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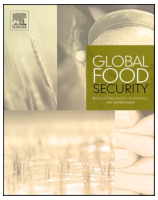

Needed global wheat stock and crop management in response to the war in Ukraine

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ABSTRACT

The war in Ukraine threatened to block 9% of global wheat exports, driving wheat prices to unprecedented heights. We advocate, that in the short term, compensating for such an export shortage will require a coordinated release of wheat stocks, while if the export block persists, other export countries will need to fill the gap by increasing wheat yields or by expanding wheat cropping areas by 8% in aggregate. We estimate that a production increase would require an extra half a million tons of nitrogen fertilizer, yet fertilizer prices are at record levels, driven by rising energy prices. Year-to-year variability plus more frequent climate change-induced crop failures could additionally reduce exports by another 5 to 7 million tons in any given year, further stressing global markets. Without stabilizing wheat supplies through judicious management of stocks and continuing yield improvements, food and national security are at risk across many nations in the world.

1. Main

Ukraine contributes to 9% of the world's wheat exports (in 2020). In 2020, the country produced 26 million tons (Mt) of which they exported 72%, which was valued at more than 3.5 billion dollars (FAO stat, 2022). The war in Ukraine threatened to block most of Ukrainian wheat exports (FAO stat, 2022). Even if part of this wheat would be exported (FAO, 2022), the areas in Ukraine sown with crops are estimated to be significantly lower than those in recent years (W et al., 2022). It is a crisis for the Ukrainian national economy and a threat to global food security. Several African and Asian countries depend on Ukrainian wheat to provide staple foodstuffs for their population. Indonesia and Egypt consume together more than 5 Mt of Ukrainian wheat per year, which corresponds to more than 20% of their annual imports. Ukraine supplies more than 40% of the wheat imported by Pakistan, and 51% by Lebanon (USDA PSD). Consequently, the risk of food insecurity and civil unrest may increase in these Ukrainian-wheat dependent countries, and potentially beyond. For example, other wheat importing countries like Brazil and Algeria, and particularly those in sub-Sahara Africa will also feel the impact from the wheat price hike caused by the export block. Wheat was priced at US$281 per ton in the beginning of February 2022 and reached US$490 per ton early March 2022 (Supplementary Fig. S3), a week after the Russian Federation invaded the Ukraine. The wheat price has remained high for several weeks and recently decreased again, but it remains exceptionally high compared to the last five years (Supplementary Fig. S3), threatening food insecurity in many importing countries.

Ninety percent of wheat exports in 2020 (the most recent year for which reliable data are available from FAO) are supplied by the world's 13 largest wheat exporting countries (Fig. 1). Across exporting countries, wheat areas have remained steady over the last two decades at about 105 million ha (Mha), even as total arable area has grown in these countries (Fig. 1). Over the same period, wheat production of the top-13 wheat exporters has increased to 325 Mt by producing more yield per unit area (mostly in the Russian Federation), with most of the additional wheat being exported (FAO stat, 2022). Global wheat exports have

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increased from about 100 Mt in 2000 to 178 Mt in 2020 (Fig. 1).

Sudden wheat price hikes have occurred in the past with devastating consequences across the world. For example, in 2007 (with less stocks available than in 2020, Supplementary Fig. S2a), late spring frosts occurred simultaneously with heat waves and droughts in central Europe causing a widespread decline in wheat yields (USDA, 2007). Combined with a prolonged drought in Australia, low yields in Ukraine and demand for biofuels (Headey, 2011), resulted in tripled wheat prices (FAO, 2008), contributing to food riots in at least 14 countries (Berazneva and Lee, 2013). Similarly, in 2010, a heatwave and fires destroyed one third of Russia's national production, causing its government to ban wheat exports. This sudden wheat export shortage caused a 50% spike in wheat commodity prices, which, in turn, has contributed to the Arab Spring unrest (Perez, 2013), followed by a migration wave affecting many countries across the world (Van Mol et al., 2016).

A short-term solution for such a food crisis would be to release wheat stocks, which in recent years have been between 50 and 80 MT and dropped in recent years to about 60 Mt (as of 2022 USDA report (USDA, 2022): Supplementary Fig. S2a). The Russian Federation, the world's largest wheat exporter has a large wheat stock but is not seen currently as a reliable supplier and may have an incentive to withhold stocks or to use them as a geo-political instrument. With no Ukrainian wheat being exported due to the current war, the other top-13 wheat exporters countries should increase exports. These countries have the necessary infrastructure for wheat exportation, with capacity to transport, sell and store grains, and additional efforts to export more wheat is most likely to come from these countries. However, in the short-term, this export boost will have to come mainly from available stocks in these countries. But in the mid- and long-term, these extra demands on wheat need to be met through higher wheat production.

The top-13 wheat export countries (omitting the Russian Federation and Ukraine) produced 214 Mt of wheat on 67 Mha, with an average yield of 3.3 t ha^{-1} in 2020 (FAO stat, 2022). To compensate for the missing Ukrainian wheat export, without contributions from the Russian Federation, will need to increase wheat grain yields by at least 8% (slightly less than the 9% export share of Ukraine as the mean yield level in the Ukraine is lower compared to the mean of the other countries) by closing the yield gap (difference between exploitable yield potential [80% of yield potential] (van Ittersum et al., 2013) and actual farmers' yield) (Fig. 2b). As an annual yield increase of 8% is far beyond the average trend in wheat yields (Grassini et al., 2013; Fischer et al., 2014), such an abrupt change in wheat yield is not likely in the short and medium-term and will require long-term preparation through research and development in yield improvements. Also, increasing yields towards the exploitable yield potential would require about half a million tons of additional N fertilizer in these countries to offset the 18 Mt lost from the Ukrainian wheat export block (Fig. 2d; Supplementary Table S4). For example, USA and Canada together would need more than 0.2 Mt of N fertilizer to achieve this goal (Fig. 2d). However, considering fertilizer prices have increased dramatically during COVID19 and more since the Russian invasion of Ukraine (Supplementary Fig. S4), high fertilizer use is a significant contributor to nutrient pollution of the environment (Foley et al., 2011) and is extremely energy intensive, such an increase in fertilizer use might not be possible or desirable (Union, 2020). Although, the increase in N fertilizer price may result in a reduction in N fertilizer applications by farmers, which would further accelerate the wheat shortage.

Alternatively, the additional wheat could come from expanding wheat production to another 5.5 Mha of cultivated area, displacing other crops or expanding into non-cultivated, less fertile areas. For example, The European Commission and several Member States are discussing a roll-back of The Green Deal – allowing farmers to sow wheat on ecologically protected areas established to meet the target of 10% ecologically protected areas by 2035 in response to the environmental crisis, in particularly the biodiversity crisis, to increase wheat production for export (Anghel, 2022). However, this would accelerate the environmental crisis and likely further reduce crop productivity in the future. And, the required area would be even larger due to low yield levels on these marginal lands (Beyer et al., 2022) (Fig. 2).

Year-to-year variability and an increase in the frequency of climate change-induced production failures could reduce exports by up to another 5 to 7 Mt in any year, further stressing global markets. This stems from the fact that total average wheat export of the top-13 wheat exporting countries normally varies by up to 5 Mt (standard deviation of time series; Fig. 1a), which is largely caused by year-to-year-climate variability (Ray et al., 2015). In addition, we estimate that crop

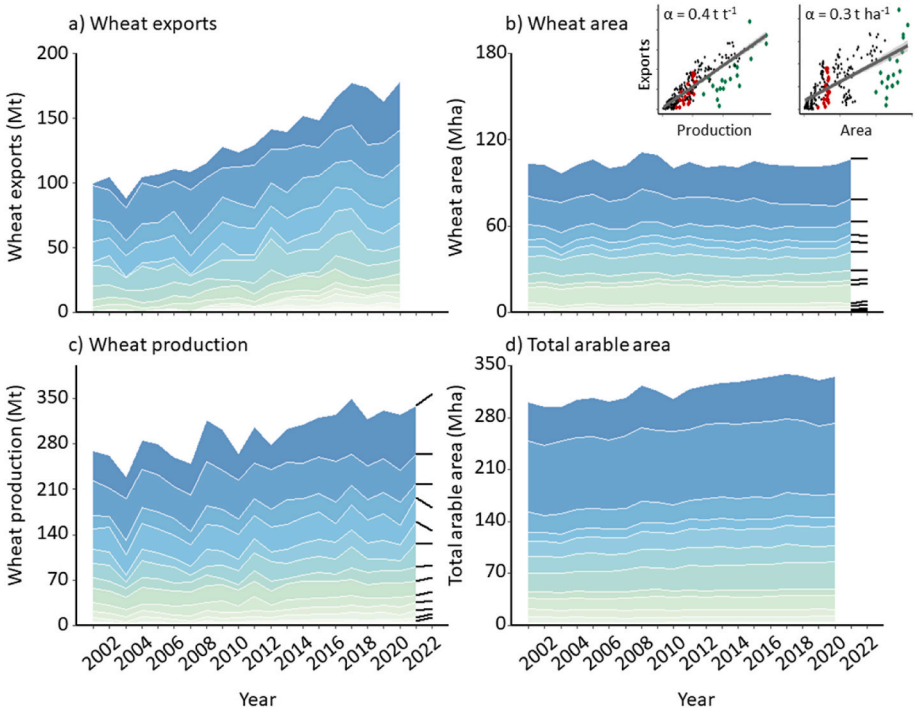

Fig. 1. Top-13 wheat exporters of the world. Reported cumulative wheat (**a**) exports, (**b**) harvested area, (**c**) production and (**d**) total arable area of the top-13 wheat export countries, accounting for 90% of recent global wheat exports. In (**b**) insets show exports versus production (left) and exports versus wheat harvest area (right) in last 20 years (FAO stat, 2022). α is the slope of a linear regression. Data were obtained from FAO Stats (FAO stat, 2022) and expanded with estimates from USDA (USDA, 2022) for 2021 and estimates for 2022 (black lines in (**b**) and (**c**)). All stacked lines are in order from largest to smallest top-13 wheat exporter, from dark blue to light green. Top-13 wheat exporters in 2020 (most recent FAO report) were (in order of exported tons per year) the Russian Federation, United States of America, Canada, France, Ukraine, Australia, Argentina, Germany, Kazakhstan, Poland, Romania, Lithuania, and Bulgaria. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

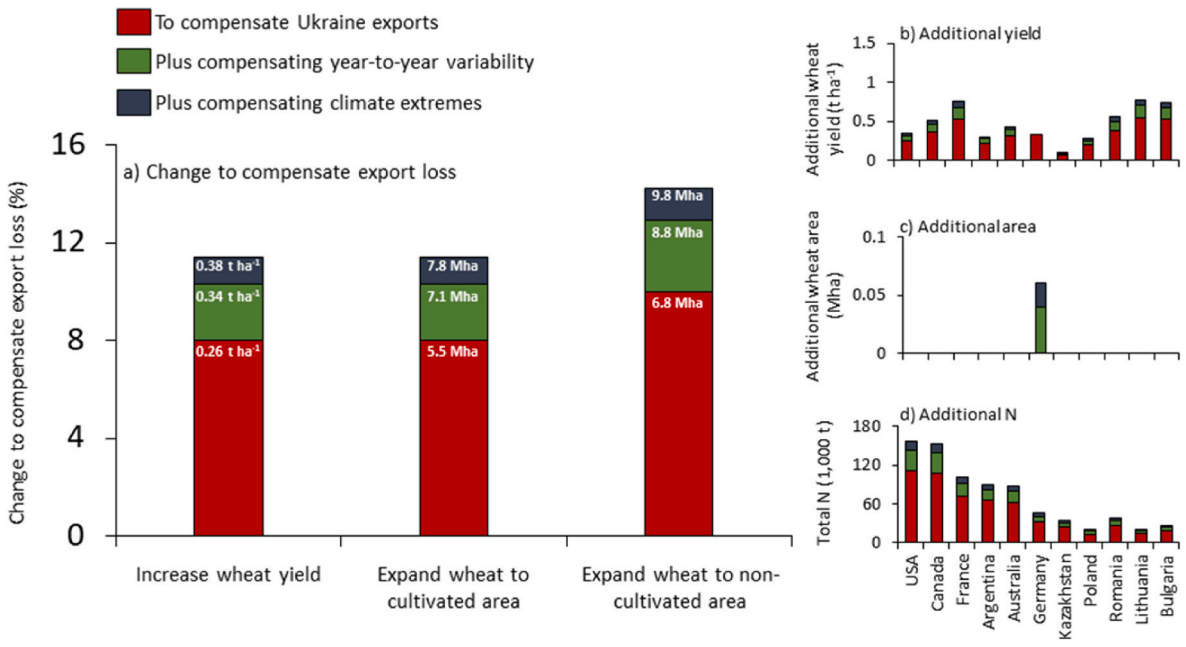

Fig. 2. Required change in wheat yield or wheat area by top-13 wheat exporting countries (excluding Russia and Ukraine) to compensate export loss by Ukraine, plus additional possible wheat export losses from year-to-year variability or climate change induced extreme losses. (**a**) Average required increase in wheat grain yield and in wheat area expanded to cultivated and non-cultivated areas. Additional required wheat (**b**) grain yield, (**c**) cultivated area and (**d**) N fertilizer for each of the top-13 exporting countries (excluding Russia and Ukraine). Wheat yield in Germany is already close to the exploitable yield level (van Ittersum et al., 2013), therefore the increase in wheat production in Germany would need to come mostly from additional wheat area. Nitrogen requirements were calculated by using 30 kg of N fertilizer being required to produce one ton of wheat grain yield (Ladha et al., 2016). An additional export decline due to year-to-year-variability was calculated as the standard deviation of the linear regression line of top-13 country total exports during FAO reported years 2001–2020 (Fig. 1). When expanding wheat to other cropped areas (i.e. replacing other crops) similar to current yield levels were assumed. When expanding wheat into currently not-cropped areas, a 20% lower yield was assumed due to less fertile land (Beyer et al., 2022).

production failures due to extreme adverse weather events in these countries in the wake of climate change could further lower exports by another 2 Mt, resulting in potential export declines of up to 7 Mt compared to an average year. An export drop of more than 7 Mt occurred in 2003 during the widespread European drought and heat-wave (Battisti and Naylor, 2009), a climate pattern also observed in 2018 and projected to become more frequent in the future with climate change (Trnka et al., 2014). Such shocks to crop production are possible in 2022 and with an increasing frequency of occurrence any year in the future with climate change (Nóia Júnior, 2021). Hence, to also account for additional wheat export losses due to year-to-year variability and possible climate extremes induced crop failures in wheat exports would require short, medium- and long-term preparations. In the short-term, this means being prepared for even more wheat stock releases.

Recent national crop yield projections indicate that the loss of Ukrainian exports is unlikely to be compensated this year. A pronounced rainfall deficit has been reported for parts of France and Germany, and their national wheat productions are not expected to exceed that of previous years (Baruth et al., 2022). In addition, Kazakhstan has declared restrictions to wheat exports during the crisis (FAS- Nur -Sultan, 2022), further stressing the global wheat export market. The projected wheat production of India and China, the two largest wheat producers and consumers, were also expected to decrease due to adverse weather conditions (Sowell and Swearingen, 2022). The consequences of such supply disruptions for the world market could be devastating as indicated in recent years. For example, the Ukrainian droughts of both 2018 and 2019, which caused its national wheat exports to drop, by 10 and 5% respectively (FAO stat, 2022), likely contributed to the decline of the per capita wheat consumption in Pakistan, a major wheat importer from Ukraine, and accelerated the number of undernourished people by 2.7 M during this period. Other wheat importing countries like Morocco, Egypt and Tunisia with limited fresh water resources to support their own crop production (Asseng et al., 2018) are also highly vulnerable to global wheat commodities prices (FAO stat, 2022).

While in the medium to long-term, Ukraine exports, which have slowly started again and crop production may be compensated elsewhere through gradual yield increases and area expansion, short-term impacts are likely to be severe for many countries across the globe and will require a better management of national stocks. Controlling part of the stocks by coordinating existing national stockholdings, currently not available, would be a way forward. Even if the war ends in the next few months and/or exports from the Ukraine become normal again, the disruption of Ukraine's grain storage and processing infrastructure, and maritime shipping capacity will have consequences on Ukraine's wheat production and export capacities beyond the 2022/2023 marketing season (FAO, 2022). Therefore, medium-to long-term wheat production improvement will be required, calling for a concerted global effort in conjunction with improved management of the climate and environmental crisis to stabilize future wheat markets (Koning, 2017). Our analysis has focused on wheat, as the main staple food in many countries, but Ukraine and the Russian Federation are also top global exporters of sunflower, rapeseed, maize and barley. The reduced supply of these commodities is adding to the global food market disruption. Actions should be taken to make agriculture less vulnerable and more resilient to the concentration of food exports in a handful of countries.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2022.100662.

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