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Mkrtchian, Alexander; Müller, Daniel

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ANALYSIS

Assessing the Impact of the Russian Invasion on Crop Production in Ukraine with Open Satellite Data

Alexander Mkrtchian and Daniel Müller (both Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Halle (Saale), Germany)

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Abstract

The Russian invasion of Ukraine resulted in substantial abandonment of fertile croplands due to combat operations, particularly along the front line. We used Sentinel-2 satellite imagery to estimate the extent of abandoned croplands on both sides of the front line after the onset of war. We find that at least 14,000 km^2 of former cropland have been left uncultivated along the front line as a result of the war, including 8,000 km^2 in areas controlled by Ukraine. It will take substantial time and effort to once again fully utilise these abandoned croplands, which are contaminated with countless mines, unexploded ordnance, and artillery craters.

Introduction

Before the full-scale Russian invasion of Ukraine in 2022, Ukraine was the sixth-largest producer of maize and the seventh-largest producer of wheat, respectively, and represented more than 30 percent of global sunflower seed production, according to the USDA Foreign Agricultural Service. By 2022, agriculture contributed approximately 10 percent to Ukraine's gross domestic product (GDP) and 42 percent of its export value. According to the State Statistics Service of Ukraine (SSSU), about three million Ukrainians, almost 20 percent of the labour force, were employed in agriculture before the war.

The Russian invasion led to substantial losses in agricultural production in Ukraine. The value added of Ukraine's agricultural sector decreased by 23 percent in 2022 compared to its 2016–2021 average (World Bank, 2024). Crop production decreased due to both the inability to cultivate some croplands and their ensuing abandonment due to their location near the front line, and because crop yields declined even in otherwise unaffected areas due to decreasing agricultural inputs. Annual statistical reports from the SSSU offer valuable information on cropland area and production of the main crops at the provincial (*oblast*) level from which the production losses after the Russian invasion can be inferred. However, statistical reporting is time-consuming, lacks spatial detail, and is prone to inaccuracies, especially in areas located close to the front line. Official statistics also do not allow for discrimination between abandoned cropland and land that is still cultivated, but is now located in occupied areas of Ukraine.

Publicly funded satellite platforms, such as those provided by the EU's Copernicus Programme, can fill this important gap by providing images at high spatial resolution, with frequent revisits, for large areas in near real time and at no additional cost. In this contribution, we summarise the impact of the war on crop production in Ukraine using official statistical data. We complement these data with information derived from satellite imagery to approximate the impacts of the war on the extent of cropland along the front line, where the most direct effects have been felt. We conclude with recommendations on how to use satellite imagery to advance monitoring and reporting of the impacts of the war on crop production in Ukraine.

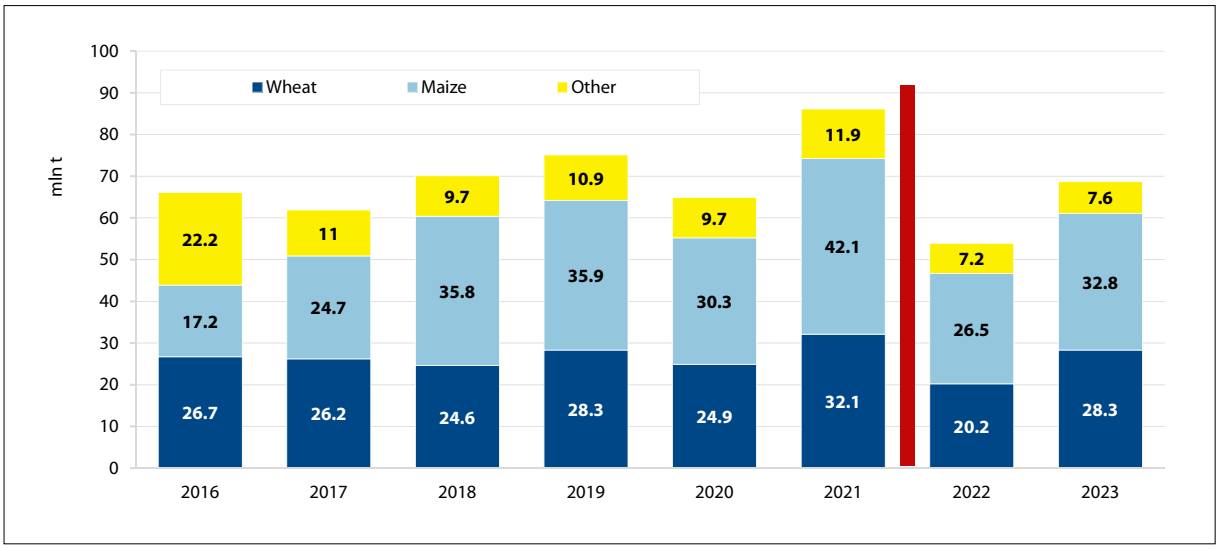
Effects of the Russian Invasion on Ukraine's Crop Production

According to official statistics, Ukrainian farmers harvested 54 million tons of grain in 2022, significantly less than in the years before the start of the full-scale invasion in February of that year (Fig. 1). Wheat production decreased by 15 and maize production by 26 percent in the marketing year 2022/2023 compared to their 2016–2021 averages, according to the SSSU. The agricultural operations in the south and east, where some of the most productive and intensively used agricultural areas in Ukraine are located, are particularly affected by the war.

Cropland abandonment occurs when cultivation becomes dangerous, unprofitable, or logistically unfeasible. Unexploded landmines and grenades can remain hidden beneath the surface of the land, as seen in the frequent reports in the media of Ukrainian farmers and agricultural workers being killed or wounded by explosions in fields. The effects of war on crop production are also felt further away from the front line, for example when inputs such as fertilisers become too expensive for farmers or they are no longer able to sell grain abroad due to blocked transportation routes.

According to the SSSU, the total planted area in 2022 decreased by 52,000 km^2, or 18 percent of the total cropland area in 2021 (Fig. 2). However, these data do not distinguish between abandoned croplands and croplands in

Figure 1: Crop Production in Ukraine in the Years Before and After the Full-Scale Invasion



Source: Data for 2016 to 2022 are from the State Statistics Service of Ukraine (SSSU); data for 2023 are taken from the forecast from the September 2023 EU JRC MARS Bulletin (Claverie et al., 2023). Data for 2022 may be imprecise due to difficulties in collecting data near the front line.

territories now occupied by the Russian Federation. Indeed, by autumn 2023, Russia had gained control of nearly three-quarters of Kherson and Zaporizhzhia Oblasts, although their administrative centres remain under Ukrainian control. Russia conquered almost the entire area of Luhansk Oblast (less than two percent was under Ukrainian control at the time of analysis) and currently has control over 57 percent of Donetsk Oblast.

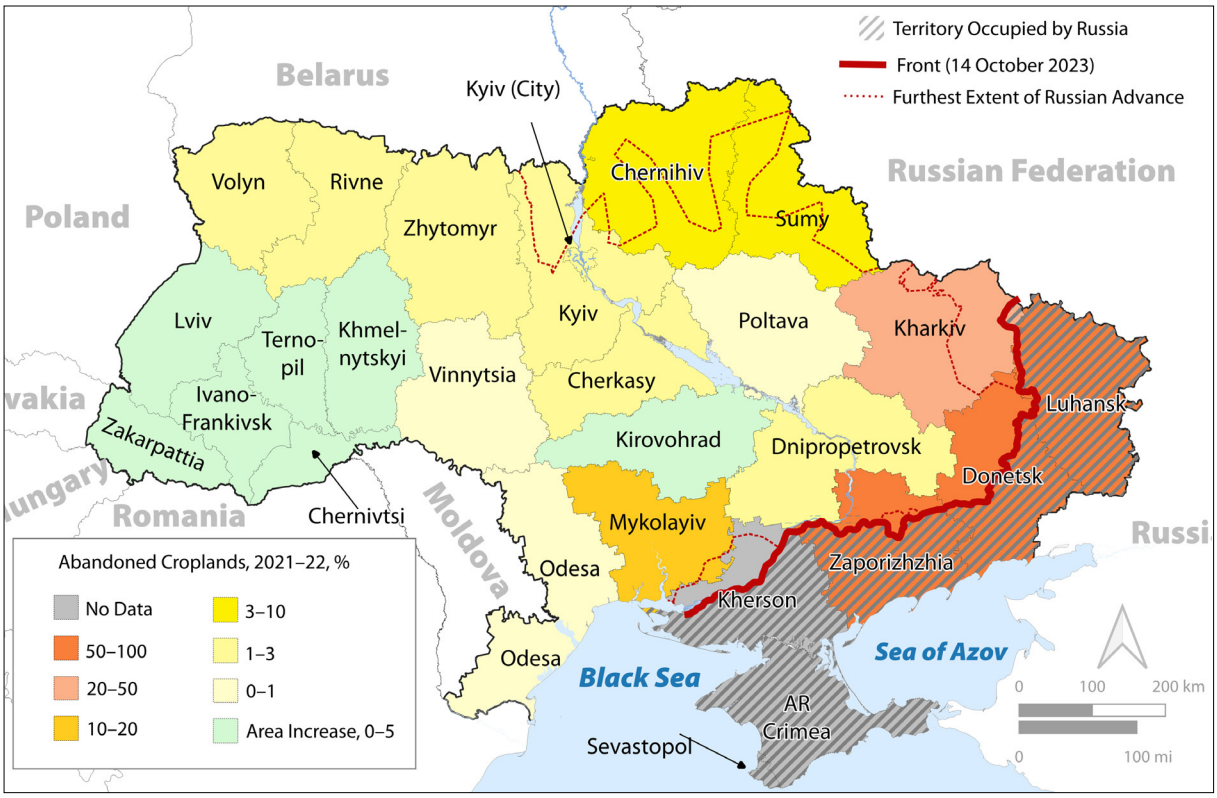
This suggests that a significant portion of the reported decline in cropland area can be attributed to the extensive occupation of Ukrainian territory by the Russian Federation, resulting in the SSSU no longer receiving data from these regions. The Russian official government gazette reported 13,000 km^2 of croplands in the Russian-occupied part of Kherson Oblast as of April 2023, of which around 1,200 km^2 (nine percent) have been abandoned (Rossiyskaya Gazeta, 2023). The Ukrainian online media outlet Texty.org.ua estimated around 16,400 km^2 of wheat and 11,100 km^2 of sunflower crops in 2023 in the Russian-occupied territories, with a prospective production of around 4.6 and 2.0 million tons, respectively (Texty.org.ua, 2023).

By contrast, cropland areas increased in regions located away from the front line and the borders with Russia and Belarus, for instance in western Ukraine along the border with Poland and Romania (Fig. 2). This may reflect the fact that some agricultural enterprises relocated some of their activities to safer regions, where they started to develop more marginal and previously unused lands.

Lower agricultural inputs are another factor contributing to the reduction in production. Production of nitrogen fertilisers in Ukraine decreased nearly 80% in 2022 compared to the previous year, according to Ukrainian officials, mainly because Russia occupied Ukraine's largest producer, the Azot plant in Severodonetsk, in 2022 (Ekonomichna Pravda, 2023). In addition, nitrogen fertilisers from Russia and Belarus were obviously no longer available, and prices for imported nitrogen fertilisers rose substantially due to the raised natural gas prices and the devaluation of the Ukrainian hryvnia. Ukraine also imported 69 percent of its potash fertilisers from Belarus in 2021 (Ukrainian Agribusiness Club, 2023). As a result, the consumption of nitrogen and potash fertilisers in Ukraine decreased between 50 and 70 percent in 2022 compared to 2021, according to an expert from Group DF, the largest producer of nitrogen fertilisers in Ukraine (Interfax-Ukraine, 2022).

The effects of lower input intensity on yields occurred throughout the country, but spatially refined data on yield declines have been lacking to date. Furthermore, yield variations are substantial in Ukraine as a consequence of the predominant (volatile) weather conditions, and typically explain up to 60 percent of year-on-year wheat yield variability (Schierhorn et al., 2021). In southeast Ukraine, for example, low yields often result from the droughts frequently experienced there. The yield declines in 2022 can indeed be attributed in part to unfavourable weather conditions for most crops, with a cold spring, a summer drought in the south, and a rainy autumn that hampered and delayed harvest. For these reasons, the largest yield declines in 2022 occurred not in the most war-affected oblasts, but in the southern part of the country where the unfavourable weather conditions were most pronounced (Fig. 3).

Figure 2: Changes in Cropland Area Between 2021 and 2022



*Source: State Statistics Service of Ukraine (SSSU); GIS data: Openstreetmap (*https://www.openstreetmap.org/copyright*) and Conflict Investigations (*https://github.com/conflict-investigations/nzz-maps*).*

Satellite Remote Sensing to Assess Cropland Abandonment along the Front Line

For more than 50 years, satellite remote sensing has been the workhorse for tracking changes in land cover, natural ecosystems, and the distribution and condition of agricultural crops. The analysis of satellite imagery is ideally suited to monitoring land surface changes caused by wars, especially when these damages extend over large areas and are clearly visible from space. The provision of high-resolution, freely available imagery in near-real-time, such as Sentinel imagery that can be accessed through Copernicus, the Earth observation component of the EU's space programme, or Landsat imagery from NASA allows accurate and timely assessments of changes in land cover without extensive field work. Cloud storage and computing platforms, such as the Google Earth Engine (GEE), enable free access to vast archives of image data and provide tools for image analysis, including algorithms for image pre-processing such as automatic masking of clouds and shadows.

We evaluated the extent of abandoned croplands in a belt along the front line, covering five oblasts that are directly impacted by ongoing warfare, with Sentinel-2 imagery. We estimated cropland abandonment along the front line in the areas controlled by Ukraine and by Russia. We used data from a global land cover product, the ESA WorldCover project, to approximate cropland distribution in 2021 (Zanaga et al., 2022). Cultivated cropland is characterised by a tessellated pattern of fields with different crop types at different growing stages; by contrast, abandoned cropland becomes overgrown with natural vegetation and typically displays a more uniform pattern. With sufficiently high summer precipitation, abandoned croplands appear greener than cultivated fields throughout the growing season, exemplified by the clearly visible abandoned plots in the centre of the Sentinel-2 image taken in summer 2023 (Fig. 4). To estimate the area of abandoned cropland, we manually digitised the areas with conspicuous patterns of abandonment on a satellite image from summer 2023 and overlaid this belt with the cropland mask taken from the 2021 WorldCover product.

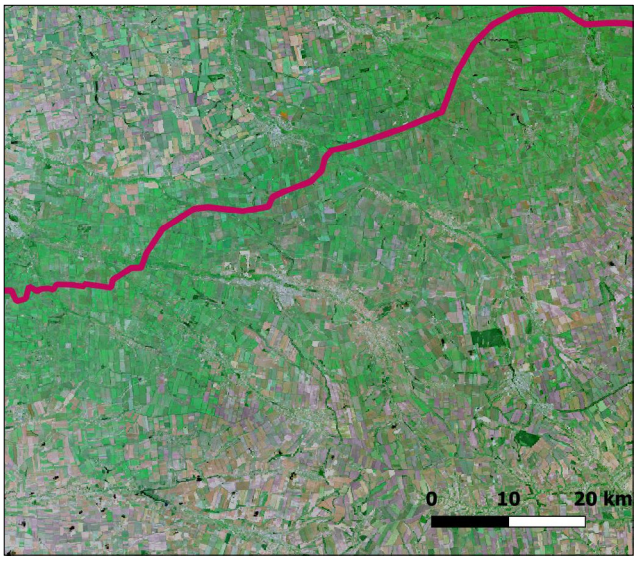
Although some croplands in Donetsk and Luhansk Oblasts in eastern Ukraine had already been abandoned after hostilities began in 2014, cropland abandonment accelerated after the beginning of the war in 2022, particularly in Zaporizhzhia and the western part of Donetsk Oblasts, which have been the focal points of military confrontation from early 2022 through the present. As a result, an approximately 60-km-wide belt of abandoned land has formed

Figure 3: Changes in Grain Yields from 2021 to 2022

*Source: State Statistics Service of Ukraine (SSSU); GIS data: Openstreetmap (*https://www.openstreetmap.org/copyright*) and Conflict Investigations (*https://github.com/conflict-investigations/nzz-maps*):*

around the front line, with few changes over the past year and a half (Fig. 5). Extensive military fortifications and mine fields are present on both sides of the front line, making the reclamation of these lands a difficult and costly task, even after an eventual end of hostilities.

Figure 4: Abandoned Croplands Along the Front Line (marked in red), Ukraine, Visible in the Sentinel-2 L2A True Colour Image Taken on June 22, 2023



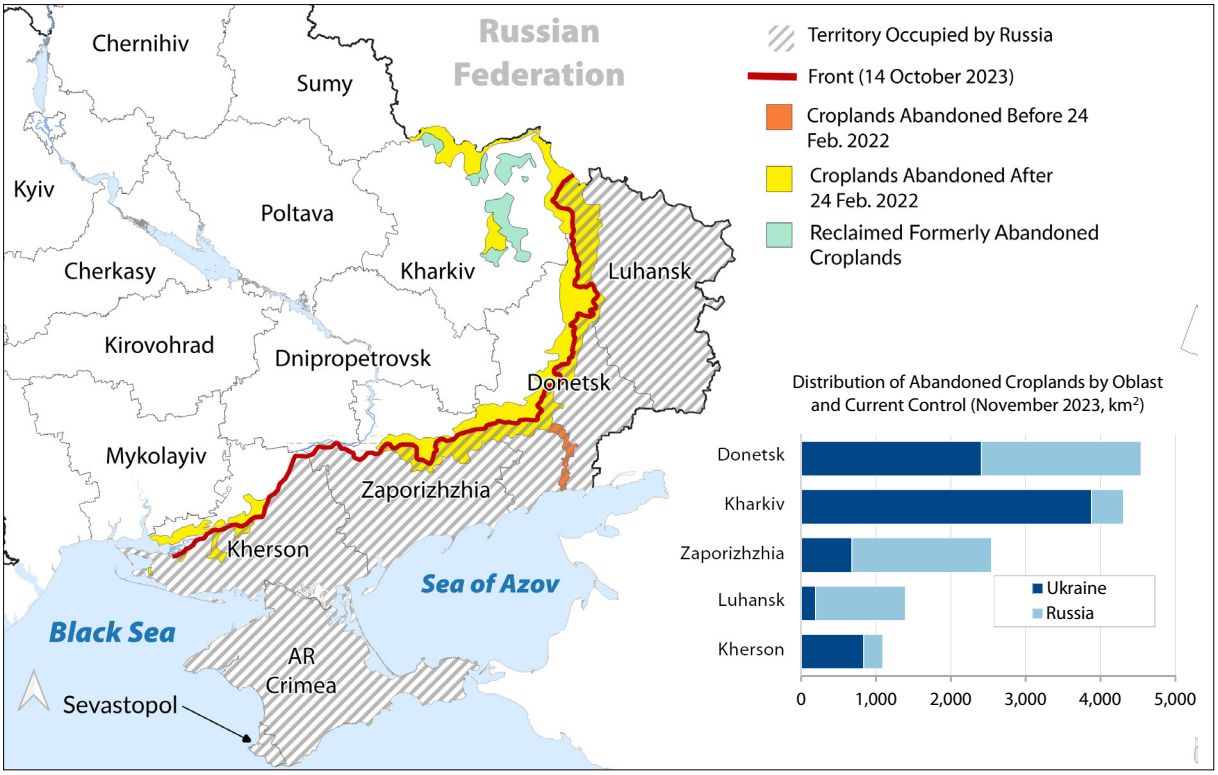
Source: Copernicus Date Space Ecosystem.

Shortly after the start of the full-scale invasion in February 2022, Russian forces conquered nearly half of Kharkiv Oblast, heavily disrupting crop cultivation in this region. Most of this area was retaken by Ukrainian forces later in the year. Owing to the comparatively low intensity of the fighting and the short duration of Russian occupation, much cultivation in this region has already resumed (Fig. 5). Only croplands in the far eastern and northern parts of the Oblast remain abandoned due to their location near the present front line.

A belt of abandoned croplands also emerged on both banks of the downstream Dnipro River in Kherson Oblast; however, abandonment is less extensive in this region because the river forms a natural barrier that weakens the intensity of the fighting. Patches of abandoned cropland can also be seen far from the combat area, mainly caused by indirect impacts of war such as high input costs, lack of labour and machinery, and poor logistics.

We estimate the total area of abandoned cropland at 13,900 km^2, of which 8,000 km^2 (57 percent)

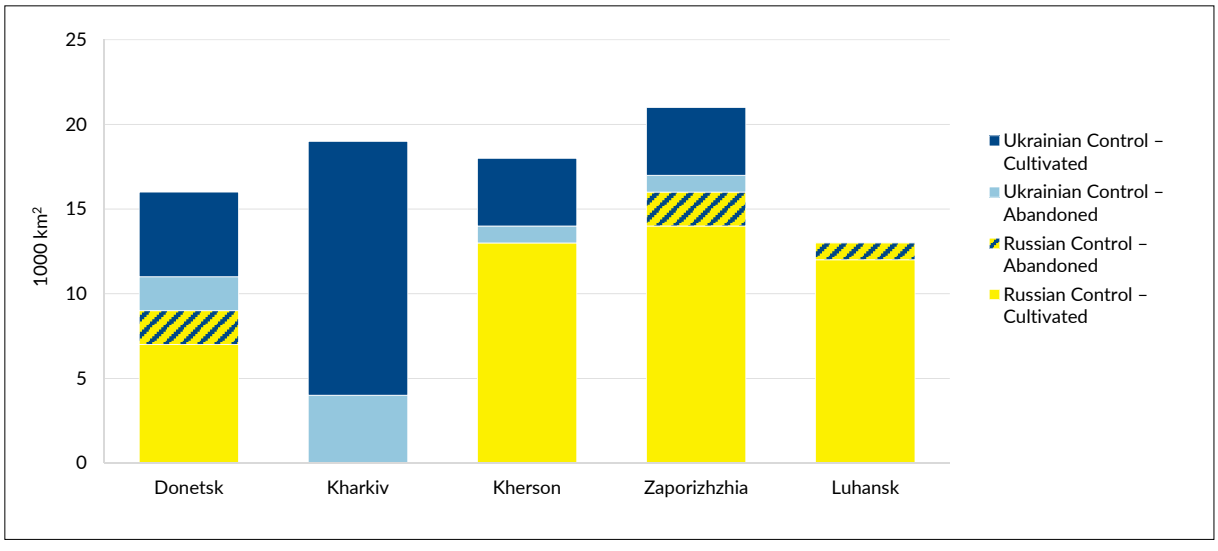
Figure 5: The Extent of Abandoned and Restored Croplands Along the Front Line as of November 2023



*Source: Own analysis; GIS data: Openstreetmap (*https://www.openstreetmap.org/copyright*) and Conflict Investigations (*https://github.com/conflict-investigations/nzz-maps*).*

is within the Ukrainian-controlled area (Fig. 6). Another 52,400 km² of Ukrainian croplands ended up in Russian-occupied territory after the onset of war. Therefore, the total loss of Ukrainian croplands (both that land abandoned but still controlled by Ukraine and land taken over by Russia) amounts to more than 60,000 km², or 18 percent of the entire cropland area of Ukraine in 2021.

Figure 6: Cultivated and Abandoned Croplands in Ukrainian- and Russian-Controlled Territory in the Five Oblasts Along the Front Line as of November 2023



Source: Own analysis.

Outlook

Future developments in cropland cultivation will depend on the unpredictable dynamics of the war and the duration of hostilities. Changes in front line position, fortification construction, and additional infrastructure damage could lead to the abandonment of more croplands and a further reduction in agricultural production. In times of war, satellite remote sensing has obvious advantages over methods that rely on field data collection to assess the extent of the effects of war on cultivation. Some farmers may not be accessible or report on time, and inspecting areas near the battlefield is dangerous. Remote sensing imagery, however, can be easily acquired and promptly analysed, regardless of the situation on the ground.

At present, statistical data from areas under Russian occupation are missing (except for sporadic data of dubious reliability from Russian sources). Satellite remote sensing can fill these information gaps, and is already widely used to monitor crop production in Ukraine during the current war. For example, the NASA harvest consortium published satellite data–based estimates of crop production in Ukraine already in 2022, including for Russian-occupied territories (NASA Earth Observatory, 2022), and the EU Joint Research Centre uses satellite data for its regularly published detailed forecasts of the current state of the Ukraine's crop (see Claverie et al., 2023).

Future efforts should be directed toward establishing a monitoring system that processes satellite data in near-real-time and on an ongoing basis to detect changes long before the arrival of the ground data. Such a monitoring system could be integrated into the official reporting routine to provide more reliable and timely statistical information. Satellite imagery can also help estimate the amount of damage inflicted on abandoned croplands and assess the feasibility of their recovery.

Advanced methods of image processing and analysis, particularly machine learning methods, offer more flexibility, versatility, and robustness compared to traditional statistical approaches and permit the derivation of valuable additional information, such as the current extent of croplands and of particular crops. The total production lost as a consequence of the war can be estimated by multiplying the extent of abandoned croplands with prospective yields. Multiplying the estimated production loss by market prices would allow for a monetary valuation of losses, which, in turn, can form the basis for quantifying eventual reparations demands.

Investments in cropland monitoring should include the development of human resources, including in the use of radar imagery that provides valid information regardless of cloud cover and the proper harmonisation of satellite-based information and field reporting. Furthermore, the collection of training and validation data for high-resolution crop-type monitoring, for instance from ongoing farming operations and images with very high resolution, should receive high priority. A functioning crop-type monitoring system would also facilitate the establishment of a land parcel information system, which would be the cornerstone for the administration and control system for disbursing EU agricultural subsidies after an eventual EU accession.

About the Authors

Dr. *Alexander Mkrtchian* is Research Associate at IAMO. His research covers land cover changes, climate data interpolation, ecosystem responses to climate change, relationships between terrain morphology and ecosystem properties, soil sheet erosion and species distribution modelling.

Prof. *Daniel Müller* is Deputy Head of the Department of Structural Change at IAMO and teaches at the Institute of Geography at Humboldt University in Berlin. His research focusses on the causes and impacts of land use change and the links between agriculture and climate change in the countries of the former Soviet Union and the Western Balkans.

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