nutrients for sugarcane (000 tons)						
Region	**N**	**P**	**K**	**Calcium**	**Sulfur**	**Gypsum**	**Total nutrients use**

Punjab	108	74	5	2	2	0	190
Sindh	28	20	1	1	0	0	49
KPK	-11	-7	0	0	0	0	-18
Baluchistan	-11	-8	0	0	0	0	-19

Virtual Nutrient Flow for cotton crop

Province-wise area, production, consumption nutrient use in production and nutrient use in consumption in cotton production in Pakistan are given in Table 6. Punjab leads in cotton cultivation with 1279 thousand acres and the highest production 5168 thousand bales. Sindh follows with 594 thousand acres and 2,998 bales. KP and Baluchistan have limited cotton production, with KP producing almost no cotton. The result revealed that per capita consumption was same for all the provinces in Pakistan i.e. 12.97 yet KPK is the province which is importing highest nutrients virtually i.e. -53 thousand tons through import from other provinces and international sources as it produces nothing just a fraction of cotton which is negligible. Baluchistan province also import nutrients to the extent of -4 thousand tons of nutrients in total for cotton. On the other hand, Punjab province has highest outflow or exports of nutrients virtually i.e. 404 thousand tons followed by Sindh Province i.e. 134 thousand tons.

Table 6: Province wise virtual nutrient use for cotton crop in Pakistan

Region	Area (000 acres)	Producing (000 bales)	Per capita consumption (Kg)	Total consumption (000 tons)	Nutrients used in production (000 tons)	Nutrients used in consumption (000 tons)
Punjab	1279	5168	12.97	1655	595	191
Sindh	594	2998	12.97	722	177	43
KP	17	1	12.97	529	0	53
Baluchistan	64	162	12.97	193	19	23
	(MNFSR 2022)		(HIES 2019)			

Table 7: Net virtual nutrients for cotton crop

	Net virtual nutrients for cotton crop (000 tons)						
Region	**N**	**P**	**K**	**Calcium**	**Sulfur**	**Gypsum**	**Total nutrients use**
Punjab	114	290	0	0	0	0	404
Sindh	59	75	0	0	0	0	134
KPK	-23	-29	0	0	0	0	-53
Baluchistan	-2	-2	0	0	0	0	-4

Punjab and Sindh are nutrient surplus regions for cotton, exporting significant amounts of nitrogen and phosphorus to meet the needs of other provinces. KP and Baluchistan have minimal cotton production but higher consumption rates, resulting in virtual nutrient deficits and a dependency on nutrient imports from nutrient-rich provinces. This distribution highlights

Punjab's and Sindh's roles as critical suppliers of cotton-related nutrients across Pakistan.

Province wise nutrient use for maize crop in Pakistan

Province-wise area, production, consumption nutrient requirement, and nutrient use in maize production in Pakistan are given in Table 8. The result revealed that per capita consumption was highest in Sindh to the tune of 17.3 Kg/ annum followed by Baluchistan at 15.98 Punjab at 15.1 and KP at 13.4 Kg/ annum. Sindh and Baluchistan provinces imported nearly 341 and 79 thousand tons of nutrients from other provinces for maize consumption, respectively. While Punjab and KPK were having surplus nutrients i.e. 298 and 64 thousand tons respectively.

Table 8: Province wise virtual nutrient use for maize crop in Pakistan

Region	Area (000 acres)	Production (000 tons)	Per capita consumption (Kg/year)	Total consumption (000 tons)	Nutrients used in production (000 tons)	Nutrients used in consumption (000 tons)
Punjab	2928	8629	15.11	1930	384	86
Sindh	11	4	17.27	962	2	342
KP	1132	887	13.39	547	168	103
Baluchistan	11	5	15.98	238	2	81
	(MNFSR 2022)		(HIES 2019)			

Table 9: Net virtual nutrients for maize crop

Net virtual nutrients for maize crop (000 tons)							
Region	**N**	**P**	**K**	**Calcium**	**Sulfur**	**Gypsum**	**Total nutrients use**
Punjab	217.83	64.14	8.31	3.40	4.35	0	298
Sindh	-248.89	-73.28	-9.50	-3.88	-4.97	0	-341
KPK	46.90	13.81	1.79	0.73	0.94	0	64
Baluchistan	-57.81	-17.02	-2.21	-0.90	-1.16	0	-79

Punjab is producing 90 percent of maize while Sindh and Baluchistan do not produce maize yet consume significant portion making them nutrient deficient provinces. However, KP produce 9.3 percent out of total production and stand at nutrient exporting province.

Province wise nutrient use for rice crop in Pakistan

Region	Area (000 acres)	Production (000 tons)	Per capita consumption (Kg/year)	Total consumption (000 tons)	Nutrients used in production (000 tons)	Nutrients used in consumption (000 tons)
Punjab	6314	5766	9.6	1226	3227.4	686
Sindh	1830	2631	22.44	1250	145.0	69

KP	162	158	10.2	417	13.0	34
Baluchistan	399	525	9.36	139	31.6	8
	(MNFSR 2022)		(HIES 2019)			

Table 10: Province wise nutrient use for rice crop in Pakistan

Province-wise area, production, consumption, nutrient use in production and consumption of rice crop in Pakistan are given in Table 11. The result revealed that per capita consumption was highest in Sindh followed by KP, Punjab and Baluchistan 22.4, 10.20, 9.6 and 9.4 kg/annum, respectively. In Pakistan overall per capita rice consumption was 12.7 Kg/year. Khyber Pakhtunkhwa imports 21 thousand tons of nutrients for rice consumption from other provinces. All the other provinces are nutrient exporting provinces except that of KPK province. Punjab province is leading in exports of virtual nutrients i.e. 2541 thousand tons.

Table 11: Net virtual nutrients for rice crop

The major chunk of rice is produced by province Punjab followed by Sindh province. KPK and

	Net virtual nutrients for rice crop (000 tons)						
Region	**N**	**P**	**K**	**Calcium**	**Sulfur**	**Gypsum**	**Total nutrients use**
Punjab	331.0	117.3	4.35	2087.0	1.57	0	2541
Sindh	54.0	22.1	0.00	0.0	0.00	0	76
KPK	-15.2	-6.2	0.00	0.0	0.00	0	-21
Baluchistan	16.5	6.7	0.00	0.0	0.00	0	23

Baluchistan produce 2 and 6 percent of overall rice production. On the other hand, side Sindh and Punjab are the main consumer of rice followed by KPK and Baluchistan. Overall only KPK is the importing province in terms of virtual nutrients due to the reason of consuming a reasonable rice quantity with minor or fractional share in overall production of rice.

Table 12: Crop wise and province wise net virtual nutrients flow

Region	**Wheat**	**Sugarcane**	**Rice**	**Cotton**	**Maize**	**Total**
000 tons						
Punjab	657	190	2541	404	298	4090
Sindh	-32	49	76	134	-341	-114
KP	-271	-18	-21	-53	64	-299
Baluchistan	-12	-19	23	-4	-79	-91

Table 12 presents the overall summary of the all crops under analysis which reveals that Punjab is the major exporting province of virtual nutrients and highest export of virtual nutrients takes place for rice crop. KPK and Baluchistan are net importer of virtual nutrients except for maize in KPK and rice for Balochistan. Sindh Province shows a mixed trend. It is net

importer of virtual nutrients in wheat and maize however in sugarcane, cotton and rice it is net exporter. Punjab emerges as the most agriculturally productive province, exporting significant virtual nutrients in all major crops. This highlights its role as the breadbasket of Pakistan, providing virtual nutrients to other provinces. The overall negative nutrient flows in Sindh, KP, and Baluchistan may be due to issues with soil fertility, low agricultural input efficiency, or poor crop yields, making these regions more reliant on nutrient imports.

Overall Nutrients Use Per Area of Cropland In Comparison With World Average

The nutrient use of inorganic fertilizers is presented by FAO stat 2023. The data is presented for three primary nutrients: nitrogen (N), phosphorus (expressed as P2O5) and potassium (expressed as K2O). Both straight and compound fertilizers are included. The average use of nutrients of the world, India and Pakistan are given below (FAO stat 2021):

Table 12: Inorganic fertilizer uses per cropland area by nutrient for year 2021 (kg per ha)

	World	**Pakistan**	**India**
	(kg/ha)		
Nitrogen N (total)	65.5	112.89	116
Phosphorus P2O5 (Total)	28.8	38.46	46.6
Potash K2O (total)	24.4	1.95	15.1
Source: FAO stat database 2023			

The nitrogen content (total) applied or available to crops in Pakistan and India is significantly higher than the world average. Pakistan has a nitrogen application of approximately 73% higher than the world average, while India's nitrogen application is around 77% higher than the global figure. This indicates a higher intensity of nitrogen fertilizer use or natural nitrogen availability in these countries compared to the global average. Phosphorus levels in Pakistan and India are also higher than the world average, though the difference between India and Pakistan is notable. India's phosphorus levels are approximately 62% higher than the world average, while Pakistan's levels are around 34% higher. This suggests that phosphorus fertilization or natural availability is more pronounced in these countries compared to the global average. The use of potash (K_2O) is much lower in Pakistan and its application has been discouragingly low in all the major crops, with only 1.95 kg/ha compared to the world average of 24.4 kg/ha. This is a substantial difference, indicating that Pakistan has significantly lower potash application or availability. India's potash application is also lower than the global average, but not as drastically as that of Pakistan. India has about 62% less than the world average.

Table 13: Province wise consumption of fertilizer Nutrients for the year (2021-22)

	Nitrogen	Phosphate	Potash	Total
000 nutrient tons				
Punjab	2638.0	791.0	50.0	3479.0
Sindh	934.0	236.0	18.0	1188.0
KPK	148.0	37.0	2.1	187.1
Baluchistan	117.0	29.0	1.4	147.4
Total	3837	1093	71.5	5001.5
Source: NFDC 2023				

Province wise consumption of fertilizer nutrients in thousand nutrient tons mentioned in table 13 reveals that nitrogen is the most widely consumed fertilizer nutrient across all provinces, accounting for 76.7% of the total consumption (3,837 out of 5,001.5). Punjab is the dominant consumer, using more than half of all fertilizer nutrients. Potash consumption is the lowest in all regions, reflecting limited use compared to Nitrogen and Phosphate.

Table 14: External Trade Scenario of imported fertilizers and export potential

Total value of exports of food and textile groups	24,746,920
Total value of imported fertilizer	845,538
Net value (exports - imports)	23,901,382
Source: Pakistan Bureau of Statistics 2022	

The agriculture sector (food crops and cotton) and textile sector (through cotton production) are the main users of imported fertilizers in Pakistan. This aligns with the significant role these sectors play in Pakistan's economy, particularly in exports. Food and textile group contribute 5,416,875 and 19,330,045 thousand USD in foreign exchange earing through exports. Major export in food group is of rice worth thousand USD 2,511,512 and the exports from textile group include cotton and cotton products (raw cotton, cotton yarn, cotton cloth, cotton carded or yarned, knitwear, bed wear, towels, tents, canvas and tarpaulin, readymade garments). The cumulative exports of both the groups is of worth 24,746,920 thousand USD. While the import of fertilizer during 2022 is of worth 845,538 which means substantial trade surplus of agricultural exports compared to fertilizer imports exist indicating a highly favorable return on investment in fertilizer imports. Fertilizer use is essential for supporting the production of major export commodities, especially rice and cotton products**,** which significantly contribute to Pakistan’s foreign exchange earnings and economic growth.

Discussion

Punjab and Sindh being the leading exporters of agricultural commodities i.e. wheat and rice among food crops and cotton being cash crop use significantly high volumes of chemical-based fertilizers (nitrogen, phosphate, and potash) to enhancement of production. However, provinces like KP and Baluchistan, produce relatively less output with less fertilizer consumption and depend on the production of Punjab and Sindh being exporting provinces. This creates an economic and resource dependency of importing provinces on exporting provinces. The government of Pakistan has been supporting the farmers with the fertilizer subsidies for many years. Economic Coordination Committee (ECC) of Pakistan has approved subsidy of PKR 2500/bag (USD 11.31) of DAP fertilizer for year 2022. Recently the Federal Government has removed the subsidies for gas because major fertilizer companies had significant increase in their profits during FY 2023-24 notwithstanding any parallel drop in urea prices for farmers. If the situation persists and subsidies on fertilizers are removed, net-exporting regions would face sharp risks due to increased input costs, particularly fertilizers. This would lead to lower profitability and increased vulnerability for soil nutrient depletion and dwindling the sustainability of agricultural production and virtual nutrient management. In the absence of subsidies output prices may be guided by the market forces and untimely imports as in the past could result in lower output prices favoring the net importing provinces. Moreover, Illegal exports of fertilizers across border has also affected the availability of fertilizer in KP and Baluchistan which resulted in less consumption of fertilizer and resultantly import of virtual nutrients in the form of major agricultural commodities. Furthermore, imperfect markets and poor supply chains create fertilizer shortfall and price impulsiveness that inexplicably affect exporting provinces, making it harder for farmers to maintain soil fertility and productivity. Moreover, there is a chance of placing unequal burden on exporting regions to sustain national food security and exports. The issue of fertilizer supply volatility is more pronounced in KP and Baluchistan due to comparatively weaker supply chains, attributable security concerns and geographical terrains of the provinces. Majority of fertilizer production hubs of Urea and DAP are located in Sindh and Punjab making these provinces natural exporters of raw fertilizers and positioning them as critical suppliers of fertilizers, enabling virtual nutrient flows to other regions. While this supports national agricultural productivity, it also creates economic dependencies and places pressure on the soil resources of Sindh and Punjab.

Conclusions

The research calculates inflow and outflow of virtual nutrients embedded for five major agricultural commodities i.e. wheat, rice, maize, cotton, and sugarcane across all the provinces of Pakistan for 2021-22.

Research revealed that Punjab is a major exporting region of virtual nutrients for all crops under analysis while highlighting its role as the breadbasket of Pakistan, providing virtual nutrients to other provinces. Both KP and Baluchistan import the virtual nutrients for major commodities from other provinces or international markets. Sindh's twin role as both an importer and exporter displays that while it has a robust production system for certain crops, such as cotton and rice, it is unable to meet local demand for crops like maize and wheat. Over time, Punjab's nutrient-rich soils may face depletion if its role as a major nutrient exporter continues without adequate replenishment strategies. Moreover, there is economic and food reliance of importing region on exporting ones due to which nutrients benefits flow from production region to the consumption region emphasizing the need for adequate nutrient management strategies. If the farmers in the exporting regions are unable to maintain productivity due to high cost of inputs the food security and national export earnings could be affected.

Recommendations

1. It is strongly commended to improve the supply chains in the importing regions to ensure timely and equitable access to fertilizers that unswervingly supports the virtual nutrient flow by maintaining soil fertility and agricultural productivity. Reinforcement of infrastructure, improved distribution networks, and implementing strategic policies can mitigate the risks of shortfalls and raise regional agricultural productivity. Moreover, there is a need for stronger monitoring, regulation, and sustenance contrivances to guarantee impartial access to fertilizers across all provinces.
2. Establishing up-to-date fertilizer storage services in net importing provinces is vital for smooth and uninterrupted supply and timely access to fertilizers. It will result in stable prices and improve the virtual nutrient flow by enabling consistent nutrient replenishment and sustainable agricultural practices across regions.
3. Encouraging indigenous natural gas production can be profitable for the farmers, fertilizer manufacturers to promote the stable price mechanism by warranting a steady supply of reasonably priced fertilizers. This promotes a balanced and sustainable nutrient cycle across regions by empowering farmers to sustain soil fertility and agricultural output, which in turn supports virtual nutrient flow.
4. Chemical-based fertilizers represent a significant portion of agricultural input costs with huge financial burden. To mitigate the challenge of high-cost fertilizer importing regions need to cultivate high-value crops that can support in maximizing returns on nutrient inputs and improve trade balances.

Novelty Statement

The research presents a unique estimation of interprovincial virtual nutrient flows in Pakistan, quantifying the direction and magnitude of nutrient surpluses and deficits for five major agricultural commodities. By focusing on the transfer of key nutrients (N, P, K, Calcium, Sulfur, and gypsum) embodied in agricultural commodities, the study highlights specific nutrient import-export dynamics and the implications for importing and exporting regions. This highlights the original contribution of the study in calculating nutrient flows and offering region-specific recommendations.

Author's Contribution

Sidra Majeed

Data collection, Data analysis, report writing,

Dr. Nadeem Akmal

Data collection, data analysis, overall review of research

Dr. Muhammad Azam Niazi

Conception of idea, overall review of research

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