JARQ 58 (2), 93-111 (2024) https://www.jircas.go.jp

Impact of Fertilizer Price and Subsidy on the Global Wheat Market

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Abstract

This study examined how an increase in fertilizer prices will affect the global wheat market and how fertilizer subsidy program will mitigate that impact by developing a partial equilibrium model. All scenarios demonstrated that increasing fertilizer prices drove global wheat prices higher and increased price volatility from a three-year average for 2019-2021 to 2040. Among the countries covered by this model, India and Ukraine are the most vulnerable wheat-producing countries affected by fertilizer price increases. The simulation scenario showed that a fertilizer subsidy program in India will contribute to stabilizing wheat price in the long term, considering the current fertilizer price increase trend. This study concludes that Ukraine will be the most vulnerable country affected by input price change, as well as India. Therefore, to prevent international wheat price increase and volatility, international cooperation is urgently required for Ukraine in mitigating the fertilizer price increase, as well as other input price increases.

Discipline: Social Science
Additional key words: India, nitrogen, Ukraine, wheat price stability

Introduction

Fertilizers are one of the major input elements in growing agricultural crops. They accounted for approximately 60% of the registered yield increase in the last 50 years (Stewart et al. 2005). Among fertilizers, the three primary macronutrients (nitrogen (N), phosphorus (P), and potassium (K)) are the important elements in growing crops. Fertilizer prices have been increasing since June 2020. A combination of factors contributed to the increase in fertilizer prices. Natural gas, used as both feedstock and energy source in the production of ammonia, accounts for 70% - 80% of ammonia production costs (Hebebrand & Laborde 2022). Natural gas prices surged, especially in Europe. Simultaneously, fertilizer users are recovering from the COVID-19 pandemic. Furthermore, the world's largest fertilizer exporter, Russia, restricted fertilizer supply to international markets soon after its aggression of Ukraine. The prices of diammonium phosphate (DAP), triple superphosphate (TSP), urea, and potassium chloride peaked in April 2022, and these prices have decreased since then and are still at a historically high level (Fig. 1).

Adams et al. (1977) demonstrated that a 20% reduction in fertilizer supplies decreases the value of agricultural production by 4%. Burrell (1989) found that an increase in fertilizer prices meant a decrease in fertilizer use in the case of the UK. Brunelle et al. (2015) found that the supply-side response to increasing fertilizer prices could lower crop yields. Furthermore, they concluded that higher food prices induced a higher demand for fertilizers. In Japan, decreasing fertilizer price to rice producer price ratio contributed to increasing fertilizer use and rice yield (Hayami 1973). Increasing fertilizer use, derived from a decreasing fertilizer price to agricultural price ratio, contributed to an increase in agricultural output in Japan (Yamaguchi 1983). On the basis of these previous studies, it is hypothesized that increasing the fertilizer price to agricultural producer price ratio can decrease fertilizer use and the increasing producer price of agricultural products can increase fertilizer use. These fertilizer applications will have an

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Received 21 February 2023; accepted 3 August 2023.

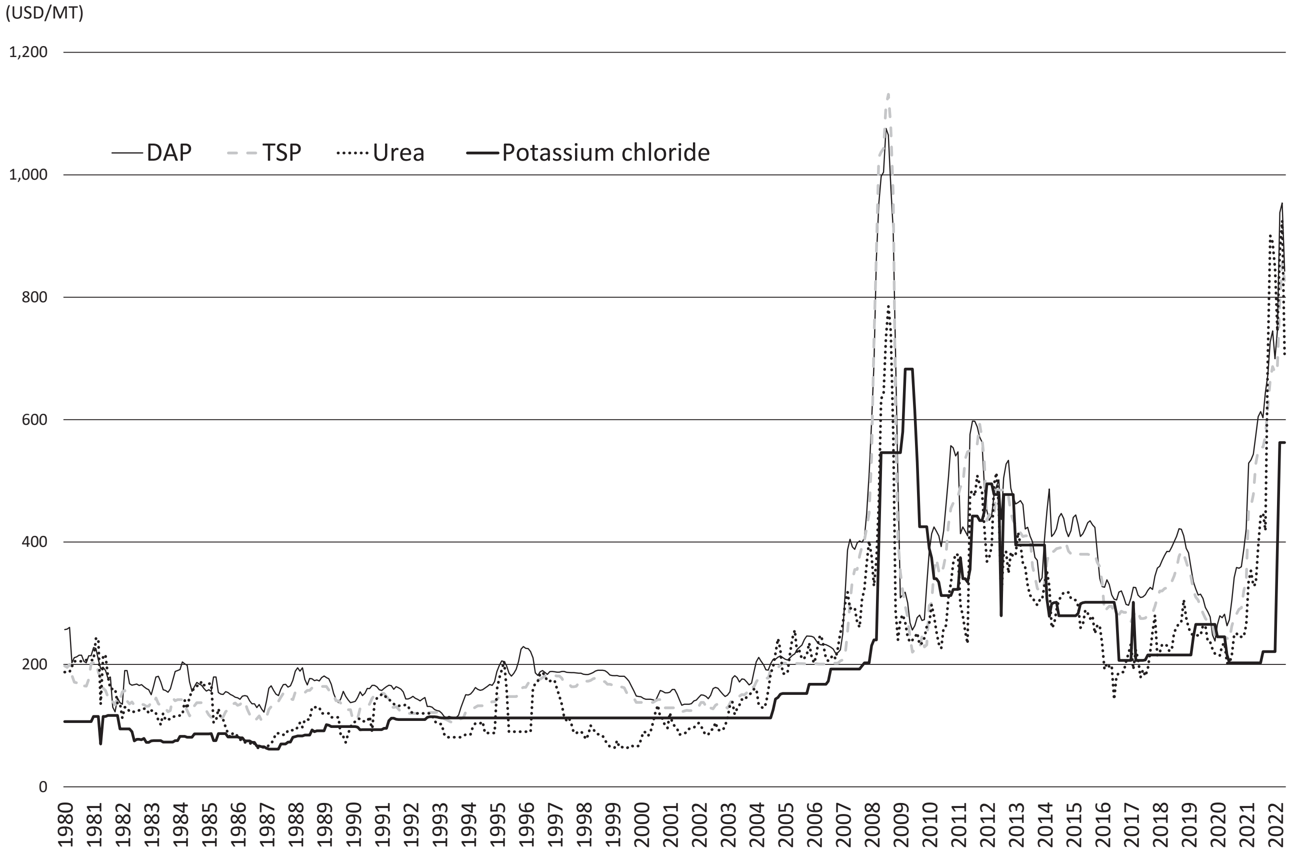

Fig. 1. Fertilizer prices
Source: World Bank (2022)
Note: DAP: diammonium phosphate, TSP: triple superphosphate

impact on crop yield and its market.

The volatility of wheat prices is increasing[1] and has a strong impact on global food security. For wheat and corn, fertilizer prices alone account for over one-third of the total operating costs and 15% - 20% of the total costs (Heady & Fan 2008). It is expected that the increasing fertilizer prices will increase production costs and will decrease producer margins. It is concerning that these price increases can have a negative impact on the wheat yield and harvested areas in many countries without adequate policy measures to mitigate the fertilizer price increase. In other circumstances, Wijetunga & Saito (2017) concluded that fertilizer subsidy reduction reduced rice productivity in the case of Sri Lanka. It is also expected that fertilizer subsidies can mitigate the impact of increasing fertilizer prices.

This study targets the fertilizer subsidy program in India, and most of its subsidies are used for wheat production. Consequently, this study targets the global wheat market, which is influenced by the fertilizer price increase. Koizumi (2019) examined how agricultural investments will affect wheat price volatility under climate change. However, it did not cover fertilizer use and other input prices. Therefore, this study included them and examined how increasing fertilizer prices will affect global wheat markets and their price volatility by factoring in future climate change and how fertilizer subsidies will mitigate the impact on global wheat markets. A partial equilibrium model (the Wheat Economy Climate Change (WECC) model) was developed, in addition to incorporating exogenous fertilizer prices and other input elements into the model.

[1] The coefficient of variation (CV) of international wheat prices was 0.1664 from 1985 to 1995, 0.2425 from 1996 to 2005, 0.2645 from 2006 to 2015, and 0.3583 from January 2016 to July 2022. Calculated from monthly wheat price (Wheat, No. 1 Hard Red Winter, ordinary protein, Kansas City) from World Bank (2022).

Method and data

1. Structure of the developed WECC model and data for regression

The WECC model covers the wheat markets in 11 countries and 2 regions. The base year range is 2019-2021 (a three-year average for 2019-2021, hereinafter 2019/21). Each country's market consists of production, consumption, exports, imports, and ending stocks until 2040 (Fig. 2). The equations for the developed WECC model are shown in the Appendix. The historical yield, planted area, harvested area, and production data for wheat[2] were derived from Production, Supply, and Distribution (PS&D) (USDA-FAS 2022). Wheat producer prices and competitive agricultural producer prices were derived from FAOSTAT (FAO 2022). Fertilizer use for

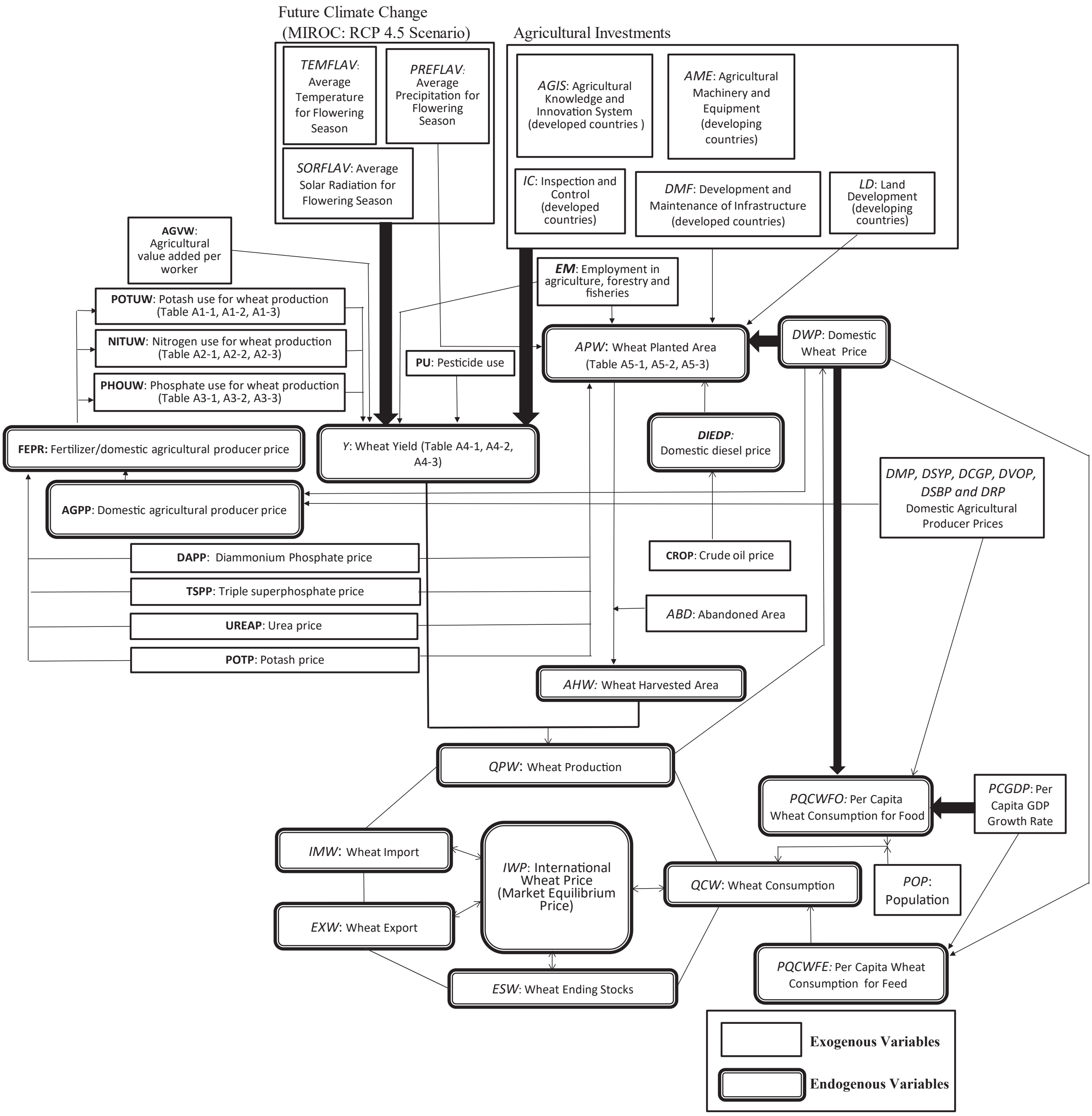

Fig. 2. Structure of the developed WECC (Wheat Economy Climate Change) model

[2] The results of unit root tests (ADF test) confirmed that the time-series data of dependent variables and explanatory variables used in this study are stationary series.

wheat production and pesticide use data were derived from FAOSTAT (FAO 2022), and fertilizer prices were derived from the World Bank (2022). Domestic diesel prices were derived from OECD-FAO (2022). These data were used for regression in the time-series analysis.

2. Baseline assumptions and scenarios

Baseline projection adopted a set of assumptions for the general economy, agricultural policies, and technological changes without any policy shocks during the projection period.[3] The exogenous variables for per capita GDP growth rate, population, and international commodity prices are listed in Appendix Tables A6-1 and 6-2.[4] This study assumed that current agricultural and trade policies will continue and abandoned areas will become zero in all countries throughout the projection period.

The fertilizer uses (nitrogen, phosphate, and potash) in the model in the selected countries were derived from FAOSTAT (FAO 2022), and the wheat use to total fertilizer use ratio of nitrogen, phosphate, and potash in each country was derived from the International Fertilizer Association. These ratios ranged between 2.5% and 43.6% in 2018 (Table 1). This study hypothesized that these wheat use ratios of 2018 will be constant from 2022 to 2040. This study applied the fertilizer price projections, derived from the World Bank Commodities Price Forecast (2021 October) (World Bank 2021), to the baseline assumption from 2022 to 2035. This study assumed that the average changing rate of fertilizer price from 2030 to 2035 will continue to be the same after 2036. Therefore, the prices of DAP, potassium chloride, and urea will decrease by 1.2%, 1.4%, and 1.3% per annum from 2019/21 to 2040, respectively, and TSP's price will increase by 1.3% per annum (Table 2). The nitrogen, phosphate, and potash subsidies in India decreased by 0.9%, 2.3%, and 6.6%, respectively, from 2015 to 2020 (Table 3). This study applied these changing rates (from 2015 to 2020) to the fertilizer subsidy rate of change in India from 2022 to 2040 as a baseline assumption. This study also assumed that pesticide use and domestic diesel prices will be constant from 2022 to 2040. This study applied that the current growth rate of agricultural knowledge and innovation systems, and development and maintenance of infrastructure[5] from 2006 to 2021 will continue during the outlook period (2019/21-2040)[6] (Appendix Table A6-3).

This study applied alternative scenarios to the baseline outlook. For scenario 1, this study assumed that the fertilizer prices (DAP, potassium chloride, TSP, and urea) will increase from 2022 to 2024. These price projections were derived from the World Bank Commodities Price Forecast (April 2022), and these prices will increase by 47.3%-160.4% from 2022 to 2024, compared to the baseline assumption. This study applied the annual growth rate of these prices from the baseline assumptions after 2025. The average fertilizer prices will increase between 61.4% and 132.4%, compared to the baseline from 2022 to 2040. This study used the Indian fertilizer subsidy program as an alternative scenario. Among models covering countries and regions, the fertilizer subsidy program is currently applied only to India. India is one of the largest wheat producers, but the yield is lower than the yields of other main producers.[7] Therefore, it is expected that maintaining the fertilizer subsidy program will increase and stabilize the wheat yield in India and the global wheat supply. For scenario 2, this study also assumed that fertilizer subsidies in India will be constant after 2022, under the fertilizer price increase projection in scenario 1. For scenario 3, this study applied these changing rates (2012-2020) of Indian fertilizer subsidies to the changing rates from 2022 to 2040, under the fertilizer price increase assumption in scenario 1.

[3] The climate variables (temperatures, precipitation, and amount of solar radiation) for both the baseline projection and scenarios come from the climate change projections of Model for Interdisciplinary Research on Climate (MIROC), a global climate model under the RCP 4.5 scenario. Spatially averaged climate variables for each country are computed similarly to the historical climate data used for regression. For detailed climate variables, refer to Koizumi (2019).

[4] Population data for all countries were obtained from the 2022 revision (medium variant) of World Population Prospects, United Nations (2022). Per capita real GDP was also treated as an exogenous variable, and GDP growth rate assumptions were based on the World Economic Outlook 2022 (IMF 2022). These GDP growth rates are available up to 2027. This study assumed that the average per capita GDP growth rate from 2022 to 2027 in each country and region will continue to be the same rate in 2028-2040. Competing commodity prices were derived from the OECD-FAO Agricultural Outlook 2022-2031 (OECD-FAO 2022).

[5] These are derived from OECD (2022).

[6] This study also assumed that the current growth rate of land development and agricultural machinery and equipment from 1990 to 2007 in Egypt and Pakistan (the rest of the world) will continue during the outlook period. These data were derived from FAOSTAT (FAO 2022).

[7] The wheat yield in India was 3.5 MT/ha and the yields in France, Germany, and China were 7.2, 7.4, and 5.7 MT/ha, respectively, in 2019/21 (Table 4).

Table 1. Nitrogen, phosphate, and potash uses for wheat production (baseline projection)

(ton)

Countries/Region	Fertilizer use	Wheat use rate (2018)	2019/21	2040	Annual growth rate (2019/21-2040)
Argentina	Nitrogen use	36.2%	484,991	684,387	2.0%
	Phosphate (P_2O_5) use	27.1%	220,250	299,685	1.8%
	Potash (K_2O) use	–	–	–	–
Australia	Nitrogen use	33.8%	452,339	618,000	1.9%
	Phosphate (P_2O_5) use	28.3%	271,441	289,508	0.4%
	Potash (K_2O) use	14.0%	40,228	43,373	0.4%
Canada	Nitrogen use	33.0%	932,415	536,823	−3.2%
	Phosphate (P_2O_5) use	28.0%	318,640	469,632	2.3%
	Potash (K_2O) use	19.0%	115,045	160,704	2.0%
China	Nitrogen use	15.9%	4,191,803	4,787,923	0.8%
	Phosphate (P_2O_5) use	15.9%	1,597,736	1,775,887	0.6%
	Potash (K_2O) use	12.7%	1,280,087	1,708,228	1.7%
Egypt	Nitrogen use	21.5%	267,304	293,370	0.5%
	Phosphate (P_2O_5) use	13.8%	30,789	34,334	0.6%
	Potash (K_2O) use	18.3%	22,879	23,774	0.2%
France	Nitrogen use	38.5%	790,116	996,927	1.4%
	Phosphate (P_2O_5) use	23.3%	99,533	123,231	1.3%
	Potash (K_2O) use	18.7%	85,160	135,696	2.8%
Germany	Nitrogen use	31.6%	416,076	348,887	−1.0%
	Phosphate (P_2O_5) use	17.6%	38,755	38,428	0.0%
	Potash (K_2O) use	11.6%	50,083	45,164	−0.6%
Rest of EU	Nitrogen use	18.7%	1,208,047	1,369,425	0.7%
	Phosphate (P_2O_5) use	20.7%	418,399	469,559	0.7%
	Potash (K_2O) use	17.7%	361,406	483,050	1.7%
India	Nitrogen use	20.0%	3,936,127	3,662,843	−0.4%
	Phosphate (P_2O_5) use	15.2%	1,250,245	2,727,293	4.7%
	Potash (K_2O) use	6.8%	196,042	233,832	1.0%
Russia	Nitrogen use	43.6%	795,270	859,960	0.5%
	Phosphate (P_2O_5) use	35.2%	226,512	255,516	0.7%
	Potash (K_2O) use	21.7%	97,581	98,025	0.0%
Ukraine	Nitrogen use	34.0%	540,434	587,618	0.5%
	Phosphate (P_2O_5) use	25.9%	103,700	198,803	3.9%
	Potash (K_2O) use	24.7%	79,833	180,805	4.9%
USA	Nitrogen use	12.7%	1,482,928	1,670,965	0.7%
	Phosphate (P_2O_5) use	11.2%	444,602	515,591	0.9%
	Potash (K_2O) use	2.5%	107,658	116,622	0.5%

Source: Wheat use rates were derived from IFA (2022), and 2019/21 data were derived from FAOSTAT (FAO 2022).
Note: There are no data for potash use in Argentina.

Table 2. Fertilizer prices from 2019/21 to 2040 (baseline projection)

(USD/mt)

Scenario/Baseline	Fertilizer	2019/21	2022	2023	2024	2025	2030	2035	2040	Annual growth rate from 2019/21 to 2040
Baseline	DAP	406.6	587.0	433.0	378.0	325.0	335.0	380.0	326.3	−1.2%
	Potassium chloride	365.9	318.0	264.0	262.0	259.0	244.0	253.0	279.3	−1.4%
	TSP	227.8	509.0	385.0	340.0	297.0	302.0	337.0	289.4	1.3%
	Urea	319.2	367.0	288.0	260.0	259.0	256.0	278.0	251.3	−1.3%
Scenario 1	DAP	406.6	900.0	800.0	650.0	558.9	576.1	653.4	561.1	1.7%
	Potassium chloride	365.9	520.0	470.0	453.0	447.8	421.9	437.4	483.0	1.5%
	TSP	227.8	750.0	650.0	550.0	480.4	488.5	545.1	468.1	3.9%
	Urea	319.2	850.0	750.0	600.0	597.7	590.8	641.5	579.9	3.2%

Source: 2019/21 data were derived from World Bank (2022).
Note: The fertilizer prices after 2022 in baseline projection were derived from World Bank (2021). These prices from 2022 to 2024 in scenario 1 were derived from World Bank (2022), and these prices after 2025 in scenario 1 were derived from the changing rates of World Bank (2021).

Table 3. Fertilizer subsidies in India

(RP/kg)

Fertilizer	2012	2013	2014	2015	2016	2017	2018	2019	2020	Annual growth rate from 2015 to 2020	Annual growth rate from 2012 to 2020
Nitrogen	24.000	20.875	20.875	20.875	15.854	18.989	18.901	18.901	18.789	−0.9%	−3.3%
Phosphate	21.804	18.679	18.679	18.679	13.241	11.997	15.216	15.216	14.888	−2.3%	−6.7%
Potash	24.000	18.833	15.500	15.500	15.470	12.395	11.124	11.124	10.116	−6.6%	−9.9%

Source: Ministry of Chemicals and Fertilizers in India (2022)

Results

Under the baseline assumptions, fertilizer use in the main wheat producing countries is projected to change from −3.2 to 4.9% from 2019/21 to 2040 (Table 1). Global wheat production and consumption are expected to increase at a rate of 1.0% per annum from 2019/2021 to 2040 (Table 4). World wheat exports and imports are expected to increase at rates of 1.3% and 1.5% per annum, respectively, during the same period (Table 4). The international wheat price is projected to increase from 249.5 USD/t during 2019/21 to 452.8 USD/t in 2040. The CV of international wheat price from 2019/21 to 2040 is 0.3975. The average international wheat price from 2019/21 to 2040 is 385.1603.

Projections were made using various fertilizer price scenarios in selected countries for comparison against the baseline projection. Under scenario 1, fertilizer prices to wheat producer prices will increase from 2022 to 2040 as a result of the fertilizer price increase. Fertilizer use in all countries and regions is projected to decrease by 0.04%-29.2% compared to the baseline outlook from 2022 to 2040 (Table 5). Among them, the decreasing rate of fertilizer use in Ukraine will be larger than that in other countries. The Ukrainian wheat yield is expected to decrease by 3.5%, but its harvested area and production are predicted to increase by 2.4% and 1.9%, respectively, compared to the baseline outlook average from 2022 to 2040 (Table 6). The nitrogen, phosphate, and potash use in India are expected to decrease by 21.7%, 9.4%, and 6.7%, respectively (Table 5), and the Indian wheat yield and production are expected to decrease by 4.2% and 9.5%, respectively. Global wheat production and consumption are expected to decrease by 1.6%, and global wheat exports and imports are expected to decrease by 0.7%. Consequently, the international wheat price is expected to increase by 114.2% (Table 7).

Under scenario 2, fertilizer prices to wheat producer prices will increase from 2022 to 2040 as a result of the fertilizer price increase. The nitrogen, phosphate, and potash use in India are expected to decrease by 21.2%, 8.2%, and 4.5%, respectively (Table 5), and the Indian wheat yield and production are expected to decrease by 3.9% and 8.4%, respectively, compared to the baseline

Table 4. World wheat markets (baseline projection)

Countries/ Region	Yield (MT/ha)			Harvested area (1,000 ha)			Production (1,000 MT)		
	2019/21	2040 (projection)	Annual growth rate (2019/21-2040)	2019/21	2040 (projection)	Annual growth rate (2019/21-2040)	2019/21	2040 (projection)	Annual growth rate (2019/21-2040)
World	—	—	—	219,512	248,394	0.7%	772,117	916,512	1.0%
Argentina	3.0	3.0	−0.02%	6,558	6,630	0.1%	19,847	20,085	0.1%
Australia	2.3	2.2	−0.1%	11,921	13,755	0.8%	28,027	30,873	0.6%
Canada	3.1	3.9	1.5%	9,640	10,131	0.3%	29,835	39,989	1.7%
China	5.7	5.7	−0.001%	23,559	25,528	0.5%	134,932	146,188	0.5%
Egypt	6.4	7.1	0.6%	1,387	1,802	1.6%	8,890	12,763	2.2%
EU	—	—	—	23,856	22,012	−0.5%	134,637	131,053	−0.2%
France	7.2	7.4	0.2%	4,667	4,103	−0.8%	33,376	30,347	−0.6%
Germany	7.4	7.1	−0.3%	2,930	2,334	−1.3%	21,816	16,605	−1.6%
Other EU	4.9	5.4	0.6%	16,260	15,576	−0.3%	79,446	84,101	0.3%
India	3.5	3.6	0.2%	30,600	34,765	0.8%	107,015	126,102	1.0%
Russia	2.8	3.1	0.6%	27,875	31,702	0.8%	78,040	97,734	1.3%
Ukraine	4.1	3.8	−0.4%	7,092	7,328	0.2%	29,199	27,976	−0.3%
USA	3.3	3.6	0.6%	15,020	17,645	1.0%	49,041	64,250	1.6%

Countries/ Region	Consumption (1,000 MT)			Exports (1,000 MT)			Imports (1,000 MT)		
	2019/21	2040 (projection)	Annual growth rate (2019/21-2040)	2019/21	2040 (projection)	Annual growth rate (2019/21-2040)	2019/21	2040 (projection)	Annual growth rate (2019/21-2040)
World	767,218	908,181	1.0%	199,126	247,962	1.3%	193,412	247,962	1.5%
Argentina	6,350	7,566	1.0%	13,605	12,491	−0.5%	5	17	7.6%
Australia	8,167	9,295	0.8%	20,161	21,597	0.4%	431	441	0.1%
Canada	9,461	10,315	0.5%	21,857	29,553	1.8%	609	578	−0.3%
China	141,333	153,609	0.5%	887	957	0.4%	8,565	10,923	1.4%
Egypt	20,467	25,169	1.2%	661	1,469	4.8%	12,153	13,998	0.8%
EU	107,250	100,721	−0.4%	33,009	34,786	0.3%	5,143	4,734	−0.5%
India	101,844	114,615	0.7%	3,701	11,550	6.9%	21	19	−0.5%
Indonesia	10,400	12,652	1.2%	345	475	1.9%	10,745	13,136	1.2%
Russia	41,417	43,010	0.2%	35,528	54,220	2.5%	342	168	−4.1%
Ukraine	9,000	8,299	−0.5%	18,889	19,646	0.2%	119	64	−3.5%
USA	30,482	31,861	0.3%	25,080	32,666	1.6%	2,713	2,519	−0.4%

outlook average from 2022 to 2040 (Table 6). The changing rates of fertilizer use, yield, and production in India under scenario 2 are lower than those under scenario 1 because of the fertilizer subsidy in India. Global wheat production and consumption are expected to decrease by 1.6%, and global wheat exports and imports are expected to decrease by 0.5%. As a result, the international wheat price is expected to increase by 109.0% (Table 7).

Under scenario 3, the nitrogen, phosphate, and potash use in India are expected to decrease by 22.7%, 10.8%, and 7.2%, respectively (Table 5), and the Indian wheat yield and production are expected to decrease by 4.6% and 10.2%, respectively, compared to the baseline outlook average from 2022 to 2040 (Table 6). The decreasing rates of fertilizer use, yield, and production in scenario 3 are greater than those in scenarios 1 and 2. Global wheat production and consumption are expected to decrease by 1.6%, and global wheat exports and imports are expected to decrease by 0.9%. Consequently, the international wheat price is expected to increase by 117.7% (Table 7).

The parameters of potash use for wheat, deciding wheat yield in India and Ukraine, are lower than those in Russia and Canada. However, the parameters of nitrogen use for wheat production, deciding wheat yield in India

Table 5. Scenario impact on fertilizer use for wheat (2022-2040)

Countries/Region	Fertilizer use	Changing rate between Scenario 1 and Baseline projection	Changing rate between Scenario 2 and Baseline projection	Changing rate between Scenario 3 and Baseline projection
Argentina	Nitrogen use	−12.0%	−12.0%	−12.0%
	Phosphate (P_2O_5) use	−1.1%	−1.0%	−1.1%
Australia	Nitrogen use	−0.5%	−0.5%	−0.5%
	Phosphate (P_2O_5) use	−0.8%	−0.8%	−0.8%
	Potash (K_2O) use	−0.2%	−0.3%	−0.2%
Canada	Nitrogen use	−6.6%	−6.6%	−6.6%
	Phosphate (P_2O_5) use	−1.8%	−1.9%	−1.7%
	Potash (K_2O) use	−2.5%	−2.6%	−2.4%
China	Nitrogen use	−9.6%	−9.6%	−9.7%
	Phosphate (P_2O_5) use	−0.7%	−0.8%	−0.7%
	Potash (K_2O) use	−4.7%	−4.7%	−4.6%
Egypt	Nitrogen use	−6.2%	−6.2%	−6.2%
	Phosphate (P_2O_5) use	−2.9%	−3.0%	−2.9%
	Potash (K_2O) use	−1.8%	−1.9%	−1.8%
France	Nitrogen use	−4.7%	−4.8%	−4.7%
	Phosphate (P_2O_5) use	−0.7%	−0.8%	−0.6%
	Potash (K_2O) use	−2.7%	−2.5%	−2.9%
Gernany	Nitrogen use	−5.3%	−5.4%	−5.2%
	Phosphate (P_2O_5) use	−1.5%	−1.6%	−1.5%
	Potash (K_2O) use	−0.9%	−1.1%	−0.8%
Rest of EU	Nitrogen use	−0.7%	−0.7%	−0.6%
	Phosphate (P_2O_5) use	−0.2%	−0.2%	−0.2%
	Potash (K_2O) use	−0.6%	−0.6%	−0.6%
India	Nitrogen use	−21.7%	−21.2%	−22.7%
	Phosphate (P_2O_5) use	−9.4%	−8.2%	−10.8%
	Potash (K_2O) use	−6.7%	−4.5%	−7.2%
Russia	Nitrogen use	−4.6%	−4.7%	−4.5%
	Phosphate (P_2O_5) use	−1.2%	−1.3%	−1.2%
	Potash (K_2O) use	−1.8%	−2.0%	−1.7%
Ukraine	Nitrogen use	−29.2%	−29.3%	−29.2%
	Phosphate (P_2O_5) use	−1.7%	−1.7%	−1.6%
	Potash (K_2O) use	−4.5%	−4.7%	−4.4%
USA	Nitrogen use	−1.0%	−1.0%	−0.9%
	Phosphate (P_2O_5) use	−0.2%	−0.2%	−0.2%
	Potash (K_2O) use	−0.04%	−0.03%	−0.05%

and Ukraine, are much larger than those in other countries. In addition, the parameter of phosphate use for wheat production, deciding wheat yield in Ukraine, is greater than those in other countries.[8] Fertilizer use for wheat production has a negative correlation to the changing rate of domestic fertilizer price to domestic wheat producer price ratio.[9] The domestic urea, phosphate, and potassium price to domestic wheat price ratios are projected to increase, and these increasing ratios can drive decreased use of nitrogen, phosphate, and potash for wheat production in Ukraine and India. Among all scenarios, the decreasing rates of fertilizer use for

[8] Refer to Appendix Tables A4-2 and A4-3.
[9] Refer to Appendix Tables A1-1, A1-2, A1-3, A2-1, A2-2, A2-3, A3-1, A3-2, and A3-3.

Table 6. Average changing rate of wheat production between scenarios and baseline from 2022 to 2040

Countries/Region	Scenario 1 2022-2040	Scenario 2 2022-2040	Scenario 3 2022-2040
Yield			
Argentina	−0.2%	−0.2%	−0.2%
Australia	0.0%	0.0%	0.0%
Canada	−1.9%	−1.9%	−1.9%
China	−0.7%	−0.7%	−0.7%
Egypt	−0.9%	−0.9%	−0.9%
France	−0.4%	−0.4%	−0.3%
Germany	−0.5%	−0.5%	−0.4%
Other EU	−0.2%	−0.2%	−0.2%
India	−4.2%	−3.9%	−4.6%
Russia	−1.1%	−1.1%	−1.0%
Ukraine	−3.5%	−3.5%	−3.5%
USA	0.0%	0.0%	0.0%
Rest of the World	0.8%	0.7%	0.8%
Area Harvested			
Argentina	53.5%	53.2%	53.7%
Australia	−1.4%	−1.5%	−1.3%
Canada	−1.8%	−2.0%	−1.7%
China	−1.1%	−1.2%	−1.0%
Egypt	−10.7%	−10.8%	−10.7%
France	3.5%	3.4%	3.6%
Germany	−0.6%	−0.8%	−0.5%
Other EU	−4.8%	−4.9%	−4.7%
India	−5.5%	−4.7%	−5.9%
Russia	−14.0%	−14.1%	−14.0%
Ukraine	2.4%	2.2%	2.6%
USA	7.6%	7.4%	7.7%
Rest of the World	1.9%	1.8%	2.0%
Production			
World	−1.6%	−1.6%	−1.6%
Argentina	53.2%	52.9%	53.4%
Australia	−1.4%	−1.5%	−1.3%
Canada	−3.9%	−4.1%	−3.7%
China	−1.7%	−1.8%	−1.6%
Egypt	−11.5%	−11.6%	−11.4%
EU	−2.4%	−2.5%	−2.3%
France	3.2%	3.1%	3.3%
Germany	−0.9%	−1.1%	−0.8%
Other EU	−5.0%	−5.1%	−4.9%
India	−9.5%	−8.4%	−10.2%
Russia	−14.8%	−15.0%	−14.7%
Ukraine	1.9%	1.7%	2.1%
USA	7.6%	7.4%	7.7%
Rest of the World	2.9%	2.7%	3.0%

Table 7. Average changing rate of global wheat market between scenarios and baseline from 2022 to 2040

	Changing rate between Scenario1 and Baseline projection from 2022 to 2040	Changing rate between Scenario 2 and Baseline projection from 2022 to 2040	Changing rate between Scenario 3 and Baseline projection from 2022 to 2040
World			
Production	−1.6%	−1.6%	−1.6%
Consumption	−1.6%	−1.6%	−1.6%
Exports	−0.7%	−0.5%	−0.9%
Imports	−0.7%	−0.5%	−0.9%
International wheat price	114.2%	109.0%	117.7%

Table 8. Scenario impact on international wheat price (2019/21-2040)

Scenario/Baseline	Coefficient of variation (CV)	Standard Deviation	Average
Baseline	0.3975	153.1202	385.1603
Scenario 1	1.0931	1,049.6084	960.2177
Scenario 2	1.0578	983.9689	930.1956
Scenario 3	1.1156	1,094.3354	980.9760

wheat production and yield in India and Ukraine are greater than those in other countries in all scenarios from 2022 to 2040 (Table 5). Therefore, India and Ukraine are the most vulnerable wheat producing countries to be affected by the fertilizer price increase, among the countries covered in this model.

Among scenarios, the average changing rates of wheat production in India divided by the average changing rate of international wheat price are 0.0832 in scenario 1, 0.0771 in scenario 2, and 0.0867 in scenario 3.[10] The ratio of the average changing rate of wheat production to average changing rate of international wheat price is the highest in scenario 3. As a result, the deceasing wheat production in India contributes to increasing international wheat price due to its decreasing fertilizer subsidy. Therefore, it shows that maintaining fertilizer subsidy can contribute in preventing international wheat price increase. The CVs of the international wheat prices from 2019/21-2040 to 2040 in all scenarios are higher than those in the baseline projection (0.3975) (Table 8). As a result, the CV is calculated as 1.0931 (scenario 1), 1.0578 (scenario 2), and 1.1156 (scenario 3) as shown in Table 8. The CV from scenario 3 is the highest of all scenarios.

Conclusion

This study examined how increasing fertilizer prices will affect global wheat markets and their price volatility and how fertilizer subsidies will mitigate the impact on global wheat market.

This study showed that increasing fertilizer prices led to decreasing fertilizer use for wheat production and wheat yield by increasing fertilizer price to wheat producer price ratio. The study demonstrated that increasing fertilizer prices could lead to a decrease in wheat production. These fertilizer price increases can affect the wheat markets through the changing rates of fertilizer use for wheat production, wheat yield, and planted areas. All scenarios showed that increasing fertilizer prices drove international wheat prices higher and led to price volatility. In scenario 2, constant fertilizer subsidies in India could mitigate the increase in international wheat prices and their volatility by mitigating the decreasing fertilizer use for wheat production, wheat yield, production, and exports. By contrast, in the case of scenario 3, further reduction of fertilizer subsidies in India could drive a further increase in international wheat prices and volatility. The simulation results suggest that the fertilizer subsidy program in India will contribute to price stability in the mid-long term by considering the fertilizer price increasing trend. The fertilizer subsidy program is an effective policy measure to mitigate the impact of the fertilizer price increases.

Among all scenarios, the decreasing rates of fertilizer use for wheat production and yield in India and Ukraine were larger than those in other countries from 2022 to 2040. In the case of scenario 2, the decreasing

[10] 9.5/114.2 in scenario 1, 8.4/109 in scenario 2, and 10.2/117.7 in scenario 3.

rates of nitrogen and potash use in Ukraine were greater than that in India and other countries, when the Indian fertilizer subsidy was constant from 2022 to 2040. In other scenarios, the decreasing rates of phosphate and potash use in India were greater than that in Ukraine and other countries. According to this study, the wheat yields in India and Ukraine are more sensitive to increasing fertilizer prices than those in other countries. Therefore, India and Ukraine are the most vulnerable wheat producing countries affected by the fertilizer price increase among the main wheat producing countries studied in this model. India has a fertilizer support program. However, Ukraine did not have one. This study concludes that Ukraine will be the most vulnerable country affected by the chemical fertilizer price change, as well as India. Therefore, to prevent international wheat price increase and volatility, international cooperation is urgently required for Ukraine to support in mitigating the fertilizer price increase, as well as other input price increases, lack of agricultural labor, and investments. The CV and standard deviation from each scenario tend to have higher value than baseline values. This study may require considering other methods of analysis for price volatility. This is a future direction of this study.

Acknowledgements

The author wishes to thank Dr. Motoki Nishimori, a staff member of the Institute for Agro-Environmental Sciences, NARO, Japan, for providing the historical and forecast climate data.

The author appreciates contributions from Dr. Tadashi Yoshihashi, Dr. Ai Leon, Dr. Fujio Nagumo, Dr. Jun Furuya, and Dr. Eiichi Kusano of the Japan International Research Center for Agricultural Sciences (JIRCAS) for providing the fertilizer data and technical inputs. The author also appreciates the crucial and valuable comments from anonymous reviewers.

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Appendix. Equations for the developed WECC model

1. Phosphate use for wheat equations depends on domestic wheat producer price, the changing rate of domestic DAP price to domestic wheat producer price ratio, domestic TSP price to domestic wheat producer price ratio, and GDP in the following equation.

$$\ln (PHOUW_{t\ c} / PHOUW_{t-1,c}) = a1 \ln ((DAPP_{t,\ c} / DWP_{t,c}) / ((DAPP_{t-1,\ c} / DWP_{t,-1c})) + a2 \ln ((TSPP_{t,\ c} / DWP_{t,c}) / ((TSPP_{t-1,\ c} / DWP_{t,-1c})) + a3 \ln (DWP_{t,c} / DWP_{t-1,c}) + a4 \ln (GDP_{t,c} / GDP_{t-1,c}) \quad 1)$$

where *PHOUW* denotes phosphate use for wheat, *DAPP* denotes domestic diammonium phosphate price, *TSPP* denotes domestic triple superphosphate price, *DWP* is the domestic wheat producer price, *GDP* is the real price base of GDP, *t* is time, *c* is countries/region, and a1-a4 are parameters (Tables A1-1, A1-2, and A1-3).

2. Nitrogen use for wheat equations depends on domestic wheat producer price, the changing rate of domestic urea price to domestic wheat producer price ratio, and GDP as follows:

$$\ln (NITUW_{t,c} / NITUW_{t-1,c}) = a5 \ln ((UREP_{t,c} / DWP_{t,c}) / ((UREP_{t-1,\ c} / DWP_{t,-1c})) + a6 \ln (DWP_{t,c} / DWP_{t-1,c}) + a7 \ln (GDP_{t,c} / GDP_{t-1,c}) \quad 2)$$

where *NITUW* denotes nitrogen use for wheat production, *UREP* denotes domestic urea price, and a5-7 are parameters (Tables A2-1, A2-2, and A2-3).

3. Potash use for wheat equations depends on domestic wheat producer price, the changing rate of domestic potassium chloride price to domestic wheat producer price ratio, and GDP.

$$\ln (POTUW_{t,c} / POTUW_{t-1,c}) = a8 \ln ((POTP_{t,c} / DWP_{t,c}) / ((POTP_{t-1,\ c} / DWP_{t,-1c})) + a9 \ln (DWP_{t,c} / DWP_{t-1,c}) + a10 \ln (GDP_{t,c} / GDP_{t-1,c}) \quad 3)$$

where *POTUW* denotes potash use for wheat production, *POTP* denotes domestic potassium chloride price, and a8-a10 are parameters (A3-1, A3-2, and A3-3).

4. Domestic DAP, TSP, urea, and potassium chloride prices are derived from the difference between international prices and fertilizer subsidies as follows:

$$DAPP_{t,\ c} = IDAPP_{t,\ c} - FESUBDAP_{t,\ c} \quad 4)$$

$$TSPP_{t,\ c} = ITSP_{t,\ c} - FESUBTSP_{t,\ c} \quad 5)$$

$$UREP_{t,\ c} = IUREP_{t,\ c} - FESUBUR_{t,\ c} \quad 6)$$

$$POTP_{t,\ c} = IPOTP_{t,\ c} - FESUBPO_{t,\ c} \quad 7)$$

where *IDAPP* is the international DAP price and *FESUBDAP* is the subsidy for DAP. *ITSP* is the international TSP price, and *FESUBTSP* is the subsidy for TSP. *IUREP* is the international urea price, and *FESUBUR* is the subsidy for urea. *IPOTP* is the international potassium chloride price, and *FESUBPO* is the subsidy for potassium chloride.

5. The wheat yield equation depends on the annual flowering season averages of temperature, precipitation, amount of solar radiation, lagging agricultural investments, fertilizer uses, employment in agriculture, and pesticide use as follows:

$$\ln (Y_{t,c} / Y_{t-1,\ c}) = a11 \ln (TEMFLAV_{t,\ c} / TEMFLAV_{t-1,c}) + a12 \ln (PREFLAV_{t,\ c} / PREFLAV_{t-1,c}) + a13 \ln (SORFLAV_{t,\ c} / SORFLAV_{t-1,c}) + a14 \ln (AGIS_{t-1,\ c} / AGIS_{t-2,c}) + a15 \ln (DMF_{t-1,\ c} / DMF_{t-2,c}) + a16 \ln (LD_{t-1,\ c} / LD_{t-2,c}) + a17 \ln (AME_{t-1,\ c} / AME_{t-2,c}) + a18 \ln (NITUW_{t,\ c} / NITUW_{t-1,c}) + a19 \ln (PHOUW_{t,\ c} / PHOUW_{t-1,c}) + a20 \ln (POTUW_{t,\ c} / POTUW_{t-1,c}) + a21 \ln (PESTU_{t,\ c} / PESTU_{t-1,c}) + a22 \ln (AGL_{t,\ c} / AGL_{t-1,c}) \quad 8)$$

where *Y* is wheat yield, *TEMFLAV* is the average temperature of the flowering season, *PREFLAV* is the average precipitation of the flowering season, *SORFLAV* is the average of the amount of solar radiation of the flowering season, *AGIS* is the investment amount of agricultural knowledge and innovation systems, *DMF* is the development and maintenance of infrastructure, *LD* denotes agricultural land development, *AME* denotes agricultural machinery/equipment, *NITUW* denotes the use of nitrogen for wheat production, *PHOUW* denotes the use of phosphate for wheat production, *POTUW* denotes the use of potash for wheat production, *PESTU* denotes the use of pesticides, *AGL* denotes employment in agriculture, and a11-a22 are parameters (A4-1, A4-2, and A4-3).

6. The wheat planted area equation depends on the domestic producer prices of wheat, competitive commodity prices, precipitation, lagging agricultural investments, domestic fertilizer prices, employment in agriculture, and domestic diesel prices as follows:

$$\ln(APW_{t,c} / APW_{t-1,c}) = a23 \ln(DWP_{t,c} / DWP_{t-1,c}) + a24 \ln(PRCAV_{t,c} / PRCAV_{t-1,c}) + a25 \ln(DMP_{t,c} / DMP_{t-1,c}) + a26 \ln(DSYP_{t,c} / DSYP_{t-1,c}) + a27 \ln(DCGP_{t,c} / DCGP_{t-1,c}) + a28 \ln(DVOP_{t,c} / DVOP_{t-1,c}) + a29 \ln(DSBP_{t,c} / DSBP_{t-1,c}) + a30 \ln(DRP_{t,c} / DRP_{t-1,c}) + a31 \ln(AGIS_{t-1,c} / AGIS_{t-2,c}) + a32 \ln(DMF_{t-1,c} / DMF_{t-2,c}) + a33 \ln(LD_{t-1,c} / LD_{t-2,c}) + a34 \ln(AME_{t-1,c} / AME_{t-2,c}) + a35 \ln(UREP_{t,c} / UREP_{t-1,c}) + a36 \ln(DAPP_{t,c} / DAPP_{t-1,c}) + a37 \ln(TSPP_{t,c} / TSPP_{t-1,c}) + a38 \ln(POTP_{t,c} / POTP_{t-1,c}) + a39 \ln(DIEDP_{t,c} / DIEDP_{t-1,c}) + a40 \ln(AGL_{t,c} / AGL_{t-1,c}) \qquad 9)$$

where *APW* is the wheat planted area, *PRCAV* is the average precipitation, *DMP* is domestic corn producer price, *DSYP* is domestic soybean producer price, *DCGP* is domestic coarse grain producer price, *DVOP* is domestic vegetable oil producer price, *DSBP* is domestic white sugar producer price, *DRP* is domestic rice producer price, *DIEDP* denotes domestic diesel price, and a23-a40 are parameters (A5-1, A5-2, and A5-3).

7. The wheat harvested area is derived from the difference between the planted and abandoned areas. Furthermore, wheat production is calculated by multiplying the harvested area and wheat yield as follows:

$$AHW_{t,c} = APW_{t,c} - ABD_{t,c} \qquad 10)$$

$$QPW_{t,c} = AHW_{t,c} * Y_{t,c} \qquad 11)$$

where *AHW* is the harvested area and *ABD* is the abandoned area. The abandoned area is an exogenous variable, and it will be utilized for simulation for future studies. *QPW* denotes wheat production.

8. The model determines the production, consumption, exports, imports, and ending stocks for each simulation year. The wheat market clearing price is obtained from the following equilibrium conditions by using the *Gauss–Seidel algorithm*: Wheat, No. 1 Hard Red Winter, ordinary protein, Kansas City, which refers to the international wheat market clearing price.

$$\Sigma \; IMW_{t,c} = \Sigma \; EXW_{t,c} \qquad 12)$$

where *IMW* denotes wheat imports and *EXW* denotes wheat exports.

Table A1-1. Estimation of parameters (phosphate use for wheat (1))

	France (EU)	*t-statistic (Year for dummy)*	Germany (EU)	*t-statistic (Year for dummy)*	Poland (EU)	*t-statistic (Year for dummy)*	China	*t-statistic (Year for dummy)*	India	*t-statistic (Year for dummy)*
a1, Domestic diammonium phosphate price /domestic wheat producer price (t/t-1)	–	–	−0.3877	*−0.9870*	–	–	–	–	−0.1771	*−1.4362*
a2, Domestic triple superphosphate price /domestic wheat producer price (t/t-1)	−0.3090	*−2.2385*	−0.3277	*−1.4232*	−0.3386	*−1.5215*	−0.0902	*−2.3789*	–	–
a3, Domestic wheat producer price (t/t-1)	–	–	–	–	0.3569	*1.6741*	0.0781	*1.6198*	0.0781	*1.6198*
a4, GDP growth rate (t/t-1)	–	–	–	–	–	–	–	–	0.3514	*3.9673*
Time trend (t/t-1)	0.3928	3.2298	−1.2418	−3.8069	0.5933	*1.2057*	0.3251	*5.1055*	0.1409	*1.3315*
Constant	12.2189	*57.5598*	17.3438	*16.3775*	10.8908	*7.6078*	14.6578	*57.0349*	13.3218	*42.3062*
Dummy 1	0.3636	*2.1392 (1998)*	0.1986	*1.6926 (2014)*	−0.5683	*−4.3836 (1991)*	0.2042	*2.0690 (1997)*	−0.2284	*−2.2874 (1993)*
Dummy 2	−0.3713	*−2.0161 (2010)*	–	–	0.3106	*2.8909 (2007)*	−0.2094	*−2.0000 (2000)*	0.3617	*3.4194 (2011)*
Dummy 3	−0.6023	*−3.4245 (2011)*	–	–	−0.2170	*−2.1703 (2014)*	−0.2299	*−2.2829 (2001)*	–	–
Sample	1992-2020		1991-2020		1991-2020		1990-2016		1990-2016	
R-squared	0.9355		0.9023		0.8855		0.9172		0.9172	
Adjusted R-square	0.8996		0.8584		0.8155		0.8924		0.8924	
Durbin-Watson stat	1.6470		1.8113		1.8739		1.1990		1.1990	

Note: Dummy variables apply to extraordinary political events, conflicts, sudden strikes on harbors and railways and others, speculative movements, and other technical and political factors, except for fundamental factors for deciding explained variables.

Table A1-2. Estimation of parameters (phosphate use for wheat (2))

	USA	*t-statistic (Year for dummy)*	Russia	*t-statistic (Year for dummy)*	Ukraine	*t-statistic (Year for dummy)*	Canada	*t-statistic (Year for dummy)*
a1, Domestic diammonium phosphate price /domestic wheat producer price (t/t-1)	−0.1099	*−0.8925*	−0.1539	*−0.1559*	–	–	–	–
a2, Domestic triple superphosphate price /domestic wheat producer price (t/t-1)	–	–	–	–	−0.1244	*−1.4299*	−0.1775	*−4.3192*
a3, Domestic wheat producer price (t/t-1)	0.0003	*0.7817*	0.0695	*3.0686*	–	–	0.0166	*1.3077*
a4, GDP growth rate (t/t-1)	–	–	–	–	0.2859	*0.9717*	0.1138	*5.3483*
Time trend (t/t-1)	0.0787	*2.2891*	0.3887	*1.6012*	−0.3162	*−1.6585*	−0.2317	*−2.1089*
Constant	13.2602	*171.2808*	13.7218	*30.2544*	8.6566	*20.4864*	11.0811	*29.5607*
Dummy 1	−0.0771	*−0.3621 (2002)*	0.3960	*2.5781 (2017)*	0.8307	*2.9969 (1997)*	−0.2990	*−1.9913 (1999)*
Dummy 2	−0.2904	*−5.9998 (2008)*	0.3896	*2.5036 (2018)*	−0.9753	*−3.9108 (2002)*	0.2921	*2.1350 (2005)*
Dummy 3	–	–	–	–	−0.8671	*−3.1876 (2007)*	−0.5400	*−3.8781 (2010)*
Sample	1991-2020		1992-2019		1994-2019		1992-2020	
R-squared	0.8864		0.9183		0.9365		0.8818	
Adjusted R-square	0.8266		0.8702		0.8867		0.7635	
Durbin-Watson stat	2.1749		1.8599		1.8326		2.1135	

Table A1-3. Estimation of parameters (phosphate use for wheat (3))

	Australia	*t-statistic (Year for dummy)*	Argentina	*t-statistic (Year for dummy)*	Egypt	*t-statistic*	Pakistan (The rest of the world)	*t-statistic (Year for dummy)*
a1, Domestic diammonium phosphate price /domestic wheat producer price (t/t-1)	−0.3159	*−1.5787*	–	–	–	–	–	–
a2, Domestic triple superphosphate price /domestic wheat producer price (t/t-1)	–	–	−0.2820	*−1.4511*	−0.4033	*−1.8128*	−0.1591	*−3.2235*
a3, Domestic wheat producer price (t/t-1)	–	–	0.0249	*1.1996*	–	–	0.1265	*1.5533*
a4, GDP growth rate (t/t-1)	–	–	–	–	–	–	0.6849	*4.7909*
Time trend (t/t-1)	0.2597	*6.5854*	0.8596	*15.8932*	0.3402	*6.5637*	0.1100	*2.9117*
Constant	12.8605	*160.0229*	9.4092	*34.6868*	5.0477	*11.4507*	11.5896	*86.5086*
Dummy 1	−0.2017	*−3.8270 (1993)*	−0.5915	*−2.8841 (2002)*	–	–	−0.1552	*−1.8121 (1994)*
Dummy 2	−0.3247	*−5.8694 (2009)*	−0.6594	*−3.9876 (2009)*	–	–	−0.2208	*−2.6548 (1996)*
Dummy 3	–	–	−0.3950	*−2.2687 (2015)*	–	–	0.1737	*2.1161 (2005)*
Sample	1993-2020		1991-2020		1992-2020		1991-2020	
R-squared	0.9254		0.9643		0.9066		0.9626	
Adjusted R-square	0.8940		0.9456		0.8692		0.9457	
Durbin-Watson stat	2.0014		1.7704		2.2865		2.1764	

Table A2-1. Estimation of parameters (nitrogen use for wheat (1))

	France (EU)	*t-statistic (Year for dummy)*	Germany (EU)	*t-statistic (Year for dummy)*	Poland (EU)	*t-statistic (Year for dummy)*	China	*t-statistic (Year for dummy)*	India	*t-statistic (Year for dummy)*
a5, Domestic urea price / domestic wheat producer price (t/t-1)	−0.3446	*−2.0619*	−0.1357	*−1.6841*	−0.0059	*−0.9133*	−0.2100	*−2.1971*	−0.0710	*−1.5803*
a6, Domestic wheat producer price (t/t-1)	−	−	0.0240	*1.4291*	0.0429	*1.6737*	0.1715	*2.3299*	0.1120	*2.3928*
a7, GDP growth rate (t/t-1)	−	−	0.1227	*1.0900*	0.2600	*1.5986*	−	−	0.1549	*4.3616*
Time trend (t/t-1)	−0.0441	*−1.8898*	−0.5107	*−3.2437*	0.2310	*1.4330*	0.1130	*2.9593*	0.1234	*3.5565*
Constant	3.4432	*195.9788*	16.7145	*32.7737*	12.5854	*24.3873*	14.8789	*130.4486*	14.3554	*132.9611*
Dummy 1	−0.1697	*−2.9085 (1992)*	0.1222	*2.2029 (2000)*	0.1554	*1.9805 (1997)*	−0.1658	*−3.3863 (1993)*	0.0795	*0.0797 (1998)*
Dummy 2	−0.1600	*−2.7834 (1993)*	−0.3494	*−2.1577 (2016)*	0.1183	*1.5734 (2007)*	−0.1759	*−3.7698 (1994)*	−0.0741	*−1.6633 (2002)*
Dummy 3	0.1190	*2.2769 (2007)*	−0.1229	*−2.7834 (1993)*	−	−	−	−	−	−
Sample	1991-2020		1992-2020		1992-2020		1991-2020		1991-2019	
R-squared	0.7155		0.8402		0.8297		0.9534		0.9871	
Adjusted R-square	0.6072		0.7646		0.7730		0.9324		0.9810	
Durbin-Watson stat	1.5263		2.1939		1.5196		2.0103		1.9845	

Table A2-2. Estimation of parameters (nitrogen use for wheat (2))

	USA	*t-statistic (Year for dummy)*	Russia	*t-statistic (Year for dummy)*	Ukraine	*t-statistic (Year for dummy)*	Canada	*t-statistic*
a5, Domestic urea price / domestic wheat producer price (t/t-1)	−0.0548	*−1.0896*	−0.3215	*−1.1870*	−0.1585	*−2.4797*	−0.0895	*−1.8180*
a6, Domestic wheat producer price (t/t-1)	0.0706	*3.4623*	0.5826	*2.4698*	−	−	0.0808	*0.9453*
a7, GDP growth rate (t/t-1)	−	−	−	−	0.3744	*1.6779*	0.4877	*2.1320*
Time trend (t/t-1)	0.0566	*2.7214*	0.2045	*1.6904*	0.2187	*1.9075*	−0.0542	*−1.5151*
Constant	14.1075	*309.4500*	13.3942	*42.7389*	11.8067	*56.1674*	12.8496	*60.3820*
Dummy 1	−0.1134	*−3.8304 (2008)*	−0.3243	*−2.5987 (2004)*	−0.4930	*−2.0310 (2003)*	−	−
Dummy 2	−	−	−0.3174	*−2.4774 (2007)*	0.4903	*1.8200 (2009)*	−	−
Dummy 3	−	−	−0.2934	*−2.2305 (2013)*	0.4113	*1.8216 (2016)*	−	−
Sample	1990-2020		1993-2019		1993-2019		1992-2020	
R-squared	0.8333		0.8451		0.8946		0.8672	
Adjusted R-square	0.7727		0.7483		0.8388		0.8141	
Durbin-Watson stat	1.9327		1.6611		1.5524		2.0897	

Table A2-3. Estimation of parameters (nitrogen use for wheat (3))

	Australia	*t-statistic (Year for dummy)*	Argentina	*t-statistic (Year for dummy)*	Egypt	*t-statistic (Year for dummy)*	Pakistan (The rest of the world)	*t-statistic*
a5, Domestic urea price / domestic wheat producer price (t/t-1)	−0.3301	*−3.4849*	−0.0349	*−1.0190*	−0.1147	*−1.2057*	−0.1396	*−1.6671*
a6, Domestic wheat producer price (t/t-1)	−	−	0.2893	*1.7848*	0.1080	*1.3517*	0.0428	*1.6453*
a7, GDP growth rate (t/t-1)	0.3288	*3.0634*	−	−	−	−	−	−
Time trend (t/t-1)	0.2828	*4.5539*	0.8313	*5.5777*	0.3408	*7.7179*	0.2243	*7.2482*
Constant	11.7409	*160.0338*	8.5969	*10.0955*	11.8069	*201.6629*	13.3328	*176.0526*
Dummy 1	−0.1960	*−2.0771 (1994)*	0.3406	*2.0252 (1996)*	−0.2253	*−4.0129 (1994)*	−	−
Dummy 2	−0.1974	*−2.1835 (1995)*	−0.2952	*−1.9068 (2015)*	−0.0902	*−1.7541 (2007)*	−	−
Dummy 3	−0.2613	*−2.9194 (2003)*	−	−	−	−	−	−
Sample	1992-2019		1995-2016		1993-2000		1992-2020	
R-squared	0.9422		0.9289		0.9207		0.9647	
Adjusted R-square	0.9179		0.9122		0.8874		0.9573	
Durbin-Watson stat	1.7630		1.2178		1.9268		1.7450	

Table A3-1. Estimation of parameters (potash use for wheat (1))

	France (EU)	*t-statistic (Year for dummy)*	Germany (EU)	*t-statistic (Year for dummy)*	Poland (EU)	*t-statistic (Year for dummy)*	China	*t-statistic (Year for dummy)*
a8, Domestic potassium chloride price /domestic wheat producer price (t/t-1)	−0.1358	*−3.0667*	−0.1786	*−1.5755*	−0.0485	*−2.2305*	−0.0861	*−1.1980*
a9, Domestic wheat producer price (t/t-1)	0.1022	*1.6270*	0.0272	*1.5572*	–	–	–	–
a10, GDP growth rate (t/t-1)	0.2362	*1.6763*	–	–	0.1054	*0.9818*	–	–
Time trend (t/t-1)	0.2362	*1.6763*	−0.7365	*−7.7033*	1.5148	*7.5608*	0.1433	*1.2277*
Constant	12.4141	*56.9933*	15.9718	*42.6063*	7.5947	*11.5635*	11.7619	*30.4219*
Dummy 1	−0.2861	*−1.4178 (1992)*	−0.1534	*−2.3364 (2005)*	−0.1971	*−2.0888 (1992)*	0.3941	*2.4282 (2007)*
Dummy 2	−0.2904	*−1.2903 (2020)*	−0.9439	*−14.2714 (2008)*	−0.2298	*−2.7941 (2004)*	–	–
Dummy 3	–	–	−0.1534	*−2.3929 (2011)*	–	–	–	–
Sample	1992-2020		1991-2020		1992-2020		1991-2020	
R-squared	0.9469		0.9681		0.9284		0.9631	
Adjusted R-square	0.9292		0.9560		0.8946		0.9491	
Durbin-Watson stat	2.1078		1.5176		1.7742		1.4107	

Table A3-2. Estimation of parameters (potash use for wheat (2))

	India	*t-statistic (Year for dummy)*	USA	*t-statistic (Year for dummy)*	Russia	*t-statistic (Year for dummy)*	Ukraine	*t-statistic (Year for dummy)*
a8, Domestic potassium chloride price /domestic wheat producer price (t/t-1)	−0.1526	*−1.3488*	−0.0145	*−1.2213*	−0.1872	*−1.3523*	−0.2408	*−1.9364*
a9, Domestic wheat producer price (t/t-1)	–	–	–	–	–	–	–	–
a10, GDP growth rate (t/t-1)	0.1258	*0.9070*	–	–	0.1278	*0.9637*	0.1803	*1.1866*
Time trend (t/t-1)	0.4256	*2.6743*	0.0415	*0.9663*	−0.3704	*−2.5093*	1.2221	*7.8692*
Constant	11.7110	*25.4366*	11.7315	*82.6247*	12.0581	*67.1882*	6.4423	*17.1270*
Dummy 1	0.4543	*3.4348 (2010)*	−0.4515	*−9.0216 (2008)*	−0.5001	*−2.6725 (1996)*	2.0578	*8.9825 (1997)*
Dummy 2	–	–	–	–	−0.5673	*−3.0138 (1998)*	0.8772	*4.2481 (1998)*
Dummy 3	–	–	–	–	0.5768	*3.0954 (2019)*	−0.4298	*−2.4593 (2003)*
Sample	1992-2020		1991-2020		1993-2019		1997-2019	
R-squared	0.9364		0.9019		0.8464		0.9739	
Adjusted R-square	0.9110		0.8645		0.7651		0.9558	
Durbin-Watson stat	1.6785		2.4016		1.9899		1.7828	

Table A3-3. Estimation of parameters (potash use for wheat (3))

	Canada	*t-statistic (Year for dummy)*	Australia	*t-statistic (Year for dummy)*	Egypt	*t-statistic*	Pakistan (The rest of the world)	*t-statistic (Year for dummy)*
a8, Domestic potassium chloride price /domestic wheat producer price (t/t-1)	−0.1491	*−1.4094*	−0.0243	*−2.8705*	−0.0671	*4.8811*	−0.1591	*−2.1378*
a9, Domestic wheat producer price (t/t-1)	–	–	–	–	–	–	0.0494	*0.9845*
a10, GDP growth rate (t/t-1)	–	–	0.0249	*0.9278*	0.6931	*3.1388*	0.1355	*1.2814*
Time trend (t/t-1)	0.1636	*1.0323*	0.2875	*5.4078*	0.1380	*1.1243*	−0.0137	*−0.9054*
Constant	9.4667	*18.5018*	10.1217	*79.4898*	8.0174	*34.1439*	8.8563	*18.6586*
Dummy 1	−0.8711	*−5.9815 (2006)*	0.2356	*2.7172 (1994)*	–	–	−1.0398	*−4.0369 (1996)*
Dummy 2	0.0202	*1.1345 (2015)*	−0.2395	*−2.7495 (2003)*	–	–	−0.6573	*−2.5246 (2001)*
Dummy 3	–	–	–	–	–	–	0.6808	*2.5119 (2007)*
Sample	1983-2020		1992-2020		1991-2020		1992-2020	
R-squared	0.8710		0.8599		0.8706		0.8049	
Adjusted R-square	0.7824		0.8038		0.8294		0.7269	
Durbin-Watson stat	2.3581		2.0168		2.1558		1.5890	

Table A4-1. Estimation of parameters (yield (1))

	France (EU)	*t-statistic (Year for dummy)*	Germany (EU)	*t-statistic*	Poland (EU)	*t-statistic (Year for dummy)*	China	*t-statistic (Year for dummy)*
a11, Average temperature of flowering season (t/t-1)	−0.1235	*−1.5077*	−0.1245	*−1.6700*	0.1506	*1.5250*	−0.1852	*−1.1876*
a12, Average precipitation of flowering season (t/t-1)	0.1244	*1.1905*	0.0227	*1.7411*	0.1673	*2.9484*	0.1490	*2.0994*
a13, Average amount of solar radiation of flowering season (t/t-1)	0.1021	*2.5539*	0.7768	*1.2840*	0.5502	*1.6272*	0.1865	*2.0187*
a14, Agricultural knowledge and innovation system (t-1/t-2)	0.2618	*1.6493*	−	−	0.5492	*2.7276*	0.0216	*1.0583*
a15, Development and maintenance of infrastructure (t-1/t-2)	0.0557	*1.0487*	−	−	−	−	0.0573	*1.2563*
a16, Land Development (t-1/t-2)	−	−	−	−	−	−	−	−
a17, Agricultural machinery and equipment (t-1/t-2)	−	−	−	−	−	−	−	−
a18, Nitrogen use for wheat production (t/t-1)	0.0657	*2.4493*	0.1117	*1.3952*	0.1396	*1.6921*	0.0472	*1.2374*
a19, Phosphate use for wheat production (t/t-1)	0.0975	*1.1778*	0.0849	*1.0316*	0.0415	*1.8604*	0.1605	*1.3353*
a20, Potash use for wheat production (t/t-1)	0.0219	*1.5018*	0.0831	*1.1374*	0.1436	*3.7412*	0.1181	*2.3868*
a21, Pesticide use for wheat production (t/t-1)	−	−	−	−	−	−	−	−
a22, Employment in agriculture (t/t-1)	−	−	−	−	0.4311	*1.8960*	−	−
Time trend (t/t-1)	−0.3584	*−2.4789*	0.0768	*1.8246*	0.1153	*1.3063*	−0.0092	*−1.5536*
Constant	11.6542	*38.5041*	0.4030	*3.7341*	10.3060	*10.1927*	1.0032	*5.8164*
Dummy 1	−0.1410	*−1.9499 (1997)*	−	−	0.1216	*1.9312 (2014)*	−0.1160	*−2.8424 (2003)*
Dummy 2	0.1825	*2.2673(2002)*	−	−	−0.6805	*−1.1681(2018)*	−0.0347	*−1.0593 (2011)*
Dummy 3	−	−	−	−	−	−	0.0846	*2.3815 (2019)*
Sample	1987-2020		1982-2008		1991-2019		1998-2019	
R-squared	0.7902		0.9602		0.9027		0.9817	
Adjusted R-square	0.7357		0.9391		0.8184		0.9616	
Durbin-Watson stat	1.9379		2.2704		2.4625		1.5582	

Table A4-2. Estimation of parameters (yield (2))

	India	*t-statistic*	USA	*t-statistic (Year for dummy)*	Russia	*t-statistic (Year for dummy)*	Ukraine	*t-statistic*
a11, Average temperature of flowering season (t/t-1)	−0.1245	*−1.6700*	−0.4956	*−1.4533*	−0.7413	*−1.6171*	−0.2506	*−1.7114*
a12, Average precipitation of flowering season (t/t-1)	0.0227	*1.7411*	0.0412	*1.3811*	−0.1080	*−1.3187*	−0.2013	*−1.2449*
a13, Average amount of solar radiation of flowering season (t/t-1)	0.7768	*1.2840*	1.1075	*1.0793*	0.2910	*1.5532*	−0.0891	*−2.7438*
a14, Agricultural knowledge and innovation system (t-1/t-2)	−	−	0.3687	*1.8864*	0.4003	*1.3750*	0.1296	*1.1268*
a15, Development and maintenance of infrastructure (t-1/t-2)	−	−	−	−	0.2260	*3.2531*	0.0334	*1.5009*
a16, Land Development (t-1/t-2)	0.9143	*2.2763*	−	−	−	−	−	−
a17, Agricultural machinery and equipment (t-1/t-2)	−	−	−	−	−	−	−	−
a18, Nitrogen use for wheat production (t/t-1)	0.2117	*1.3952*	0.0364	*1.4791*	0.1145	*1.4305*	0.1884	*1.3540*
a19, Phosphate use for wheat production (t/t-1)	0.0849	*1.0316*	0.1550	*1.7521*	0.0617	*1.0164*	0.1985	*1.5613*
a20, Potash use for wheat production (t/t-1)	0.0831	*1.1374*	0.0609	*1.4366*	0.2245	*1.7624*	0.1508	*1.7270*
a21, Pesticide use for wheat production (t/t-1)	−	−	−	−	−	−	−	−
a22, Employment in agriculture (t/t-1)	−	−	0.3648	*1.0107*	0.6640	*2.2744*	0.8558	*1.6474*
Time trend (t/t-1)	0.0768	*1.8246*	0.0746	*1.5308*	−0.0088	*−0.7495*	−0.8264	*−1.5188*
Constant	0.4030	*3.7341*	0.6850	*1.8528*	1.1531	*1.4852*	4.6710	*2.8305*
Dummy 1	−	−	−0.0549	*−2.0667 (1996)*	−0.1786	*−1.9858 (2003)*	−	−
Dummy 2	−	−	−0.1796	*−2.4368 (2002)*	−	−	−	−
Dummy 3	−	−	0.1136	*1.7255 (2016)*	−	−	−	−
Sample	1982-2019		1991-2019		1997-2019		2001-2017	
R-squared	0.9602		0.8832		0.9345		0.9173	
Adjusted R-square	0.9391		0.7484		0.8559		0.7354	
Durbin-Watson stat	2.2704		1.8819		1.9245		2.3118	

Table A4-3. Estimation of parameters (yield (3))

	Canada	*t-statistic (Year for dummy)*	Australia	*t-statistic (Year for dummy)*	Argentina	*t-statistic (Year for dummy)*	Egypt	*t-statistic (Year for dummy)*	Pakistan (The rest of the world)	*t-statistic (Year for dummy)*
a11, Average temperature of flowering season (t/t-1)	−0.3254	*−1.8784*	−0.2409	*−1.3580*	0.1306	*0.8858*	0.3797	*3.1135*	−0.1866	*−1.1841*
a12, Average precipitation of flowering season (t/t-1)	0.0072	*0.9853*	0.1754	*2.7038*	0.1545	*1.3502*	−0.0089	*−1.0101*	0.0766	*3.7721*
a13, Average amount of solar radiation of flowering season (t/t-1)	−0.5876	*−1.4973*	0.1524	*2.1764*	−0.2411	*−1.0111*	0.0059	*0.9601*	1.1169	*2.0829*
a14, Agricultural knowledge and innovation system (t-1/t-2)	0.0684	*0.9529*	0.0900	*1.6079*	0.0552	*0.9567*	−	−	−	−
a15, Development and maintenance of infrastructure (t-1/t-2)	0.1349	*1.2847*	−	−	0.0157	*1.2895*	−	−	−	−
a16, Land Development (t-1/t-2)	−	−	−	−	−	−	0.6834	*2.9749*	−	−
a17, Agricultural machinery and equipment (t-1/t-2)	−	−	−	−	−	−	0.1276	*1.6589*	−	−
a18, Nitrogen use for wheat production (t/t-1)	0.1443	*1.5979*	0.1510	*1.8372*	0.1791	*0.9808*	0.0956	*1.5515*	0.1297	*1.5003*
a19, Phosphate use for wheat production (t/t-1)	0.1574	*0.9383*	0.1084	*1.2929*	0.1027	*1.8712*	0.0202	*0.9889*	0.0842	*1.5858*
a20, Potash use for wheat production (t/t-1)	0.1978	*1.7408*	0.0179	*0.9832*	−	−	0.1144	*0.9685*	0.0668	*3.1402*
a21, Pesticide use for wheat production (t/t-1)	−	−	−	−	−	−	−	−	−	−
a22, Employment in agriculture (t/t-1)	0.8220	*2.1995*	0.6784	*1.0983*	0.0774	*1.0670*	0.1565	*1.8945*	−	−
Time trend (t/t-1)	0.5263	*2.0617*	−0.0344	*−0.9530*	0.1721	*1.2428*	−0.3147	*−3.4634*	0.5153	*1.2634*
Constant	2.1144	*1.0585*	0.1785	*1.1314*	−0.7966	*−1.3696*	1.1565	*15.2572*	−0.5813	*−1.3669*
Dummy 1	−0.1168	*−1.9193(2002)*	0.5297	*2.7215(1995)*	−0.0236	*−1.0434(2005)*	−0.1286	*−5.5484(2000)*	0.1104	*3.4505 (2000)*
Dummy 2	0.1167	*1.5419 (2016)*	−0.5833	*−3.3723(2002)*	−0.2955	*−1.6534(2008)*	−0.1317	*−5.7848(2010)*	−	−
Dummy 3	−	−	−0.5523	*−3.4696(2006)*	−0.2751	*−1.6178(2012)*	−0.0270	*−1.1604(2014)*	−	−
Sample	1991-2019		1991-2019		2001-2019		1991-2019		1991-2019	
R-squared	0.9172		0.9023		0.8529		0.9619		0.9830	
Adjusted R-square	0.8552		0.7896		0.6747		0.9175		−0.9645	
Durbin-Watson stat	1.9485		2.5075		1.9026		2.2164		2.4438	

Table A5-1. Estimation of parameters (planted area (1))

	France (EU)	*t-statistic (Year for dummy)*	Germany (EU)	*t-statistic (Year for dummy)*	Poland (EU)	*t-statistic*	China	*t-statistic (Year for dummy)*
a23, Domestic wheat producer price (t/t-1)	0.3263	*9.3488*	0.3985	*2.4402*	0.1355	*1.2250*	0.1504	*3.6642*
a24, Average precipitation (t/t-1)	0.5139	*7.9154*	−0.0504	*−1.5976*	0.6666	*1.8369*	0.2677	*2.6238*
a25, Domestic maize producer price (t/t-1)	−0.2333	*−7.8241*	−0.0448	*−1.3087*	−0.0323	*−1.7451*	−0.1101	*−1.5882*
a26, Domestic soybeans producer price (t/t-1)	−	−	−	−	−	−	−	−
a27, Domestic coarse grain producer price (t/t-1)	−	−	−0.3394	*−0.8505*	−	−	−	−
a28, Domestic vegetable oil producer price (t/t-1)	−	−	−0.0134	*−1.2646*	−	−	−	−
a29, Domestic white sugar producer price (t/t-1)	−	−	−0.0196	*−0.9443*	−0.1603	*−3.5538*	−	−
a30, Domestic rice producer price (t/t-1)	−	−	−	−	−	−	−0.2120	*−1.3991*
a31, Agricultural knowledge and innovation system (t-1/t-2)	−	−	0.1671	*1.2910*	0.8562	*2.0333*	0.3589	*5.0272*
a32, Development and maintenance of infrastructure (t-1/t-2)	0.6525	*8.1952*	−	−	0.2747	*1.9746*	−	−
a33, Land development (t-1/t-2)	−	−	−	−	−	−	−	−
a34, Agricultural machinery and equipment (t-1/t-2)	−	−	−	−	−	−	−	−
a35, Domestic urea price (t/t-1)	−0.0498	*−8.8202*	−0.0784	*−1.2011*	−0.0843	*−1.4777*	−0.0226	*−3.7733*
a36, Domestic DAP price (t/t-1)	−0.0108	*−7.1660*	−	−	−0.0584	*−1.4101*	−0.0172	*−1.8312*
a37, Domestic TSP price (t/t-1)	−	−	−0.0295	*−1.0194*	−	−	−	−
a38, Domestic potash price (t/t-1)	−0.0398	*−8.4754*	−0.0605	*−0.9715*	−0.1710	*−1.2168*	−0.0802	*−3.1421*
a39, Domestic diesel price (t/t-1)	−0.3575	*−4.6294*	−	−	−0.7834	*−2.4956*	−0.0240	*−1.7349*
a40, Employment in agriculture (t/t-1)	0.2994	*3.0800*	0.4307	*0.9938*	0.6347	*1.5750*	−	−
Time trend (t/t-1)	2.1621	*7.6887*	0.3298	*1.5235*	−1.4246	*−1.7962*	−0.7394	*−4.5366*
Constant	7.4935	*8.042*	13.8492	*25.289*	18.8103	*7.8191*	11.9739	*28.5124*
Dummy 1	−0.0049	*−1.2923(2014)*	−0.0929	*−2.1730(2019)*	−	−	−0.1296	*−4.5171(2004)*
Dummy 2	−0.0091	*−0.9803(2018)*	−0.2870	*−5.6538(2020)*	−	−	0.0219	*1.1548(2009)*
Dummy 3	−	−	−	−	−	−	−	−
Sample	2001-2019		1992-2020		2000-2019		2000-2019	
R-squared	0.9989		0.9591		0.9920		0.9724	
Adjusted R-square	0.9818		0.9045		0.9747		0.9079	
Durbin-Watson stat	2.6469		2.1645		2.0597		2.5959	

Table A5-2. Estimation of parameters (planted area (2))

	India	*t-statistic*	USA	*t-statistic (Year for dummy)*	Russia	*t-statistic (Year for dummy)*	Ukraine	*t-statistic (Year for dummy)*
a23, Domestic wheat producer price (t/t-1)	0.0406	*0.7977*	0.1730	*5.0995*	0.4343	*4.5497*	0.3227	*11.3577*
a24, Average precipitation (t/t-1)	0.0527	*1.5012*	0.4190	*2.8295*	0.2792	*1.4002*	−0.1846	*−11.6979*
a25, Domestic maize producer price (t/t-1)	−	−	−0.3171	*−2.5870*	−0.4110	*−6.2700*	−0.9451	*−2.3515*
a26, Domestic soybeans producer price (t/t-1)	−	−	−	−	−	−	−	−
a27, Domestic coarse grain producer price (t/t-1)	−	−	−0.0239	*−1.0122*	−0.1797	*−2.3895*	−0.1399	*−2.2216*
a28, Domestic vegetable oil producer price (t/t-1)	−	−	−	−	−	−	−	−
a29, Domestic white sugar producer price (t/t-1)	−	−	−	−	−	−	−	−
a30, Domestic rice producer price (t/t-1)	−0.0685	*−1.5290*	−	−	−	−	−	−
a31, Agricultural knowledge and innovation system (t-1/t-2)	−	−	1.0254	*0.9244*	0.2888	*5.4935*	0.6516	*7.1290*
a32, Development and maintenance of infrastructure (t-1/t-2)	−	−	0.0281	*0.7353*	0.0684	*2.9082*	0.4711	*18.9089*
a33, Land development (t-1/t-2)	0.8588	*0.9740*	−	−	−	−	−	−
a34, Agricultural machinery and equipment (t-1/t-2)	−	−	−	−	−	−	0.0067	*1.1433*
a35, Domestic urea price (t/t-1)	−0.0196	*−1.6117*	−	−	−0.1425	*−5.6965*	−0.1390	*−1.5230*
a36, Domestic DAP price (t/t-1)	−0.0808	*−0.7692*	−0.0237	*−0.9347*	−	−	−0.3769	*−1.2710*
a37, Domestic TSP price (t/t-1)	−	−	−	−	−0.1531	*−3.1631*	−	−
a38, Domestic potash price (t/t-1)	−0.0413	*−1.3722*	−0.0374	*−0.9363*	−0.0630	*−1.9523*	−0.4372	*−6.7484*
a39, Domestic diesel price (t/t-1)	−	−	−0.0393	*−1.2297*	−0.3006	*−5.1097*	−0.9311	*−5.3727*
a40, Employment in agriculture (t/t-1)	−	−	1.0254	*0.9244*	0.7016	*2.2365*	0.9400	*11.5171*
Time trend (t/t-1)	0.1167	*1.1912*	−0.7846	*−2.7178*	0.5136	*1.6158*	−0.2612	*−1.5635*
Constant	9.7915	*41.447*	12.1593	*14.145*	9.1074	*11.1783*	11.8023	*10.0041*
Dummy 1	−	−	−0.1456	*−3.0890(2019)*	−0.0329	*−1.4155(2013)*	−0.4606	*−12.4243(2014)*
Dummy 2	−	−	−	−	−	−	−	−
Dummy 3	−	−	−	−	−	−	−	−
Sample	1992-2018		2001-2019		2000-2019		2001-2019	
R-squared	0.9470		0.9857		0.9949		0.9994	
Adjusted R-square	0.9082		0.9142		0.9677		0.9905	
Durbin-Watson stat	2.0209		1.8226		2.2312		2.2186	

Table A5-3. Estimation of parameters (planted area (3))

	Canada	*t-statistic (Year for dummy)*	Australia	*t-statistic*	Argentina	*t-statistic (Year for dummy)*	Egypt	*t-statistic*	Pakistan (The rest of the world)	*t-statistic*
a23, Domestic wheat producer price (t/t-1)	0.1771	*1.8318*	0.0140	*1.7315*	0.2170	*2.9539*	0.2526	*1.8483*	0.1015	*2.0981*
a24, Average precipitation (t/t-1)	0.0525	*1.2286*	0.3961	*2.7866*	0.8257	*1.2855*	0.1034	*0.9456*	0.0077	*1.2332*
a25, Domestic maize producer price (t/t-1)	−	−	−	−	−	−	−	−	−	−
a26, Domestic soybeans producer price (t/t-1)	−	−	−	−	−0.6401	*−1.4088*	−	−	−	−
a27, Domestic coarse grain producer price (t/t-1)	−	−	−0.0251	*−1.3346*	−0.2085	*−1.0986*	−	−	−	−
a28, Domestic vegetable oil producer price (t/t-1)	−0.1350	*−1.2537*	−	−	−	−	−	−	−	−
a29, Domestic white sugar producer price (t/t-1)	−	−	−	−	−	−	−	−	−	−
a30, Domestic rice producer price (t/t-1)	−	−	−	−	−	−	−	−	−	−
a31, Agricultural knowledge and innovation system (t-1/t-2)	0.1317	*1.1392*	0.2952	*3.2883*	−	−	−	−	−	−
a32, Development and maintenance of infrastructure (t-1/t-2)	0.1271	*1.6312*	−	−	−	−	−	−	−	−
a33, Land development (t-1/t-2)	−	−	−	−	−	−	0.4696	*0.8886*	−	−
a34, Agricultural machinery and equipment (t-1/t-2)	−	−	−	−	−	−	−	−	−	−
a35, Domestic urea price (t/t-1)	−0.0351	*−1.3870*	−0.0530	*−0.8999*	−0.0928	*−3.2863*	0.2052	*1.6402*	−0.0225	*−1.5992*
a36, Domestic DAP price (t/t-1)	−0.3398	*−3.4026*	−	−	−	−	−0.2282	*−0.7497*	−	−
a37, Domestic TSP price (t/t-1)	−0.0859	*−1.0497*	−0.1420	*−0.9307*	−0.0924	*−1.4449*	−0.1939	*−0.1585*	−0.0280	*−2.5821*
a38, Domestic potash price (t/t-1)	−0.0900	*−0.9799*	−0.0212	*−1.4526*	−	−	−0.0376	*−1.3682*	−0.0230	*−0.9071*
a39, Domestic diesel price (t/t-1)	−	−	−0.1692	*−1.2482*	−	−	−	−	−	−
a40, Employment in agriculture (t/t-1)	0.6866	*1.3040*	−	−	0.3331	*2.4826*	0.2240	*1.5087*	0.2725	*0.8002*
Time trend (t/t-1)	0.0567	*1.6067*	−0.4127	*−3.2767*	1.6420	*2.3818*	0.1542	*1.6725*	0.0193	*0.9411*
Constant	9.0546	*9.1022*	11.1862	*24.891*	8.2303	*16.0406*	6.2082	*10.221*	9.0461	*21.4967*
Dummy 1	0.0982	*1.1851(1992)*	−	−	−0.0822	*−1.4543 (2005)*	−	−	−	−
Dummy 2	−0.2707	*−3.3110(2002)*	−	−	−	−	−	−	−	−
Dummy 3	0.2182	*2.0285(2008)*	−	−	−	−	−	−	−	−
Sample	1992-2019		2001-2020		2002-2019		1993-2016		1991-2014	
R-squared	0.9531		0.9262		0.9316		0.8894		0.8902	
Adjusted R-square	0.8735		0.8441		0.7094		0.7881		0.7703	
Durbin-Watson stat	1.8044		2.4816		1.9062		2.7776		2.4713	

Table A6-1. Exogenous variables (1)

Countries/Region	Annual changing rate (2022-40)	
	Per Capita GDP	Population
EU	5.0%	−0.1%
China	7.5%	−0.2%
India	8.7%	0.7%
United States	4.6%	0.4%
Russia	0.4%	−0.3%
Ukraine	6.3%	−1.0%
Canada	4.8%	0.7%
Australia	3.8%	0.8%
Argentina	3.8%	0.5%
Indonesia	6.9%	0.6%
Egypt	5.7%	1.5%

Sources: IMF (2022) and United Nations (2022)

Table A6-2. Exogenous variables (2)

(USD/ton)

	2019/21	2040
International corn price	164	196.7
International coarse grain price	179	198.3
International rice price	375	415.5
International soybean price	402	446.1
International vegetable oil price	768	902.0
International white sugar price	430	452.6

Source: OECD-FAO (2022)

Table A6-3. Exogenous variables (3)

	Countries/Region	Annual changing rate (2022-2040)
Agricultural knowledge and innovation system	Australia	1.8%
	Canada	−0.5%
	United States	3.1%
	European Union	2.0%
	Argentina	−0.3%
	China (People’s Republic of)	5.4%
	India	2.9%
	Russia	1.3%
	Ukraine	3.1%
Development and maintenance of infrastructure	Australia	0.4%
	Canada	−2.6%
	United States	5.9%
	European Union	−4.3%
	Argentina	−1.4%
	China (People’s Republic of)	7.1%
	India	6.1%
	Russia	0.9%
	Ukraine	−2.5%

Source: OECD (2022)