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Cash crop or food crop? socioeconomic and geopolitical factors affecting smallholder farmer crop selection in times of crisis in southwestern Tajikistan

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Tajikistan's agricultural sector, primarily dominated by cotton cultivation, has experienced significant changes since the Soviet era. Although farmers introduced food crops into agricultural production to ensure food security after the collapse of the Soviet Union in 1991, the government still mandates that cotton cultivation occupy a considerable portion of Tajikistan's limited irrigated land. However, following the recent Covid-19 pandemic crisis, farmers have encountered the need to reassess their agricultural practices, given constrained governmental assistance and a range of socioeconomic considerations. This research adopts resilience as a conceptual framework to examine the coping strategies of smallholder farmers in the Khatlon region of Tajikistan, with a specific emphasis on the period spanning from 2019 to 2022. At the outset, our research employed the snowballing technique to increase respondent participation, later transitioning to a representative sample size that facilitated the collection of qualitative data from around 100 semi-structured interviews, 10 focus groups, and personal visits to agricultural fields over the course of four years. The paper not only demonstrates the overall creativity of Tajikistani farmers in growing and selecting non-cotton crops in this most recent period of crisis, but also points to wealthier farmers' generally greater willingness to adopt technological innovations and gain new knowledge to apply to them. Although these strategies have been taken in order to address farmers' immediate needs in troubled times against the backdrop of the existing state cotton policy, their sustainability remains uncertain. While the qualitative focus of this study bears certain inherent limitations, the data collected nevertheless show that this period of crisis has been generative for many farmers as they seek out new methods of subsistence.

KEYWORDS

resilience, coping strategies, subsistence, post-Soviet, Covid-19, Central Asia

Introduction

Tajikistan's agricultural trajectory seemed to diverge from its customary cotton-focused approach, as the country's president urged citizens "to pick up shovels" and "plant potatoes" during his address to the nation on the holy month of Ramadan in 2020 (Tajik Sputnik News, April 4, 2020)¹. This stance either appeared to challenge the state's practice of central planning and unspoken cotton policy mandating farmers to allocate over half of their irrigated land to growing cotton or was aimed at a different audience than cotton farmers.² The informal cotton-growing policy poses substantial restrictions for smallholder farmers, who are left with limited land of varying quality on which to cultivate food crops and other agricultural produce in an attempt to earn enough profit to support themselves. Indeed, cotton has been a strategic crop for Tajikistan for many decades, dating back to the Soviet era, thus leaving farmers with few opportunities to cultivate other crops. As an elderly farmer interviewed for this study commented, "Cotton is white and innocent on the outside but has a dark soul on the inside," referring to the hard labour and extreme conditions endured by smallholder farmers who cultivate cotton under changing socioeconomic conditions (Farmer interview, May 2022). The farmer was in his late seventies and had worked as an agronomist during the Soviet period on a collective farm. His lifelong experience had helped him to understand the high price of cotton cultivation under changing socio-economic conditions.

The respondents for this study are smallholder farmers, locally known as *dehkhans* farmers, from southwestern Tajikistan who were interviewed between 2019 and 2022. All of them inherited redistributed land from the collective or state-owned farms known locally as *kolkhozes* and *sovkhozes*, following the collapse of the USSR in 1991, in addition to inheriting Soviet-era agricultural practices. Although it is tempting to view their current cultivation practices as merely a continuation of the Soviet fixation on cotton, the realities of recent crises, beginning in 2020, such as Covid-19 and the Russian-Ukrainian War since 2022, have forced most Tajikistani smallholders to reconsider their practices and adopt new technologies, methods and crops. Tajikistan's demographic increase since 1991, from 5.6 million to 9.7 million people in 2021 (World Bank, 2021b), has necessitated more food crops to feed the growing population, likely putting greater pressure on domestic agriculture production. Many farmers' adoption of new strategies, however, is reliant on a number of socioeconomic factors, such as age, income, knowledge, family size and land area.

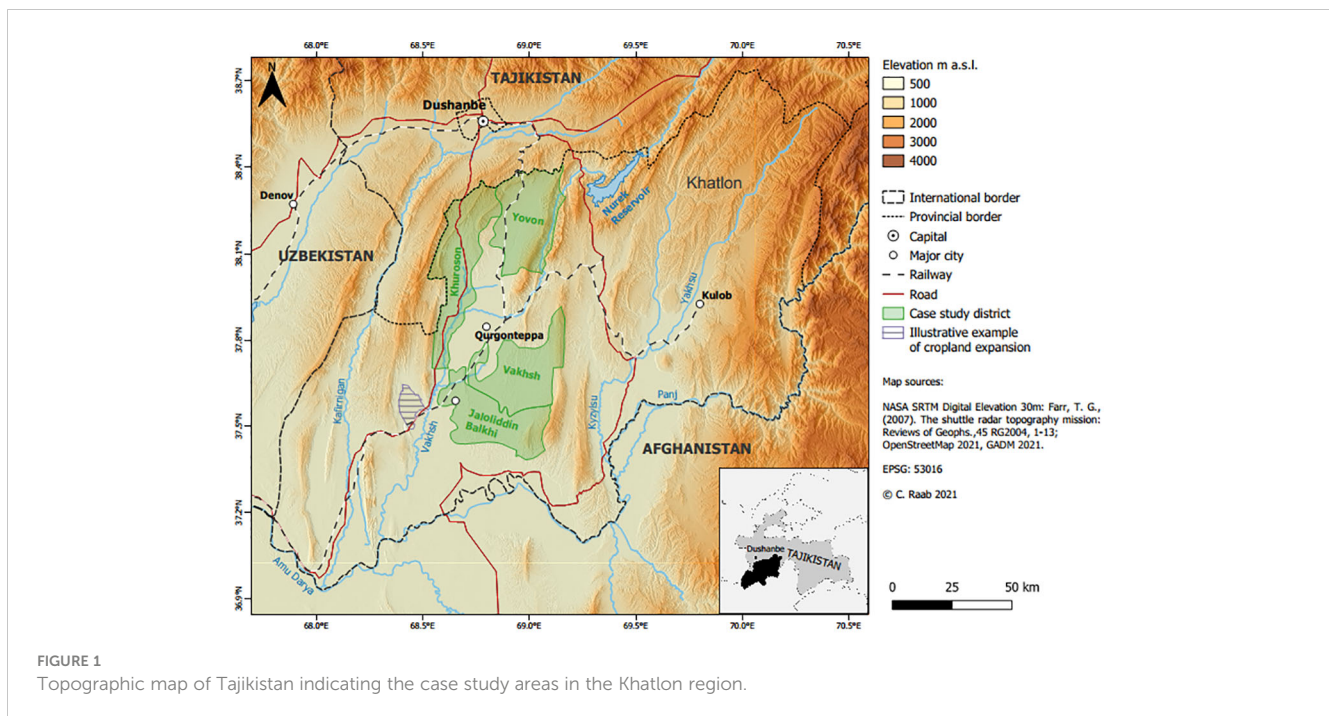
Several studies have analysed the political economy of cotton production in Tajikistan and identified various challenges faced by smallholder farmers, including limited access to land, water and credit, as well as government policies prioritising the production of this over other crops (Atta, 2009; Hofman and Visser, 2014; Hofman, 2021). Additionally, some of these studies have highlighted the role of gender in shaping farmers' experiences and livelihood strategies (Mukhamedova and Wegerich, 2018). However, the significance of other food crops has increased in recent times, following the period of crisis detailed earlier, and yet research on the role of these crops remains limited.

The farmers interviewed for this study have demonstrated a strategic approach to maximising profits from their land under the dual conditions of a government mandate to grow a certain amount of cotton and reduced access to agricultural resources and inputs such as seeds, fertilisers, pesticides and machinery. In this regard, we wonder if the crops grown on the remaining 40 per cent of smallholder farmers' land not devoted to cotton production meets the country's immediate food security needs. In other words, we investigate how farmers dispose of their "non-cotton lands" and what justifies their choice of certain crops under the changing conditions of the last four years – which have created a series of "disturbing factors" such as market imperfections, uncertainty and price volatility, which can affect farmers' decision-making and practices (Urruty et al., 2016). In this vein, the research questions we address in this paper are as follows: (i) What disturbing factors affect smallholder farmers' crop selection for land not dedicated to cotton cultivation? (ii) What role does the socio-economic context of smallholder farmers play in their resilience strategies?

The research questions we address in this paper are highly relevant for understanding the challenges faced by smallholder farmers in Tajikistan and their strategies, which we consider "resilience strategies." Resilience has emerged as a crucial concept in understanding the capacity of social-ecological systems to withstand and recover from disturbances and change (Pauline et al., 2022). Our study seeks to uncover resilience strategies, such as crop diversification, sharecropping, the application of organic fertilisers and livestock management, that smallholders employ to sustain their livelihoods and improve their well-being. The paper aims to provide a comprehensive analysis of how farming practices and approaches have evolved from 2019 to 2022, when the bulk of the data was collected in four districts of the Khatlon region, namely the Jaloliddini Balkhi, Vakhsh, Khuroson and Yovon districts (Figure 1). The paper begins by providing background information on the study area, including a brief overview of the historical, political and economic factors that have shaped agriculture in Tajikistan. The methodology section outlines the approach and data collection, while the conceptual framework discusses the theoretical underpinnings of the research. This is followed by exploring economic crises of the past three years and their impact on agriculture. The empirical results section presents the empirical findings, followed by a discussion of their implications for policymakers and practitioners. The paper concludes with a summary of the key takeaways and suggestions for further research.

1 <https://tj.sputniknews.ru/20200427/krisis-ekonomika-tajikistan-koronavirus-1031141289.html>

2 The prevalence of the informal cotton mandate may be underestimated, as the complex and sensitive nature of government policy and related discussions often deters farmers from discussing it, despite anonymity. The estimation of 50 percent of land area devoted to cotton cultivation is based on interviews with farmers.



Background and study area

Tajikistan, a land-locked agrarian country in Central Asia, has been influenced by a Soviet past (1924-1991)³ that has shaped its ongoing economic and political development. The production of cotton was prioritised during the Soviet period due to Tajikistan's favourable climate, and it has had a profound impact on the country's agricultural sector and economy. Central planning bodies had the responsibility of establishing production goals for cotton and other crops, which the state and collective farms had to fulfil (Pomfret, 2002). The state's control over production also ensured that farmers were not affected by market fluctuations, as agricultural inputs such as seeds, fertilisers and pesticides were supplied at controlled prices. Following independence in 1991, Tajikistan, like other former Soviet republics, underwent a period of political and economic instability. Specifically, the country was marred by a civil war from 1992 to 1997, which led to substantial fatalities and the destruction of infrastructure, as well as a significant decline in living standards, production and employment (World Bank, 2017). The agricultural sector underwent significant changes within a new market economy in which smallholder farmers had to compete for limited resources and manage inherited land plots (Porteous, 2003). The country's population increase, aligned with challenges posed by Covid-19 and the Russian-Ukrainian War, have compelled Tajikistani farmers to prioritise their survival by focusing on higher-yielding and higher-revenue crops, especially non-cotton yields.

The Khatlon region, located in the south-western part of Tajikistan, serves as the study area and is recognised as one of the

country's primary agricultural zones. It covers 17 per cent of Tajikistan's total land area and accounts for 48 per cent of arable land, contributing to approximately half of the country's agricultural output. This region is characterised by challenging agricultural conditions such as obsolete irrigation systems and an arid climate. While the average size of a small-scale farm is 4.56 hectares (Tajik National Statistics, 2021), average arable land per person has considerably decreased to 0.123 hectares due to population growth (Khodzhaev, 2018). This decrease indicates a scarcity of available land and potential challenges regarding food security and rural livelihoods.

The disintegration of the Soviet Union altered agricultural conditions in the study area, necessitating smallholder farmers to adapt to a market economy and privately manage inherited land plots. With the requirement to produce food crops to sustain a growing population on shrinking land plots, while also meeting government quotas for cotton production, farmers in this region lack the necessary resources to cultivate ample fodder for an increasing cohort of livestock, and so the reconsideration of cotton cultivation in times of crisis, and the importance of food and fodder crops, represents a significant transformation.

Resilience as a conceptual framework in a local context

Resilience has gained considerable attention in recent years, particularly in the context of climate change. The concept has been recognised as a crucial framework for understanding how societies can adapt to and cope with the impacts of climate change (Folke et al., 2010). As such, it has been widely used to inform policy and practice related to climate change adaptation and mitigation (Field et al., 2014). In the context of rural areas, it is also a widely used

³ Encyclopædia Britannica. (2021). Tajikistan - The Soviet era. Retrieved from <https://www.britannica.com/place/Tajikistan/The-Soviet-era>.

concept particularly in times of crisis, such as natural disasters, economic downturns and pandemics, when rural communities must adapt to and overcome unique challenges related to maintaining their livelihoods and accessing basic services such as food, healthcare and education (Nelson et al., 2007). The concept of resilience refers to the ability of a system or community to resist or recover from shocks and stresses while maintaining essential functions and identities (Nelson et al., 2007). Tiftonell (2014) highlights how the ability of smallholder farmers to cope with and adapt to these challenges is important for their resilience and well-being (Tiftonell, 2014). However, resilience is not simply the ability to cope, but also includes the processes of adaptation and transformation that contribute to decision-making and well-being (Castleden et al., 2011).

Resilience is shaped by one's socioeconomic context, including access to natural resources and finance, market conditions, social capital and institutional support as well as the ability to generate diversification, innovation and capacity-building. Smallholder farmers follow strategies to increase resilience by reducing their vulnerability to risks, increasing their adaptive capacity and strengthening their ability to recover from shocks (Czekaj et al., 2020). In Tajikistan, "resilience" as a term is not commonly used in the vocabulary of smallholder farmers, but their responses to crisis very much fall under this category.⁴ Mirroring their counterparts globally, Tajikistani smallholder farmers have adopted the resilience strategies of crop diversification, technological innovation, financial investment, capacity-building and collective action, which we will briefly introduce in this section.

Crop diversification is one of the most common resilience strategies used by smallholder farmers around the world. By diversifying their crops and livestock, farmers spread risks and reduce exposure to market fluctuations and climate-related risks. The findings suggest that diversifying crops can contribute to reducing the risks associated with crop failures, pests and diseases and climate variability. Furthermore, crop diversification can also help to improve soil quality, increase biodiversity and provide alternative sources of income. By reducing dependence on a single crop, smallholder farmers can better withstand economic shocks and changes in market demand (Lin, 2011). However, challenges exist in both scientific and policy domains to promote the adoption of management strategies for crop diversification. To facilitate adoption, farmers require knowledge on how to optimise diversified structures to maximise production and profits, which can be achieved through crop and landscape simulation models and stakeholder-based participatory research (Kassie et al., 2013).

Access to finance and insurance is also critical for building resilience. Smallholder farmers often lack access to credit and insurance, which can limit their ability for investments or to cope with losses. Kassie et al. (2013) found that access to credit was positively associated with the adoption of innovative agricultural practices among

smallholder farmers in Tanzania. Similarly, Antonaci et al. (2014) highlighted the importance of microfinance and crop insurance in building resilience among smallholder farmers in sub-Saharan Africa. Although Tajikistan has both public and private agricultural insurance programmes, in addition to microfinance and credits, such initiatives are not widely adopted by Tajikistani farmers due to exploitative interest rates, limited institutional capacity and a lack of awareness of their existence, particularly in remote rural areas. Consequently, many Tajikistani farmers rely on their own financial capital in the form of physical assets or remittances from family members working abroad (World Bank, 2021a).

Another important strategy for building resilience in rural communities is the promotion of social capital and collective action. Bourdieu formulated the concept of social capital as 'aggregate of the actual or potential resources which are linked to the possession of a durable network of more or less institutionalized relationships of mutual acquaintance and recognition' (Bourdieu and Richardson, 1986, p. 258). Relevant studies have demonstrated that social capital refers to networks, norms and trust that facilitate cooperation and coordination among individuals and groups (Tompkins and Adger, 2004). In times of crisis, strong social capital can facilitate mutual aid, information-sharing and resource-pooling. Collective action, which involves working together to achieve shared goals, can also be an effective means of building resilience, because by working together, rural communities can pool resources and knowledge to overcome challenges and sustain livelihoods. This has been quite a natural method for Tajikistani farmers, given local practices of family cohesion, whereby smallholding farmers are likely to combine their resources and land with their relatives for mutual benefits.

Capacity-building and knowledge are also important for building resilience among smallholder farmers, who often lack the knowledge and skills needed to adopt new technologies and improve their skills. Capacity-building and training programmes can help them expand in this regard, as well as access markets and subsequently improve their livelihoods. Nkegbe and Kuunibe (2014) found that obtaining technical advice from extension officers on soil and water conservation practices was positively associated with resilience among smallholder farmers in Northern Ghana. Despite the continued presence of Soviet-era practices, the agricultural sector in Tajikistan has seen some advancements through technical support and training programmes offered by international development organisations.

Finally, it is worth noting that resilience is a complex and multidimensional concept that has been subject to debate and critique in the social science literature (Olsson et al., 2015). Some have argued that the concept of resilience can be used to justify inaction or to shift responsibility for addressing challenges onto vulnerable communities. As such, it is important to approach the concept of resilience critically and to consider the social, economic and political factors that contribute to resilience and vulnerability in rural areas (Scoones, 2016).

Methodology

The nature of Tajikistan's political environment limits the ability of researchers to develop trust among locals easily, and

⁴ In vernacular Tajiki, farmers tend to express their strategies by saying 'Shukhronai Khudo. Asos salomatist. Bo yak rohe bo dushvorikho muboriza mebarem', which means 'We are thankful to God. As long as we are healthy, we can cope with our difficulties'.

especially over a short period. It is for this reason that this study relies on repeated visits to selected case study areas over a four-year period, from 2019 to 2023. The individuals interviewed during these visits came from personal contacts and local partners, helping us to reach a significant number of respondents for our research. In order to avoid a biased dataset, we visited the same area every year and talked to the same farmers, thereby allowing us to add depth to their initial answers. This method produced more reliable results, as it allowed us to track changes in their decision-making from year to year. This close, sustained contact with farmers meant that we conducted true “field work,” in that rather than interviewing them in private, we went to the fields with them to both discuss and observe their work. This way, we were able to participate in nearly every aspect of the growing season, starting from sowing seeds to harvesting crops.

Our research methods included semi-structured interviews (n=100) with individual farmers, household members, agronomists and academics. These respondents were accumulated over the course of four years of field visits, interviews and focus groups with farmers in south-western Tajikistan, during which time the first author used the snowballing technique to approach local farmers. The first respondent was a personal contact, a local agricultural specialist who introduced the authors to other relevant respondents. Further interviews were carried out with state officials from the chosen districts, scientists from research institutions and academic representatives from local agricultural institutes and universities.

In addition, focus groups were conducted with the participation of around 10-12 individual farmers each, as well as participant observations while visiting the agricultural fields. All data were obtained through close personal interactions and are largely qualitative, thus reflecting the farmers’ decision-making and resilience strategies in reaction to the emerging crisis. Interviews were conducted in the Russian and Tajik languages, with detailed notes taken and later translated into English. Tajik-language interviews were conducted with the help of a local translator.

Tajikistan’s cautious attitude toward foreigners influenced the willingness of farmers to provide comments on the government’s role in mitigating the crisis. While this limited our understanding of the farmers’ relationship with the government during this period, our study still provides valuable insights into their responses and actions in adapting to the crisis. In order to respect the privacy of our respondents, none of the interviews or focus groups was recorded. The qualitative data were analysed within the resilience conceptual framework, and quantitative data, along with existing statistical data, were processed in Excel.

Results

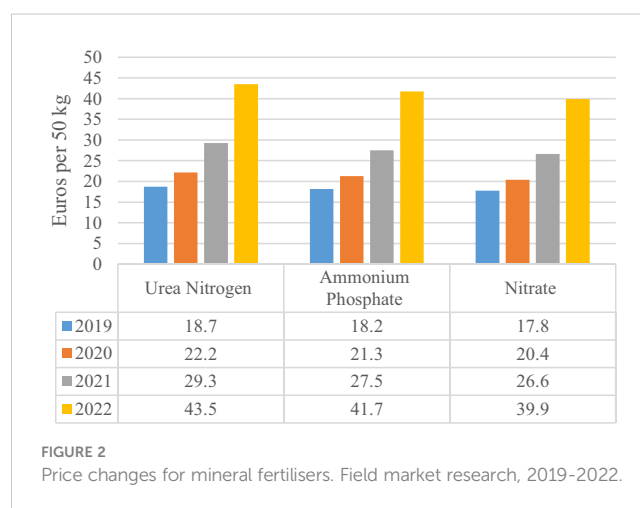
The Covid-19 pandemic has seriously affected the socioeconomic situation of smallholder farmers in Tajikistan, who are struggling to maintain their livelihoods in times of crisis (Hofman, 2021). Its impact on the country’s agricultural sector is

particularly remarkable given its critical role in the economy and ensuring food security. Historically, in order to maximise agricultural production, the Soviet government implemented intensive agricultural practices aimed at maximising the use of existing land by building large irrigation systems and providing a regular supply of nitrogen fertilisers in large volumes (Hamidov et al., 2020). Today, farmers are forced to purchase fertilisers from other countries, since there is very little domestic production in this regard.

Covid-19 restrictions on the import of agricultural inputs intensified the economic challenges faced by farmers, particularly those growing cotton, which is known for its high input requirements (Expert interview, May 2022). As a result, farmers faced additional costs associated with sourcing alternative inputs, reduced yields or lower quality outputs, which significantly affected their profits and livelihoods. From 2019, fertiliser prices doubled due to border closures and the temporary suspension of exports from other countries during the Covid-19 pandemic (Figure 2), forcing Tajikistani farmers to rely on their own internal resources (i.e., off-farm income and material assets). This situation was further aggravated as of February 2022, as the Russian-Ukrainian War terminated the Russian supply of fertiliser to other countries, including those in Central Asia (von Cramon-Taubadel, 2022).

Covid-19 also had a detrimental effect on farmers’ financial resources, in that family members working as labour migrants in Russia were not able to send remittances home, due to job cuts (Hofman, 2021). The Khatlon region is a major source of migrant labour, driven by low wages and high levels of unemployment, particularly in the agricultural sector (Bakanova et al., 2015). Farmers rely on income from remittances during the agricultural season when they invest resources in their crops and receive the earliest income only nine months after sowing (Farmer interviews, 2019-2022).

Tajikistani consumers and the government have responded very differently to this situation. Due to the disruption in agricultural input supplies, the prices of farmers’ final products have gone up dramatically in a short time, leading to widespread consumer



discontent. Consumers frequently blame farmers for this situation, while the government sees the rise in prices as a temporary issue that farmers will address on their own terms. However, due to limited government support, farmers often struggle to cover major expenses on their own, such as clearing runoff and drainage from agricultural fields, covering electricity expenses for machine irrigation and purchasing seeds and fertilisers. Additionally, the government continues to heavily promote cotton production, which often lead to farmers becoming even more reliant on remittances to make ends meet.

Crop area dynamics

As cotton is a nutrient-intensive crop, it requires large volumes of fertiliser (approx. 450 kg/ha on average) – a Soviet-era agricultural practice – which farmers now find difficult to afford at increased input prices (Expert interview, December 2021). In the current economic situation, conventional cash crops requiring large expenditures on inputs are becoming unprofitable. In turn, Tajikistani smallholder farmers are forced to shift to other crops, such as grains, vegetables and fruits; in their opinion, these produce higher yields with nearly the same amount of input, thus generating more profits.

As Figure 3 demonstrates, yield dynamics vary across different crops. Fruits and vegetables consistently demonstrate an increasing trend in yields from 2015 to 2020, suggesting both farmers' enthusiasm for their cultivation and these crops' great potential for profit. Grains exhibited fluctuations in crop yields, experiencing decreases, such as in 2018, while cucurbits were relatively stable, with small yield increases over the years. However, cotton production is generally subject to more volatility, as it depends fully on external factors such as variable input prices.

Nevertheless, smallholder farmers' limited agricultural land makes it quite challenging to incorporate new crops without reducing the area put aside for another one. The cultivation of profitable food crops, however, enables them to earn the money

required to “fill” the gap between actual and required cotton production. Cases of falsified cotton production numbers have been demonstrated by another scholar (Hofman, 2021), but this field research points to smallholder farmers' attempts to compensate for profit from non-existent cotton by growing other crops. In other words, farmers use the profit from cultivating non-cotton crops to officially register the land used for it as cotton-producing, as mandated by the state. This is why the official statistical data on cotton production often remain constant despite shifts in actual production (Figure 4).

Figure 4 offers insights into the annual agricultural yield, measured in hectares, for five distinct crops and spanning the years 2015 to 2020. Examining the data reveals trends and fluctuations in crop production over this six-year period. Notably, wheat production, started at 106,387 hectares in 2015, experienced minor variations in subsequent years, including a decrease to 97,252 hectares in 2018, followed by an increase to 103,937 hectares in 2019 and 103,003 hectares in 2020. Similarly, cotton cultivation began with 96,587 hectares in 2015, remaining relatively steady in 2016 and 2017, with a slight rise to 103,229 hectares in 2018, followed by consistent levels around 103,000 hectares in subsequent years. Cucurbit production showcased a steady upward trajectory from 27,684 hectares in 2015 to a peak of 36,273 hectares in 2019, then slightly dropping to 33,920 hectares in 2020. Fruit production, commencing at 28,049 hectares in 2015, exhibited consistent annual growth, reaching 33,061 hectares in 2020. Notably, vegetable production also displayed consistent expansion, starting at 13,936 hectares in 2015 and nearly doubling to 19,264 hectares by 2020. Overall, these data provide valuable insights into the dynamics of these crops, thereby aiding in analysing agricultural trends and planning future cultivation strategies.

Crop production and yield analyses

Agricultural land in Tajikistan is owned by the state, but according to the country's Land Code, individual farmers are

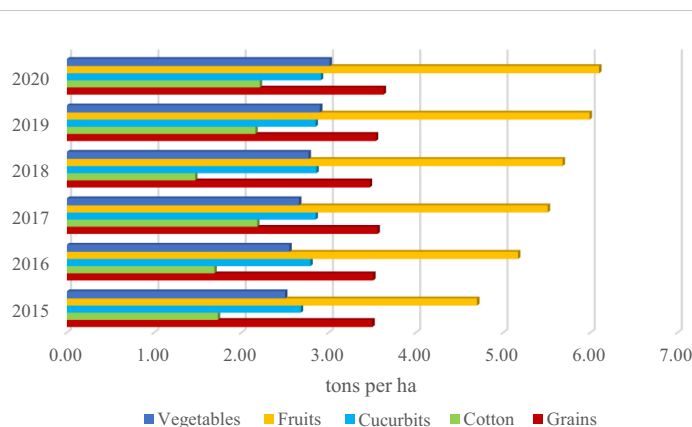
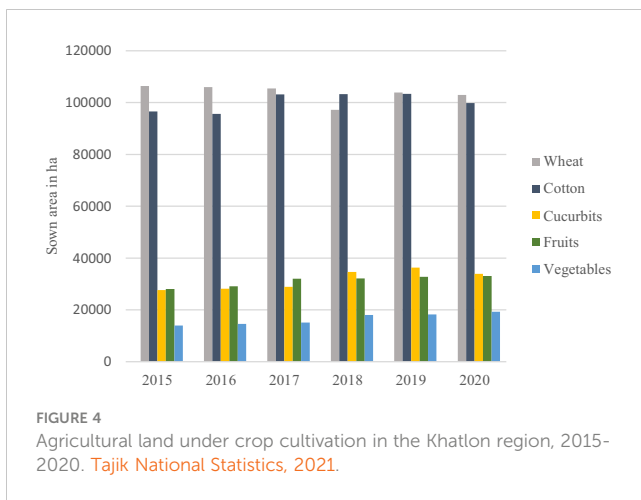


FIGURE 3

Crop yields among smallholder farms in the Khatlon region, 2015–2020. Tajik National Statistics, 2021.



granted lifetime inheritance rights to use it for agricultural purposes.⁵ Depending on the different land classifications, such as irrigated land, rain-fed land and pastureland, farmers pay an annual land tax, which is established by the state tax authority. The plots selected for the study fall under the irrigated land category, for which farmers have to pay about annually 150 euros per 1 hectare. They additionally pay for irrigated water according to fixed tariffs, amounting to about 60 euros per individual farm per year. With the exception of minor expenses such as a subscription to the local monthly newspaper, these are farmers' primary expenses; furthermore, importantly, they are fixed costs, which are relatively stable and do not depend much on external conditions.

Amidst the Covid-19 pandemic and the Russian-Ukrainian war, which led to closed borders and the attendant suspension of nitrogen fertiliser exports, the costs of agricultural inputs in Tajikistan underwent significant fluctuations from 2019 to 2022 (Table 1). Disruptions in trade and supply chains caused by the pandemic hindered the flow of essential inputs, thus impacting prices across various variables and consequently accounting for the largest share of production costs. Ploughing services escalated from 25 to 65 euros per hectare between 2019 and 2022, while land-levelling services surged from 16 to 49 euros over the same period. Tractor hoeing costs also experienced substantial growth, rising to 59 euros per hectare in 2022. Pesticide prices remained relatively stable, with only a slight increase from 2019 to 2022. However, the pivotal shortage of ammonium nitrate fertiliser, caused by the conflict-induced export suspension, contributed to a notable price rise from 45 to 74 euros per 100 kilograms during the years under examination. Urea, another essential fertiliser, witnessed a significant surge in price from 49 to 132 euros per 100 kilograms, thus exacerbating the challenges faced by Tajikistan's agricultural sector. Even the cost of using a combine harvester, an integral part of harvesting wheat, also went up due to the rise in fuel prices. Collectively, combined input costs surged from 200 to 472 euros per hectare of wheat cultivation, indicating the severe strain placed on Tajikistan's agricultural production and economy as a result of

restrictions and disruptions caused by Covid-19 and the Russian-Ukrainian War.

Due to the high import cost of wheat from neighbouring Kazakhstan, ranging from about 190 to 250 euros per tonne, Tajikistani farmers do not sell their wheat on the market, using it instead to meet their own wheat demands. As a result, there is no reliable data on the sale price of locally produced wheat.

While land processing and preparation costs for cotton are somewhat similar to those for wheat and other crops, cotton's production costs are slightly different because its requirements for fertiliser and pesticide use are much higher (Table 2). Since cotton is grown exclusively for sale, the use of sufficient inputs is very important to make a good profit. Additionally, the crop's labour-intensive nature, namely manual picking, differentiates it from others in this analysis. Even though farmers do not quantify their own family labour as costs, the labour-intensive aspects of cotton production, generally performed by family members, contribute to its overall higher input costs. These cost dynamics have simultaneously made farmers vulnerable to a number of external factors while pushing them to adopt resilience strategies to cope with these challenges.

Table 3 outlines annual cotton production performance in Tajikistan from 2019 to 2022 under the impact of recent external factors. Notably, cotton cultivation, known for its intensive input and labour demands, yields varying results, especially in comparison to other more stable crops. Despite fluctuations in average yield, ranging from 2 to 3 tons per hectare, and shifting sale prices, the gross production value demonstrated an upward trend, peaking at 1,993 euros in 2022. The costs associated with cotton cultivation, considering factors like increased input expenses due to closed borders and fertiliser shortages, remained notable throughout this period, culminating in total expenses ranging from 404 to 863 euros. Despite these challenges, cotton production managed to sustain a positive gross profit across the four years, ranging from 420 to 1,130 euros per tonne. Even if input prices increased, sales prices did as well during this period of crisis.

Table 4 demonstrates the yearly performance of maize cultivation in Tajikistan within the context of rotational farming and evolving market demands, thereby reflecting the transition towards high-yield Chinese hybrid seeds, facilitated by Tajikistan's shared border with China. Over the years, maize has exhibited a notable increase in average yield, rising from 5 to 10 tonnes per hectare on average, driven by the adoption of these hybrid seeds, which are renowned for their high productivity. This shift aligns with the heightened demand for maize grain as poultry feed due to Tajikistan's expanding poultry industry (Khakimov, 2019). Despite its consistent sales prices, the gross production value of maize has demonstrated a marked upward trajectory, reaching 3,300 euros per hectare in 2022. Notably, the production costs for maize differ from those of previous crops, primarily because of the difference in seed prices (Table 5). The significant role of hybrid seeds in maize yields is evident, contributing to an upward trend in gross profits from 206 to 2,496 euro per hectare (Table 4). This transformation highlights the strategic importance of hybrid seeds and wider agricultural trends. Maize cultivation in Tajikistan is adapting to shifts in demand and technology in an attempt to boost productivity and the economy.

⁵ As amended by Law No. 891 of 01.08.2012 of the Republic of Tajikistan.

TABLE 1 Variable costs for cultivating 1 ha of wheat (in euros).

Variable costs	Unit	2019	2020	2021	2022	% change in 2022 over 2019
Ploughing service	1 ha	25	29	49	65	160
Land levelling	1 ha	16	21	33	49	206
Tractor hoeing	1 ha	16	21	49	59	267
Pesticides	Need-based	16	20	23	23	44
Ammonium nitrate	100 kg	45	49	58	74	64
Urea	100 kg	49	59	99	132	169
Combine harvester	1 ha	33	33	54	70	112
Total		200	232	365	472	136

Farmer survey, 2019-2022.

The agricultural landscape in Tajikistan during the Covid-19 pandemic and Russian-Ukrainian war witnessed significant fluctuations in input costs and production dynamics across various crops. Wheat cultivation faced challenges due to closed borders, resulting in disruptions to trade and input availability. Cotton cultivation, on the other hand, demonstrated resilience, generating profits despite constraints such as labour-intensive practices and volatile sale prices. Conversely, maize cultivation experienced a shift towards high-yielding Chinese hybrid seeds, driving increased yields and gross profits. These patterns not only emphasise how Tajikistan's agricultural sector can flexibly respond to evolving market needs and geopolitical shifts, but they also shed light on the simultaneous existence of challenges and prospects amidst global uncertainty.

While it's puzzling that there was such a notable increase in gross profit during the time of crises, not just for the mentioned crops, one farmer managed to provide an explanation: "Maybe I will sound rude, but these [events] had a positive effect ... because of the sanctions ... our sale prices and demand increased. Many of our products went to Russia, for example, even in Kazakhstan and Turkmenistan" (Farmer interview, December 2022). In short, farmers found a profitable market niche selling to countries which in need of produce during the period of

crisis we examine, benefitting further from increased prices on these goods. This financial success, however, has been short-lived: as of 2023, the country's deposits of mineral fertilizer are near exhaustion, forcing private businessmen to raise prices, as well as sell it to farmers in smaller quantities, which is decreasing their yields (Tajik National Statistics, 2022). It is still too early to make prognoses about the harvest of 2023, and any analysis of it lies beyond the scope of this paper.

Social capital, demographics and migration

In this section, we split the respondents down into three smallholder farmer categories, namely first-, second- and third-generation farmers. First-generation farmers include those who received land after the redistribution of land belonging to collective and state farms, and they are aged over 50, representing 32.8 per cent of the total surveyed farmers. Second-generation farmers are between the ages of 31 and 50, which accounts for 51.6 per cent of the total surveyed. Farmers under 30 years, as third-generation farmers, represent 15.6 per cent of the total cohort. These results suggest that the surveyed farmers are predominantly middle-aged, with a relatively small proportion of younger and

TABLE 2 Variable costs for cultivating 1 ha of cotton (in euros).

Variable costs	Unit	2019	2020	2021	2022	% change in 2022 over 2019
Ploughing service	1 ha	25	29	32	65	160
Land levelling	1 ha	16	21	33	49	206
Tractor hoeing	1 ha	16	21	49	59	267
Pesticides	Need-based	12	12	12	25	108
Ammonium nitrate	200 kg	90	98	118	148	64
Urea	200 kg	98	118	198	264	169
Seeds	1 ha	16	21	41	41	156
Total		194	228	385	653	236

Farmer survey, 2019-2022.

TABLE 3 Gross profit for cotton production (in euros).

Year	Average yield tonne/ha	Sales price per 1 tonne	Gross production value	Total costs	Gross profit
2019	2	412	824	404	420
2020	3	494	1482	438	1044
2021	3	535	1605	595	1010
2022	2.2	906	1993	863	1130

Farmer survey, 2019-2022.

TABLE 4 Gross profit for maize (in euros).

Year	Average yield tonne/ha	Sales price per 1 tonne	Gross production value	Total costs	Gross profit
2019	5	124	620	414	206
2020	5.5	124	682	478	204
2021	8	206	1648	589	1059
2022	10	330	3300	804	2496

Farmer survey, 2019-2022.

older respondents. This information could be useful in designing agricultural policies or programmes that target specific age groups, as well as in identifying potential gaps in knowledge or resources.

The results of our survey indicate that the majority of the farmers have small landholdings, with 61.1 per cent possessing less than 1 hectare of land. A total of 31.2 per cent have landholdings between 1 and 3 hectares, while only 7.7 per cent have landholdings over 3 hectares. These results suggest that small-scale farming is prevalent in the surveyed area and that most farmers have limited land resources. For example, one family whom we encountered in our field research has four second-generation farmer brothers, who jointly inherited 4 hectares of land from their father. Each brother has a family of 4-6 children, and evidently, 1 hectare per brother is not enough to support all family members. The four of them have heeded the advice of their elderly mother, who has encouraged them to merge their plots and 'divide every grain equally among every member of your families so that families do not fight' (Farmer interview, December 2020). This is just one example of how growing families maintain collective control over the first-

generation's plots and remain resilient in the face of increasing pressure. There are no formal rules about land inheritance, as each family decides on their own.

The country's population growth has put increasing pressure on Tajikistan's agricultural land, thus forcing farmers to seek alternative sources of income. Often, third-generation farmers work abroad as migrant labourers. In response to our question, "What do you want to be when you grow up?" most male children in Khatlon answered that they wanted to go to Russia. The Covid-19 pandemic, however, has led to job cuts in Russia – and the Russian-Ukrainian War has decreased the country's attractiveness for migrant workers – resulting in many families losing or forgoing their additional income sources and compelling farmers to explore alternative financing options (Akramov et al., 2021). A farmer interviewed during our field research, for example, noted that he had adjusted to pandemic conditions by selling his assets in order to make necessary investments (e.g., seeds, fertilisers, mechanisation services). This particular farmer, who had earmarked his car for sale in case of financial distress, had to sell it in spring 2022, investing

TABLE 5 Variable costs for cultivating 1 ha of maize (in euros).

Variable costs	Unit	2019	2020	2021	2022	% change in 2022 over 2019
Ploughing services	1 ha	25	29	33	66	164
Land levelling	1 ha	21	25	29	54	157
Tractor hoeing	1 ha	16	29	45	60	275
Pesticides	Need-based	9	11	25	29	222
Urea	100 kg	104	127	173	274	163
Seeds	100 kg	30	50	74	99	230
Total	1 ha	205	271	379	582	184

Source: Farmer survey, 2019-2022.

the funds in his next round of cotton production. The farmer sadly added, 'My car gave me freedom of movement, but I had no choice but to sell it in order not to miss the agricultural season' (Farmer interview, December 2021). Although this tactic might not be sustainable in the long term, the farmer nevertheless adopted it as a last-resort resilience strategy in the face of financial challenges exacerbated by Covid-19 and other past crises. Families that do not have sellable assets are forced to take out credit with high interest rates from local banks and thus fall into debt, with the hope that they will be able to pay them off once the borders open and the flow of remittances recovers.

As third-generation farmers leave to seek work abroad, agriculture is left largely in the hands of the first and second generations, who, due to their advanced age, are more likely to have been severely affected by the Covid-19 pandemic, thereby disrupting their flow of profits. For example, in 2021, a first-generation farmer was unable to tend to his cotton crops during the growing season because of the negative health effects of Covid-19. As the younger generation of his family had left to find work in Russia, he was the only one able to take care of the crops that year – meaning that they suffered because of his deteriorating health.

Separately, first-generation farmers possess knowledge and practices inherited from the Soviet era. However, as they leave the agricultural sector, the second generation takes over but continues to rely on the same practices. These practices are not being replaced by modern ones, as the younger, better educated generation often prefer to migrate in search of better employment opportunities abroad; statistics show that 85 per cent of the migrants from rural areas are between 15 and 44 years. Second-generation farmers rely mainly on traditional practices passed down from their fathers and do not have a formal education in agriculture. One interviewed farmer stated that they are the "people's academics," locally known as *narodnye*, having learned everything from their fathers (Farmer interview, October 2021).

Subsistence and crop diversification

Tajikistan's agricultural sector has long been a significant contributor to the country's economy, with cotton cultivation playing a pivotal role in the national identity and in economic development. Nevertheless, despite the government's efforts to promote domestic food production, the country remains heavily reliant on imports to meet its basic food needs, particularly for major staple crops such as wheat. This overreliance on imports exposes Tajikistan's food prices to high levels of volatility during times of economic crisis, leading to substantial challenges in ensuring food security for its citizens. In fact, recent statistics indicate that only about 40–45 per cent of Tajikistan's demand for wheat is satisfied by local production, while the remaining share is met through imports, primarily from Kazakhstan (Tajik National Statistics, 2021).

Given the volatility of market conditions for staple food crops, farmers interviewed in the study frequently reported a preference for cultivating these crops themselves, subsequently utilising their own resources, such as seeds and plots, in order to ensure reliable

access to basic food items for their households. This strategy of household food production emphasises the potential role of small-scale agriculture in enhancing food security at the local level, particularly in contexts where access to affordable staple foods may be compromised by unstable markets caused by external factors (Hashmiu et al., 2022). This is particularly important given Tajikistan's dietary traditions, making it the country with the highest per capita consumption of wheat in the world (Buisson and Balasubramanya, 2019). The preponderance of wheat cultivation among smallholder farmers in Tajikistan reflects a longstanding tradition of prioritising this crop as a resilience strategy, particularly among first-generation farmers who experienced food scarcity during the Soviet era. As a result, wheat has become the second-most grown crop by smallholder farmers, albeit often at the expense of other crops. This pattern of prioritising wheat production has persisted over time and has been reinforced by recent events, such as the Covid-19 pandemic, which sparked panic buying and revived memories of stockpiling during previous crisis periods. Given the high demand for land associated with wheat cultivation, there is a need to explore alternative strategies for smallholder farmers to promote crop diversification and enhance the resilience of the agricultural sector.

The third crops of choice for Tajikistani smallholder farmers are maize and alfalfa. Farmers possess Soviet-era knowledge of crop rotation for these crops, which are largely dedicated to producing animal fodder. While taking second place to the production of wheat, which farmers need for their families' survival, maize and alfalfa are critical for the survival of their livestock: Khatlon lacks pasture lands, meaning that farmers must grow their own animal feed. Tajikistan has a total of 17.9 million livestock, including cattle and sheep. The Khatlon region alone has 5.6 million farm animals, which constitutes about 31 per cent of the country's total. With a population of over 3 million people, each citizen in the Khatlon region would have around 1.9 heads of livestock (Tajik National Statistics, 2021).⁶ These figures suggest that livestock farming plays a significant role in the rural economy of Tajikistan, particularly in the Khatlon region, as farmers can slaughter animals and sell the meat – or use some of it for their own consumption. Farmers therefore see livestock as a major investment, because they are investing a tremendous amount of money in terms of buying feed and fattening the animals in order to make a profit later. The cultivation of maize and alfalfa is necessary to sustain these animals, thus highlighting the resilience of Tajikistani farmers who prioritise their basic needs for survival and invest in long-term livelihood strategies.

Because of the crop hierarchy described above, there is limited space available for cultivating other crops, making diversification a challenging task. While some pioneering farmers have introduced alternative techniques to increase their resilience to shocks and stressors, crop hierarchy remains deeply ingrained within the agricultural sector. This is due in part to the historical experiences of Tajikistani farmers, who have developed resilience strategies based

⁶ This is a rough estimate, and the actual number may vary depending on factors such as the distribution of livestock among different households and the types of livestock being raised.

on the Soviet-era approach of prioritising wheat as a stockpile crop to ensure food security during times of scarcity. Despite the challenges posed by this practice, some smallholder farmers have been experimenting with diversification techniques and alternative crops, such as fruits and vegetables, to help adapt to changing market demands. However, these efforts remain limited and are often hindered by a lack of resources and technical knowledge.

Technologies and knowledge

One of Khatlon's increasingly used agricultural trends in recent years is a shift towards new technologies, such as greenhouses, plastic sheeting and drip irrigation, often introduced by international development organisations. The region's warm climate allows farmers to continuously grow and harvest vegetables, which are always in demand and produce high yields compared to other crops. As a result, farmers' investments in greenhouse technology nearly always pay off, as they can harvest profitable vegetables over the course of several years. While some have been able to adopt new technologies to improve their agricultural practices and enhance their resilience to various shocks and stresses, such as climate change and economic instability, not all farmers have the financial means or technical knowledge to do so. As a result, they may be more vulnerable to external pressures and less able to adapt to changing conditions. Greenhouses have made it possible, however, to cultivate and consume fresh vegetables almost year-round – a development, which one farmer noted, 'allows one to eat fresh tomatoes and cucumbers without waiting for the summer season, which is particularly important in areas where access to fresh fruits and vegetables is limited' (Farmer interview, November 2021).

There is also a smaller but growing trend towards intensive orchards for fruit cultivation. Government policy has encouraged farmers to expand the area of their orchards – nearly impossible, given the physical limitations of their plots – so they adopt these techniques at the expense of cotton cultivation. This represents a shift from traditional fruit farming toward more market-oriented cultivation; in the former, farmers must wait at least five years before their first harvest, while intensive orchards can produce yields after one year (Expert interview, June 2022). Fruit varieties from intensive orchards – such as Californian peaches – are better preserved during long periods of transportation, and so the potential profitability of intensive orchards has pushed farmers to reduce the cultivation of other crops.

What farmers gain in profits, however, they lose in taste. One farmer described these new fruit varieties as looking 'perfect' and 'having no defects' but being tasteless, in great contrast to the traditional fruits grown in Tajik orchards. However, switching from intensive cotton farming to intensive orchards raises questions about the long-term viability of the latter, as these developments are so recent, and so experts have been unable to pass judgment on the sustainability of intensive orchards – especially given their claim that they will be able to properly assess the situation in ten years, at the earliest. In other words, it is still difficult to tell whether the sacrifice of these fruits' taste and appearance is worth the money.

One particularly pioneering farmer has been considering similar consumer demands, albeit with pumpkins, even switching varieties in order to increase profits. Traditional local pumpkin varieties are very large in size, and consumers find them difficult to use when preparing just one meal. Instead, this farmer has chosen to grow Chinese hybrid pumpkin varieties, as they are much smaller, thus allowing him to sell a greater number: 'They are easy to pick up and take home', the farmer said about his new pumpkins, 'and they're also very good-looking' (Farmer interview, March 2022). Although farmers cannot necessarily accommodate the size of the market, these strategies suggest a readiness to adapt to the demands of Tajikistani consumers for more aesthetically pleasing produce with a long shelf life.

Not all crops, however, rely on new technologies; some simply use farmers' limited land in ways that are more efficient. Strawberries and alfalfa, for example, are grown by some farmers in the shade of trees on intensive orchards – thus making use of land that would otherwise lay fallow. Strawberries in particular also produce yields several times throughout the season and are easy to sell on the market: some farmers say that they earn more from them than from any other crop. Nevertheless, both strawberries and alfalfa are highly nutrient-intensive crops, and experts say that growing them in such proximity to other crops may not be wise (Expert interviews, November 2021). Tajikistani farmers, as we discuss below, are most interested in making an immediate profit, but it is still too soon to tell if their resilience strategies of growing more land-efficient crops will be sustainable in the long term.

Fertiliser substitutes and sharecropping

The rise in fertiliser prices caused by the crises of recent years has forced Tajikistani farmers to use their own limited fertiliser substitutes, such as animal and green manure. This adaptive behaviour reflects their ability to manage resources efficiently in the face of adversity, while also reducing their dependence on external inputs. Animal manure is available to most Tajikistani farmers from their livestock, but given its limited quantity, it is mixed with any remaining nitrogen fertilisers. Some farmers also grow fodder crops (e.g., alfalfa or grass) with the intention of turning it into green manure or bio-humus, whilst a small number have even stressed their belief in organic farming – although some are sceptical about its prospects: one agronomist noted, 'In order to shift Tajikistan entirely to organic farming, we would need so much livestock, which would cover the entire territory of the country' (Expert interview, May 2022). While organic farming promises reduced input costs, it also reduces overall crop yields – as investigated in other countries like India and Sri Lanka (Röös et al., 2018), where reduced yields due to transition to organic farming have caused food insecurity. For this reason, there was a need to transform forest cover into agricultural land to address food demand (Reddy et al., 2022). However, such a prospect is hardly feasible in Tajikistan, as about 93 per cent of the country is mountainous. As Tajikistan's agriculture plays an important economic role as a source of income and food security, many farmers cannot afford to convert fully to organic production, as

it entails losses, especially during a conversion period of three years or more. Consequently, without external assistance from the state or external financing, as the experience of other countries shows, many farmers leave organic production during the first two years (Reddy et al., 2022).

Research conducted by Mukhamedova and Pomfret (2019) on the survival of sharecropping in Central Asia suggests that it is a second-best option of land use for farmers due to institutional constraints in Central Asia. Land reform has been a slow process, and many input markets remain imperfect, leading to the adoption of sharecropping as a more flexible arrangement than fixed rent. Its legal status is unclear in Central Asia, which therefore limits the representativeness of the data, but the study indicates that sharecropping has not disappeared with the advent of economic development (Mukhamedova and Pomfret, 2019). Our field research conducted during the crisis periods in Tajikistan revealed that sharecropping in the Khatlon region emerged as a prevalent and effective resilience strategy among the farmers, as it allowed them to overcome the challenges of limited resources and keep their land plots, as according to Article 37 of the 1996 Land Code, land may be withdrawn from use due to 'non-rational use' or lack of cultivation for a year, and then subsequently reassigned to those capable of effectively managing it.

To maximise their time and resources, as well as hold on to their plots, some farmers unable to manage their entire territory increasingly exercise sharecropping. In fact, the pandemic has given the practice new life, as it offers employment opportunities for Tajikistani labour migrants who were forced to return home, largely from Russia. Sharecropping in Khatlon, then, has somewhat reversed the trend of out-migration to Khatlon to in-migration into the region so that former labour migrants can benefit from local farmers' uncultivated land. In these situations, neither the original farmers nor the sharecroppers grow cotton as their major crop: at most, the original farmers grow cotton on half of their remaining land, while the sharecroppers seek to maximise profit on their plots by growing vegetables, strawberries and other profit-oriented crops. Their cultivation patterns are now leading to broader shifts in crop selection among Tajikistani farmers, pointing to a broader trend to seek out new crops in times of economic crisis.

Discussion

Although the period of crisis that we examine herein is not the first "shock" to Tajikistani farmers' work and lives, it has strengthened resilience strategies that they had already begun to practice, such as pooling resources between several smallholder farmer families, adopting new agricultural technologies and considering different approaches to land use, namely sharecropping and organic agriculture. Even though farmers are limited by their socioeconomic conditions (i.e., knowledge, age, family size, land area and wealth) in their adoption of specific resilience strategies, some of them are accessible even without additional resources, such as the conventional cultivation of non-cotton crops without the use of additional technologies such as

greenhouses or drip irrigation. Although the premier role of cotton has diminished as a result of these circumstances, it remains ingrained in farmers' practices and consciousness and is unlikely to disappear from the Tajikistani landscape anytime soon.

Much research has been done on the political economy of cotton in Tajikistan, but this study aims to address the role of non-cotton crops in the shadow of the country's cotton policy. This is an important addition to existing literature, as it helps present a more nuanced and complete picture of the country's agriculture: rather than continuing to focus on cotton, we explain how and why other crops are gaining importance for farmers trying to survive. The crises of the last four years provide both an interesting opportunity and lens through which to view the transformations of Tajikistan's agriculture as farmers place increasing importance on their own subsistence and on making a profit with scant resources. The crises have engendered a particularly generative and productive time for farmers as they have been forced to reconsider their customary practices and attitudes.

While Tajikistan combines Soviet heritage and authoritarian governance, its agricultural experience bears some similarities to that of its East and South Asian counterparts, such as India, Sri Lanka and China, smallholder farmers in these countries have adopted many analogous resilience strategies in the face of their respective periods of crisis. By juxtaposing Tajikistani smallholder farmers alongside their counterparts elsewhere, this study aims to broaden scholars' understanding of agricultural resilience strategies across the globe while adding the post-Soviet experience of central planning, power asymmetries and the command economy.

This study's focus on farmers' experiences has naturally led to certain limitations. Since our primary source of data was ethnographic research based on interviews with the farmers themselves, these conversations were inherently subjective, in large part inhibited by their reluctance, for political reasons, to share certain information openly. Moreover, memory and perception are naturally mutable based on a variety of factors, not least of which must have been the most recent period of crisis. Additionally, the data we have collected are largely qualitative, meaning that a quantitative study of production remains to be undertaken by future scholars, who will hopefully be able to assess the sustainability of the practices we outline herein. Another area for future research is the permanence of the resilience strategies we have identified: it remains to be seen whether Tajikistani farmers will be able to break free of their Soviet-era trajectory and dependence on cotton.

Conclusion and policy implications

Overall, this study sheds light on the responses of Tajikistani smallholder farmers to a period of crisis from 2019 to 2022, highlighting the ways in which they have adapted and innovated in the face of adversity. While the long-term sustainability of these changes is yet to be determined, there is evidence to suggest that farmers are exploring new paths and adopting new practices to improve their resilience and adapt to changing circumstances even

in the post-crisis period. This leads us into broader assessments of path dependency, i.e., whether this past period of crisis marks the beginning of a new path for agricultural development in Tajikistan. Ultimately, scholars should aim to determine whether these agricultural developments represent a short-term response to a set of pressing issues or a long-term shift in Tajikistani farmers' approaches to profit, cultivation and subsistence, potentially informing the development of policies and interventions to support their livelihoods and enhance their resilience. In other words, our own field must adopt a more holistic approach to the existing issues of agricultural production and revenue in Tajikistan, examining not only what farmers grow, but also the circumstances that led them to grow it.

Our study has demonstrated that although opportunities are limited for those seeking to boost profits and ensure subsistence with scarce resources, it is encouraging to note that farmers are taking the initiative to accommodate the far-reaching changes they are facing. Some, for instance, are receiving support from development projects, whilst others are taking innovative steps at their own expense. As one of the pioneering farmers said about the intensive orchards he was growing, 'We learn by trial and error'. However, poorer farmers are routinely "left behind" and unable to adopt the same strategies as their wealthier counterparts. It is for this reason that we recommend that more NGOs should invest further in Tajikistan's agricultural infrastructure, specifically for those farmers who have previously been unable to participate in training, and that the government should financially support farmers whilst adapting to new strategies and technologies. We also believe that the state will work to promote new agricultural methods in an effort to popularise more modern techniques and help the population shift away from Soviet-era practices, which are unable to meet the demands of the country's growing population and changing economic and environmental situation.

Data availability statement

The datasets presented in this article are not readily available because of the sensitive nature of the research conducted in a particular country and our commitment to safeguarding the anonymity of the interviewees. If you wish to obtain access to the datasets, please direct your inquiries to the corresponding author.

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Author contributions

AZ, HA and MS contributed in the overall design and conceptual analysis of the study conducted in the southwestern Tajikistan. AZ wrote the first draft of the manuscript while HA and MS contributed to manuscript revision, read and approved the final version for submission.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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