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Agriculture and the War in Ukraine One Year Later

Olena Sambucci and Daniel A. Sumner

Ukrainian agriculture and the world food system have been remarkably resilient in the face of continuing tragedy. Ukraine has continued to supply domestic and world consumers with food staples as governments and markets have rapidly adjusted supply chains to support the world's most vulnerable.

Field damage caused by Russian artillery.
Photo Credit: Ukrainian Grain Association.

More than 16 months have passed since Russia's invasion of Ukraine on February 24, 2022. The war continues, disrupting Ukraine's farming, processing, and marketing. Our *ARE Update* article published last June summarized the situation then and reviewed likely impacts of the war on agriculture, including in California. The Russian invasion disrupted the Ukrainian 2022 summer harvest of the wheat, barley, and rapeseed crops that were planted in the fall of 2021. The invasion also disrupted the planting, production, and harvest of spring-planted barley (about 60% of barley acreage), which is harvested in the summer, as well as sunflowers, corn, and other crops harvested in the fall.

Over the past year, the war disrupted the fall planting of wheat, winter barley, and rapeseed, and the harvests of all of these crops and spring barley in the early summer of 2023. It also disrupted the 2023 planting of spring barley, sunflowers, corn, and other crops that will be harvested in the fall of 2023. Here we update the situation and outlook and consider implications for food and agriculture in Ukraine and globally. Impacts for California agriculture and consumers continue to be small and focused on sunflowers.

Situation and Outlook for Ukraine's Agriculture After 16 Months of War

Table 1 shows the recent pattern of harvested acreage and projections for the four major annual crops in Ukraine. For all crops, the 2021 harvest was prior to the Russian invasion. Fall-planted wheat and rapeseed and both winter and spring barley were

Table 1. Harvested Acreage of Major Ukrainian Crops

	2021	2022	2023 (June 9 Projection)	Percentage Change (2023 from 2021)
Crop		**Million Acres**		**Percent**
Wheat	18.3	13.1	10.6	-42
Sunflower Seeds	17.5	12.8	14.1	-20
Corn	13.6	10.1	8.4	-38
Barley	6.7	4.7	4.4	-33

Source: World Agricultural Production Foreign Agricultural Service, Circular Series WAP 6-23, June 2023. Available at: https://apps.fas.usda.gov/psdonline/circulars/production.pdf.

Table 2. Production of Major Ukrainian Crops

	5-Year Average 2017–2021	2022	2023 (June 9 Projection)	Percentage Change (2023 from 5-Year Average)
Crop		**Thousand Tons**		**Percent**
Wheat	26,927	20,900	17,500	-35
Sunflower Seeds	15,360	11,200	11,800	-23
Corn	34,646	27,000	24,500	-29
Barley	8,739	6,180	5,900	-32

Source: USDA, FAS. Available at: https://bit.ly/3pyckNP; Sambucci and Sumner, 2022. Available at: https://bit.ly/3udgR7w.

Table 3. Export Value of Major Ukrainian Crops, 2021 and 2022

	2021	2022	Percentage Change
Crop	**$ Billions**		**Percent**
Sunflower Oil	6.3	5.5	-13
Sunflower Seeds	~0	1.3	—
Corn	5.9	6.1	3
Wheat	4.8	2.7	-43
Barley	1.2	0.5	-63
Walnuts	0.1	0.1	~1
Sum	**18.3**	**16.2**	**-11.5**

Source: UN Comtrade database. Available at: https://comtrade.un.org/data/.

harvested in the summer of 2022, a few months after the war started. For wheat and barley, harvested acreage was down by almost 30%, in part because some acreage was in the conflict zone or occupied by Russian invaders. The 2023 harvested acreage is projected to decline even further. Wheat acreage is expected to be down by 42% and barley acreage by 33% from 2021 to 2023.

War disrupted planting of the fall-harvested crops in the spring of 2022 and farming activities and harvest in the fall of 2022. Sunflowers and corn both saw declines in acreage from 2021 to 2022 and further declines are projected for 2023. Harvested acres declined by 20% from 2021 to the projected harvested acreage in 2023 for sunflowers and by 38% for corn.

No reliable acreage or production information is available in the part of Ukraine that is in active conflict zones or has been occupied by Russian forces. Therefore, this area, about 20% of potentially cropped area overall, is not included in the harvested area data for 2022 and 2023.

Crop production is affected by harvested acreage and yield, which even in normal times varies from year to year in response to weather, pest pressure, and other conditions. The war has put additional pressure on Ukrainian farm practices and access to inputs. Table 2 compares crop production and projected production in 2022 and 2023 to the average of the five years before the conflict—2017 through 2021. Wheat production fell by 23% in 2022 and is projected to be down by 35% in 2023. Sunflower production is projected to be higher in 2023 than the severely depressed 2022 production because acreage is up by a few percent. In 2022, sunflower production turned out to be about 18% higher than had been projected last June. Both corn and barley production in 2023 are projected to fall modestly from the realized production in 2022, which was down severely from the five-year average.

Ukrainian Exports Since the Beginning of the War

At the start of the war, Russia's blockades of the Azov and Black Sea ports caused major delays and concerns that crops could not be exported using these sea routes. An early arrangement allowed exports to resume by rail and through Danube ports via the Solidarity Lanes. Then in July 2022, the Black Sea Grain Initiative allowed Ukraine to export food commodities through "humanitarian" corridors in the Black Sea. These two arrangements allowed the Ukrainian exports of grains, sunflower oil, and other food crops to recover to some extent.

In recent years, Ukraine has accounted for more than half of world sunflower oil exports and between 10% and 20% of world exports of barley, corn, and wheat. Ukraine also ships about 3% of world walnut exports, well behind California's 35% by value.

Ukraine remains the world's largest exporter of sunflower oil. However, because of difficulties with processing, about 20% of the export value shifted to sunflower seeds rather than oil in 2022, denying Ukraine gains from the value added. Because prices rose, total revenue from oil and seeds together went up, not down, in 2022.

With export values rising slightly for these two largest export crops, the loss of $2.1 billion in the export value of major Ukrainian crops came from the large percentage declines in the export of wheat and barley, which are harvested in the early summer. As shown in Table 3, exports of wheat fell by 43% and barley by 63%. Overall, export revenue from major crops decreased by about 11.5%.

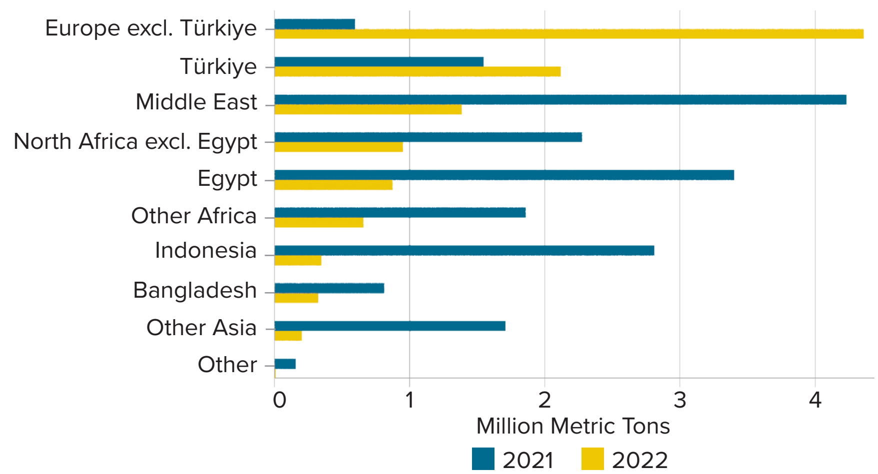
Because of the disruption in the export routes, export shipments from Ukraine were diverted to Eastern Europe and other European countries. This became controversial because diversion of grains drove down local prices in Eastern Europe, spawning complaints from farmers. Political pressure caused some governments to temporarily ban grain and other imports from Ukraine in April 2023. However, within a month, the EU began compensating affected farmers and had negotiated arrangements to keep the Solidarity Lanes open for continuing transit of exports from Ukraine.

Figure 1 shows the dramatic diversion of Ukraine's wheat exports from 2021 to 2022, even as export quantities fell by 42%. Exports to Türkiye rose by 25% and exports to other European countries as a group rose by about seven-fold. Exports to all other formerly major destinations for Ukrainian wheat, such as Egypt, other countries in North Africa, and the Middle East, fell by 67%. Exports to Indonesia, Bangladesh, and other countries in Asia fell by 84%.

Export diversions for sunflower oil and corn were similar, although not as stark as for wheat, given that their harvests are not until the fall. India and China were the top destinations for sunflower oil from Ukraine in 2021. In 2022, exports to these countries decreased by 62% (see Figure 2), with sunflower oil diverted to Türkiye, Poland, Romania, and other countries in Europe.

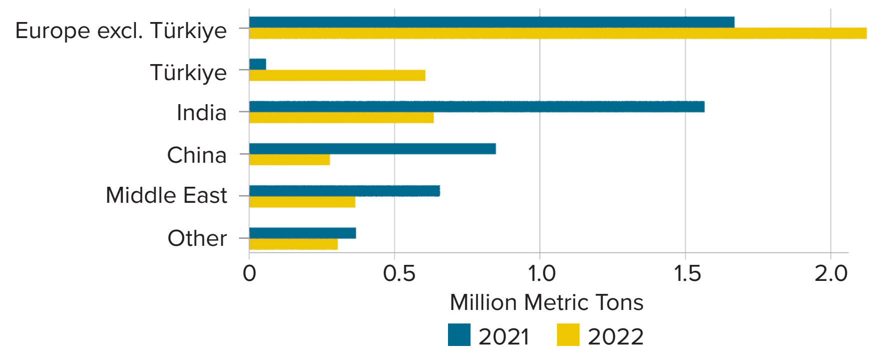
As shown in Figure 3, exports of Ukrainian corn to Europe—mostly Romania, Poland, and Hungary—increased by 83% in 2022, while exports to China, Egypt, and countries in the Middle East decreased by 40%.

Figure 1. Exports of Wheat From Ukraine, for 2022 Compared to 2021



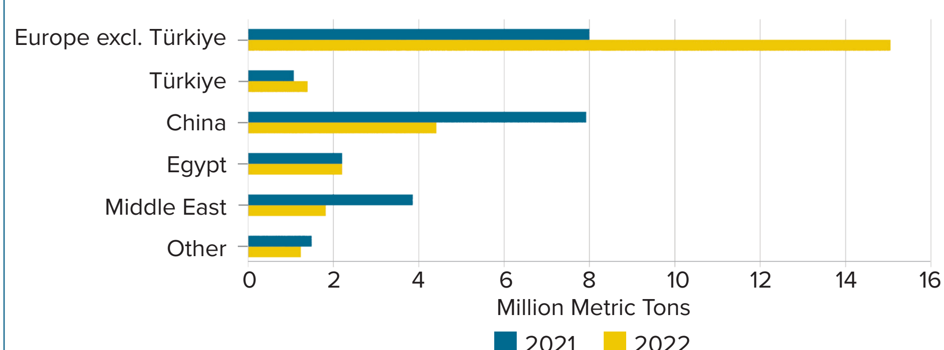
Source: UN Comtrade database. Available at: https://comtradeplus.un.org/TradeFlow.

Figure 2. Exports of Sunflower Oil From Ukraine, for 2022 Compared to 2021



Source: UN Comtrade database. Available at: https://comtradeplus.un.org/TradeFlow.

Figure 3. Exports of Corn From Ukraine, for 2022 Compared to 2021



Source: UN Comtrade database. Available at: https://comtradeplus.un.org/TradeFlow.

Changes in Ukrainian export destinations did not imply that commodities did not get to Ukraine's original export partners. Diversion means that some Ukrainian exports now go through Europe, rather than directly to their final destinations, or that other sources replace Ukrainian commodities in the original destination. For example, the June 2023 USDA WASDE report shows that imports into Bangladesh, which fell by 21% in the 2022/2023 marketing year relative to the 2021/2022 marketing year, are projected to almost recover in the 2023/2024 marketing year. Imports of wheat into Southeast Asia, including Indonesia and the Philippines, fell by

9% in the 2022/2023 marketing year but are projected to mostly recover in 2023/2024.

Likewise, the imports of wheat into North Africa for the 2023/2024 marketing year are projected to be 19% higher than they were in 2021/2022, while consumption of wheat in the Middle East is projected to be 3% higher in 2023/2024 than it was in 2021/2022.

Implications

As we discussed last year, the overlap in crops produced between Ukraine and California is small. The main connection is sunflowers. In California, sunflowers are grown almost exclusively as seed for sowing, and most of the sunflower seed was exported to Russia and Ukraine. California acreage of sunflower seed fell by about 30% to about 33,000 acres from 2021 to 2022, mostly due to severe cuts in irrigation water availability in Northern California. California sunflower seed acreage is expected to be up in 2023, but not back to the total 2021 acreage. California exports of sunflower seed have been diverted from direct shipments to Ukraine to destinations in Europe and elsewhere. Ukraine now imports more seed from some of these places as well as other suppliers.

California food consumers have not been affected measurably by the Russian invasion of Ukraine. Any global commodity price impacts have not affected costs in the United States enough to notice in retail prices.

In the past year, global efforts to relieve shortfalls in poor countries that were facing disruptions in imports from Ukraine seem to have reduced food insecurity. Conditions have not returned to normal, but much of the potential hunger has been averted. The June 2023 USDA WASDE report projects that world wheat production, trade, and ending stocks for the 2023/24 marketing year will be slightly above 2022/23 quantities.

Finally, Russia is the world's largest exporter of fertilizer and a major exporter of natural gas, which is used to produce nitrogen fertilizer. Therefore, another global agricultural apprehension about the Russian invasion was that prices of fertilizers would rise further after having risen dramatically from 2020 through the winter 2022. In fact, however, fertilizer prices began to decline in the late spring and early summer of 2022 as the war continued. Overall fertilizer prices have now fallen roughly to what they were in 2021, a decline of more than 40% compared to peak prices in early 2022.

Longer-Term Concerns

The agricultural devastation in Ukraine caused by the Russian invasion will take decades to repair. The Ministry of Agrarian Policy and Food and the Kyiv School of Economics estimated financial losses due to the damage to Ukrainian agricultural assets to be $6.6 billion. They also projected losses to Ukrainian agriculture from reduced crop and livestock production and trade to be $34.2 billion as of November 2022. These estimates have risen and are continuing to rise.

The destruction in June 2023 of the dam across the Dnipro River flooded towns and cities, as well as 25,000 acres of cropland on the right side of the river and several times more on the Russian-occupied left side. The reservoir supplied irrigation to about 1.5 million acres that produced grains, oilseeds, melons, onions, and tomatoes. Losses from this destruction alone will total many billions of dollars of farm value that will continue until repairs can be completed after Ukraine has secure access to the territory.

Of course, agricultural destruction and loss are but a small part of the suffering from the Russian invasion of Ukraine. Global consequences will continue for a very long time.

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Authors' Bios

Olena Sambucci, who was born and raised in Eastern Ukraine, is a project scientist and Daniel A. Sumner is a Distinguished Professor, both in the Department of Agricultural and Resource Economics at UC Davis. They can be reached at osambucci@ucdavis.edu and dasumner@ucdavis.edu.

For additional information, the authors recommend:

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How Is Demand Management Developing in SGMA Groundwater Sustainability Plans?

Astrid Borup Friberg, Arthur R. Wardle, and Ellen M. Bruno

Demand management will play a critical role in both reaching groundwater sustainability under SGMA and determining the economic costs of groundwater regulation. Here, we provide an update on the approval process of 116 submitted groundwater sustainability plans. We detail demand management proposals and compare how these differ between plans that have been approved and those deemed incomplete or inadequate.

Almost a decade after the passage of the Sustainable Groundwater Management Act (SGMA), the law's implementation is now well underway. Prior to SGMA, groundwater extraction was almost entirely unregulated in most of California, with overlying landowners generally being free to pump as much water as they could put to beneficial use. Persistent drawdown of aquifer levels and its corresponding costs, including seawater intrusion and land subsidence, meant new rules were necessary to ensure the sustainability of California's groundwater resources. SGMA seeks to provide those rules in a decentralized manner, vesting the power to develop rules and regulations for groundwater pumping in local agencies with existing ties to land and water management.

A previous *ARE Update* article by Wardle, Griggs, and Bruno detailed how these new local agencies, called Groundwater Sustainability Agencies (GSAs), were developed and who filled their boards. The next step of SGMA implementation was to develop a Groundwater Sustainability Plan (GSP). Today, the deadline to submit GSPs has passed, and the plans are available to view on the Department of Water Resources' (DWR) SGMA portal. Here, we describe, for the first time, the role that demand management plays in the full set of submitted GSPs.

What GSPs Do and Do Not Tell Us

Many GSPs include over 1,000 pages, reflecting the long list of criteria they are required to satisfy. Among these pages are discussions of hydrogeologic features of the relevant groundwater subbasin, projections of future water demands and supplies, water budgets, and other information necessary for the development of an effective management plan. Only one small section of the plans, usually taking up only about a dozen pages, explains the management actions GSAs are proposing to achieve sustainability.

Even in those short sections, not all proposed management actions involve demand management, by which we mean new rules that alter the incentives facing groundwater pumpers when considering how much to pump. In fact, most proposed actions seek to augment supply through means like stormwater recharge. While supply augmentation has a definite role to play in achieving groundwater sustainability throughout California, there is only so much available water with which to augment groundwater resources. A study by the Public Policy Institute of California has shown that much of the proposed supply augmentation is infeasible. Demand management will be needed to achieve sustainability targets in many basins.

Beyond the simple unavailability of adequate surface water to make up for groundwater deficits, demand management is also important for its ability to influence the costs of reducing groundwater use. The fundamental problem that led to existing drawdown is that individual pumpers making a private choice about how much to pump do not personally face the full cost of their own pumping; while they do pay for the electricity to operate the pump, they do not bear the cost of lower groundwater levels for everyone else.

Fixing this problem purely through supply augmentation risks cascading expenses, as pumpers are free to simply extract whatever recharge the GSA provides. Demand management strategies resolve this "leaky bucket" problem. But not all demand management strategies are created equal—the type of demand-side strategy and the degree to which demand is limited will have implications for how agriculture and surrounding communities are impacted.

GSPs are an imperfect guide to what will actually happen as GSAs implement SGMA. The plans laid out in GSPs are not final; they are often subject to future votes of the GSA board, regulatory approval from other agencies, or successful contract negotiations with private parties. Plus, they may be conditional on the ability to raise funding. However, DWR is currently reviewing GSPs to ensure the plans can plausibly achieve the groundwater sustainability goals set by SGMA. For most GSAs, their submitted GSP is the best publicly available evidence of what steps they plan to take in meeting their SGMA obligations.

The GSP Review Process

Though all GSP submission deadlines have passed, the GSP review process is still ongoing. For every GSP submitted, DWR must assess whether the plan is in 'substantial compliance' with the SGMA law. Though the law broadly requires GSPs to include components of both monitoring and managing overdraft, as well as more specific consequences like land subsidence and groundwater quality degradation, the statute is fairly unspecific on the details. Instead, it directs GSPs to define their own measurable objectives and milestones using the best available science, then demonstrate that the plan's proposals will be adequate to achieve those goals.

As shown in Table 1, at the time of this publication, there are 38 incomplete or inadequate GSPs, 24 approved GSPs, and 54 GSPs still under review, which gives a total of 116 submitted GSPs across California. All the GSPs that have already undergone review (and whose status is therefore either approved, incomplete, or inadequate) cover "high- and medium-priority" basins. This is due to the fact that basins classified as high- and medium-priority were required to submit plans by January 2020 or January 2022, with the subset of those facing conditions of "critical overdraft" on the faster 2020 timeline. On the other hand, the GSAs managing low- and very low-priority basins are not required, but encouraged, by DWR to submit a GSP.

Table 1. Number of GSPs by 2019 Priority Level and Review Status

Status	Priority Level	GSP Count
Approved	High	14
	Medium	10
Inadequate	High	23
Incomplete	High	15
Review in Progress	High	15
	Medium	31
	Low	1
	Very Low	7

Source: The SGMA Demand Management Action Database (DMAD). Available at: https://sgma-dmad.com.

Among the GSPs deemed incomplete by DWR, commonly cited issues include lack of coordination among GSPs (because some basins have multiple GSPs), data inconsistencies, and incorrect or inconsistent methodology. Other GSPs have not been approved because they fail to address the GSP's impacts on undesirable results in detail, for example by not being specific enough in setting minimum thresholds (e.g., for land subsidence or water quality), lacking quantification of infrastructure threatened by land subsidence, or lacking a plan to fill identified data gaps.

GSPs deemed incomplete by DWR have 180 days to issue corrections or else risk intervention by the State Water Board. Intervention aims to provoke the GSA to take corrective measures and subsequently resume local authority. This year, six basins have been transitioned to the State Water Board for state intervention.

Since the review process does not explicitly focus on the types of management actions implemented in the GSPs, a GSP that includes no demand management can still be approved, in principle. DWR's issued rejections of GSPs have not focused on inadequacies in the management actions section. Nonetheless, our collected data shows that the proportion of approved GSPs that include demand management actions is significantly larger than that of the incomplete or inadequate GSPs.

Differences in demand management actions between approved and not approved GSPs also correlate with the timing of GSP submission. Recall that only GSAs in critically overdrafted basins faced the earlier GSP submission deadline. Basins submitting under the later deadline were not critically overdrafted, and therefore, more likely to be able to achieve sustainability targets without implementing demand management.

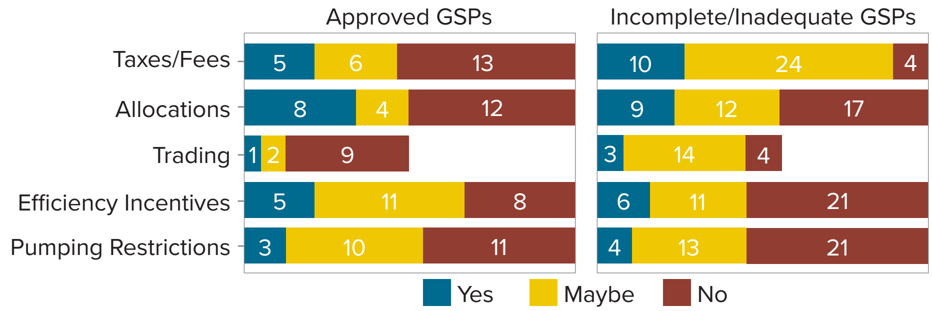
The Demand Management Strategies Pursued in GSPs

In evaluating the role of demand management in submitted GSPs, we've categorized demand management actions into a few broad categories, each with a good deal of variation within them. Below, we discuss the role of groundwater allocations and trading, taxes or fees, incentives for efficiency improvements, and outright pumping restrictions.

Taxes and fees are sometimes placed directly on groundwater extraction but are sometimes placed on less direct measures of groundwater use, like the number of irrigated acres or total acres. In discussing groundwater allocations, we include a large set of GSPs that do not make explicit reference to the word "allocations"—likely due to legal restrictions on how private property rights for groundwater can be implemented—but that do create policies that mimic the basic functions of an allocation system. For example, a GSP may introduce a tiered tax on pumping that is nearly zero up to an individual-specific cap and then prohibitively expensive above that cap. Such a scheme is clearly intended to endow a pumper with what amounts to an allocation, especially when pumpers are further allowed to trade their caps within the basin. Still, there are important distinctions between this sort of "allocation" and formal private property rights over groundwater, such as in the ability to use the allocation to, for example, collateralize a loan.

In the next sections, we look at the differences in implementation of the five mentioned demand management categories between approved and incomplete/inadequate GSPs. Results are summarized in Figure 1. We discuss the management actions in order from highest to lowest overall implementation frequency within the GSPs: 1) taxes or fees, 2) allocations, 3) efficiency incentives, and 4) pumping restrictions. We include discussion of trading in the section on allocations since having an allocation system is a prerequisite for having a trading system. Before going into detail with the demand management actions, it should be noted that GSPs' descriptions of demand management actions are often unspecific, creating uncertainty about their implementation in practice.

Figure 1. Demand Management Actions



Source: The SGMA Demand Management Action Database (DMAD). Available at: https://sgma-dmad.com.

Note: The figure shows the number of different types of demand management actions included in the GSPs that are approved (left) and either incomplete or inadequate (right). The 'trading' bar is shorter than the others to show that only GSPs with allocation plans can include trading as a demand management action.

Taxes or Fees

Among our demand management action categories, taxes are the most commonly included. GSPs consistently favor taxing groundwater extraction directly over the less direct alternative of taxing acreage, irrigated acreage, or other potential bases. This is encouraging, as taxes on groundwater extraction directly address the incentive problem that leads to unsustainable extraction. When an individual pumper privately weighs the costs and benefits of additional extraction, an appropriately set tax can adjust the "costs" side of that equation to better capture the full costs of additional pumping, inclusive of effects on other basin users.

Among the GSPs that specify the form their taxes will take, the preferred rate structure is tiered, where marginal tax rates increase after crossing certain pumping thresholds, as opposed to a flat tax rate that remains the same regardless of the amount extracted. This can help to maintain the correct incentives at the margin while avoiding massive tax bills. The preference for tiered tax rates also reflects the fact that, for many GSPs, the tax actually functions as a way to implement allocations.

Most GSPs do not include plans for the rates themselves, and many implement taxes primarily for the purposes of raising revenue to cover GSA operating costs rather than explicitly as a strategy for adjusting pumpers' incentives. It is unclear whether the tax rates that GSAs eventually implement will be set at a level that successfully aligns pumpers' behavior with sustainability targets.

Allocations and Trading

A fixed allocation of extraction rights distributed among basin users, when combined with the ability to trade, also provides a flexible way of meeting sustainability goals at minimized cost. Under an allocation and trading scheme, a private pumper deciding how much to extract will have to weigh the benefits of additional pumping against the price of extraction permits. If the overall allocation is set appropriately, the price of the permits will reflect the real scarcity of the underlying groundwater resource. Without trading, allocations still set a useful ceiling, preventing excessive pumping, but may leave people with inadequate allocations without a cost-effective route to secure more water. Less than half of the GSPs that include allocations also include trading of those allocations.

Though the economic benefits of trading can be achieved no matter how initial allocations are distributed, determining how initial allocations will be made is a major political question that comes with implications for equity. Allocations based on historical use can reward people who have overused groundwater in the past. We find a difference in the allocation base between approved and incomplete/inadequate GSPs. The approved GSPs with allocations all determine allocations based on historic pumping, whereas almost all of the incomplete/inadequate GSPs that include allocations use acreage as their allocation base. These two schemes would result in meaningfully different initial allocations in areas where the water intensity of land use is variable.

Some GSPs limit allocations to a certain time period (typically one year), meaning allocations cannot be carried over in time. The San Gabriel Valley GSP is one exception and explicitly allows a one-year carry-over in allocation trading, meaning that if a portion of a user's full allocation was not extracted in the previous period, the user may trade that portion in the current period. In consideration of the smallest groundwater users, several

GSPs mention that de-minimis users (mostly those relying on private wells for household use) are exempt from allocations. The Indian Wells GSP solves this problem with so-called Transient Pool Allocations, which are limited, single-use, and untradeable allocations targeted at current pumpers not receiving normal allocations.

Efficiency Incentives

Incentives to improve efficiency or limit groundwater use take many forms, each using a piecemeal approach to resolving the problem of over-extraction. Unlike a tax, which can align the incentives facing pumpers for all their pumping decisions, even in the best-case scenario, an efficiency incentive can only align incentives over the narrowly-defined, particular decisions targeted by the incentive (e.g., the single decision over whether or not to upgrade an irrigation system), while leaving other extraction decisions unchanged. On top of this, funding these programs introduces a budgetary issue, potentially requiring new or higher taxes. Setting the right prices, through either taxes on extraction or the trading of allocations, will create the needed incentives for groundwater sustainability and render something like a voluntary land fallowing program unnecessary.

Five out of the twenty-four approved GSPs include definite plans for efficiency incentives. Examples targeted to residential users include rebates for efficient fixtures and appliances, greywater reuse systems, stormwater capture and reuse, or turf removal. Other incentives target agricultural users, such as incentives for improvements to irrigation efficiency, voluntary land fallowing, crop rotation, or conversion to less water-intensive crop types.

Ad-Hoc Pumping Restrictions

Pumping restrictions prohibit pumpers from extracting water under certain conditions with little flexibility. Examples of ad-hoc pumping restrictions would be hard caps on extractions in drought years or bans on pumping in areas under immediate threat of seawater intrusion.

Overall, the descriptions of pumping restrictions are very vague. Some GSPs mention restrictions as part of their allocation scheme, and others simply state that extraction will be restricted to a certain amount without specifying how the restrictions will work in practice. The majority of GSPs that mention pumping restrictions reserve it as an intervention for worst-case scenarios of extreme drought or the failure of other projects and management actions to achieve sustainability and avoid undesirable results. No GSP relies primarily or even substantially on these ad-hoc pumping restrictions to achieve sustainability.

Our Data Are Publicly Available

To make these data readily available, we created the SGMA Demand Management Action Database (DMAD), where anyone can bulk download the data we collected and present here, or find a specific GSA on a map of California and see what demand management strategies that agency is proposing. The SGMA DMAD can be accessed at https://sgma-dmad.com.

Concluding Thoughts

While we are still in the early stages of SGMA implementation, a look at the proposed management strategies across the 116 submitted plans provides insight into how agencies will achieve sustainability. Demand management will play a critical role in both reaching sustainability and determining the economic costs of groundwater regulation.

Almost 20% of GSPs contain no mention of demand management and are instead depending exclusively on supply augmentation. Many of the others propose strategies with unnecessarily high costs.

Incentive-based strategies like pricing and trading have the potential to achieve sustainability goals at lower cost than allocations without trade or single-dimension efficiency programs. GSAs should take this into consideration, and keep tabs on the performance of their neighbors pursuing different strategies, as they continue to fine-tune their plans for achieving sustainability.

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Authors' Bios

Astrid Borup Friberg is an undergraduate student researcher, Arthur R. Wardle is a Ph.D candidate, and Ellen M. Bruno is an assistant professor of Cooperative Extension, all in the UC Berkeley ARE department. Arthur and Ellen can be reached at arw@berkeley.edu and ebruno@berkeley.edu, respectively.

For additional information, the authors recommend:

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Economic and Climatic Determinants of U.S. Farmer Suicide

Qi Wu, Pierre Mérel, and Richard J. Sexton

Farmers around the world commit suicide at high rates relative to the general population, but factors causing farmers to commit suicide are not well understood. We study the role of economic and climatic factors in farmer suicide in the United States from 1999–2017 based on a panel of county-level data. We find that extreme heat is positively associated with farmer suicide. Chronic unfavorable economic conditions are also associated with an increase in farmer suicide.

Suicide is a perplexing societal issue. As in many other countries, in the United States, farmers commit suicide at exceptionally high rates compared to the general population. Statistics compiled by the Centers for Disease Control and Prevention (CDC) indicate that suicide rates in the United States among male, working-age farmers, ranchers, and other agricultural managers were the highest at 44.9 per 100,000 population of any occupational group in 2012 and the fourth highest at 32.2 per 100,000 population in 2015, the most recent results available.

Despite being at an increased risk of violent death, suicide in particular, farmers are significantly understudied in the area of violent workplace fatalities. Our research was designed to address the void in understanding on this critical topic by studying the role that climatic and economic factors may play in causing farmer suicides in the United States. We combined nonpublic vital statistics from the CDC, PRISM daily weather data from Oregon State University, and U.S. Department of Agriculture National Agricultural Statistics Service (USDA NASS) economic data into a county-year panel to estimate the effects of weather variables and economic factors on farmer suicides.

Summary Statistics

The CDC data do not identify suicide victims by occupation, so we use suicides committed at a farming site as a proxy. We report briefly on socio-demographic characteristics of these suicide victims during 1999–2017 based on the CDC statistics. Table 1 shows that the majority of farmers who committed suicide were white males. In 2017, 64% of U.S. farmers were males. However, about 90% of the farmers who died by suicide were males. The racial composition of farmer suicide victims in the United States is consistent with the racial composition of the farming population, with over 96% of farmer suicide victims being white. Table 2 summarizes the occurrence of farmer suicides by age. More than half of the farmers who committed suicide were 45 or older.

Table 3 shows that nearly 60% of U.S. farmers committing suicide utilized firearms, compared to 50.4% of the general population. The second most common manner of suicide for farmers was hanging, strangulation, and suffocation.

Farmer suicide has been a significant problem in California. From 1999–2017, 231 California farmers committed suicide, 5.6% of the U.S. total. California had the second-highest U.S. farmer suicide total during this period, following Texas, with 495 farmer suicides. Mirroring the national statistics, 91% of California suicide victims were male, and 93% were white. California suicide victims were somewhat younger than the national average, with 46.8% being 45 or older.

Analysis

We formulated an econometric model to analyze farmer suicides at the county level in the United States from 1999–2017, with 57,095 county-year observations in total. The variable we seek to explain is the number of farmer suicides in a county in a given year, a variable that ranges from zero to five. Explanatory variables in the model include precipitation during the growing season (defined as March 1–September 30), temperature during the growing season measured in terms of degree-days aggregated over the

Table 1. U.S. Farmer Demographics and Suicide Occurrence

	U.S. Farmers	Farmer Suicide	
Sex	**Percent**	**Number**	**Percent**
Female	36	334	10.16
Male	64	2,952	89.84
Total	**100**	**3,286**	**100**
Race	**Percent**	**Number**	**Percent**
White	95.4	4,009	96.28
Black	1.3	69	1.66
American Indian	1.7	48	1.15
Others	1.6	38	0.91
Total	**100**	**4,164**	**100**

Source: Farmer demographics: USDA NASS, 2017; Farmer suicide by sex (2003–2017) and race (1999–2017): CDC, 2019.

Table 2. Farmer Suicide Occurrence by Age Group

Age	Number	Percent
Under 24 Years	567	13.62
25–34 Years	619	14.87
35–44 Years	787	18.90
45–54 Years	925	22.21
55–64 Years	664	15.95
65 Years and Over	601	14.43
Age Not Stated	1	0.02
Total	**4,164**	**100**

Source: CDC, 2019.

growing season, and proxies for the strength of the agricultural economy in the county in each year.

Degree-days (DD) is an agronomic concept that measures the amount of exposure to temperatures conducive to crop production. In some cases, researchers separate DD into growing degree-days (GDD), intended to represent temperatures suited to crop growth, and harmful degree-days (HDD), which represent the hottest temperatures that may damage crops or harm livestock.

We chose 10 C (50 F) as the base value to compute DD. The PRISM weather data contain daily minimum, T_{min}, and maximum, T_{max}, temperatures on a 2.5 x 2.5 mile grid for the contiguous United States. We used formulas from the scientific literature to convert T_{min} and T_{max} to DD, with the basic idea being that warmer temperatures contribute greater DD and better crop growing conditions over a range of DD values, but that eventually the hottest temperatures (highest values of DD) are harmful to crops and livestock and may also have adverse psychological impacts on people. We computed DD on a daily basis for each U.S. county by aggregating across the PRISM grids within the county using cropland area weights. The daily DD were then summed across the March 1–September 30 growing season. We also estimated specifications using 8 C (46.4 F) as the base value for computing DD and also separating DD into GDD and HDD.

Precipitation levels were also available for each day at each grid cell from the PRISM database. They were then aggregated for the whole growing season and to the county level using cropland area weights.

To study the impacts of conditions in the agricultural economy on farmer suicides, we constructed indexes of economic conditions at the county-year level based upon the ten leading U.S. agricultural products according to the USDA cash value ranking: corn, soybean, wheat, hay, grapes, cattle and calves, milk, broilers, hogs, and chicken eggs. The historical national prices of the ten products from 1999 to 2017 were retrieved from USDA NASS. These prices were converted to real values (2017 dollars), and the 19-year average real price was computed for each crop, *c*. The deviation of the real price in any year *t* from the historical average measures the relative economic conditions for crop *c* in year *t*. Specifying the difference ($D_{c,t}$) in logs yields the measure in percentage terms. The index of economic conditions in a county was then constructed as the weighted sum of the $D_{c,t}$, with the weights representing the relative importance of each commodity, based upon sales value in that county.

Agriculture in some counties is animal-based, while in others, crop production dominates. Crops like corn, hay, and soybeans are significant feed inputs for animal production, meaning that high prices ($D_{c,t} > 0$), while good news for the crop producers, are bad news for livestock producers. To address this problem, we created separate indexes for crops, $I_{C,t}$, consisting of corn, soybeans, wheat, hay, and grapes, and animal products, $I_{A,t}$, consisting of cattle and calves, milk, broilers, hogs, and chicken eggs. Finally, we separated U.S. counties into those with animal-dominant agriculture, crop-dominant agriculture, and agriculture that was relatively balanced between crop and animal production.

Table 3. Farmer Suicide Occurrence by the Manner of Suicide

Manner of Death (1999–2017)	Count	Percent
Intentional Self-Poisoning	281	6.75
Hanging, Strangulation, and Suffocation	1,304	31.32
Discharge of Firearms	2,424	58.21
Jumping From a High Place	23	0.55
All Other Unspecified Means and Their Sequelae	132	3.17
Total	**4,164**	**100**

Source: CDC, 2019.

Results

We found that precipitation during the growing season was positively and statistically significantly associated with farmer suicide. However, when we decomposed counties into those that relied primarily upon rainfall for agriculture and those that relied primarily upon irrigation, we found no statistically significant effect of precipitation in the rainfed counties, where one would logically expect to find the most significant impact of precipitation, given agriculture's reliance upon it. It may be that the positive and significant effect of precipitation on farmer suicide across all counties reflects the psychological impact on farmers of cloudy, rainy, and gloomy days, an effect that has been studied considerably in the general literature on suicide, albeit without reaching a definitive conclusion.

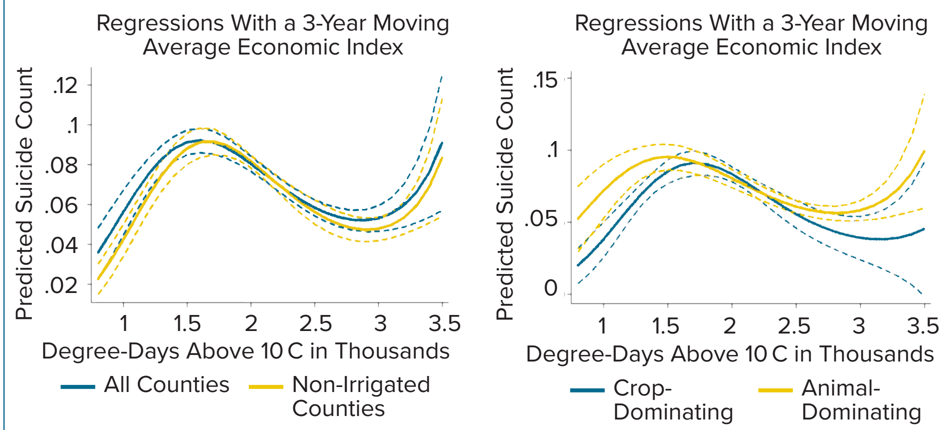
To understand the effects of temperature (measured as DD) on farmer suicide, we chose to specify the relationship as a flexible polynomial, given the ex-ante expectation that moderate heat is beneficial for crop production and animal health but that extreme heat is harmful to both crops and animals and may be a precipitating factor in farmer suicide. We thus modeled the relationship between farmer suicide count in a county and year and DD in that county and year as a cubic function, i.e., we created variables for DD, DD^2, DD^3. The hypothesis is that moderate heat is inversely related to farmer suicide, but extreme heat, manifested primarily in the effect of DD[3], is positively associated with farmer suicide.

Results are illustrated in Figure 1, where the left-side panel shows the cubic relationship for all counties and for non-irrigated counties only. The results are very similar. Farmer suicide is decreasing in DD over a considerable range, reflecting favorable growing conditions, but is increasing in DD for the highest temperatures. About 10% of the DD observations in the sample fall into the extreme heat category where farmer suicide is increasing in DD. Notably, the robustness of this finding was confirmed by models which separated DD into GDD and HDD, where we found that HDD, measured in terms of temperatures of 34 C (93.2 F) and higher was associated with higher farmer suicide counts.

The right-side panel compares the effect of DD for crop- and animal-dominant counties. Notably, the positive effect of high DD on farmer suicide is only present in animal-dominant counties. The hottest U.S. counties typically rely upon irrigated agriculture for crop production, and thus farmers have some ability to modulate irrigation in response to temperatures. Farmers with animal operations have less opportunity to control the impacts of extreme heat, and, moreover, may experience severe psychological impacts from seeing animals under their care and stewardship suffer, and possibly die, due to extreme heat.

Finally, we turn to the impacts of our economic indexes. A first key finding was that a model relating farmer suicide in a given year to only the economic conditions in that year produced insignificant results for the effect of economic conditions—a single bad year for the agricultural economy is not associated with higher farmer suicide counts. However, when we constructed the economic index as a three-year moving average—the average of the current year's index and the indexes from the past two years—we found a negative and statistically significant effect. Good, prolonged economic conditions in a county were associated with a reduced farmer suicide count. This effect was present for the crop index in crop-dominating counties and for the animal index in animal-dominating counties and was robust to alternative specifications of the model. For instance, a one standard deviation increase in the three-year moving average crop (animal) index is associated with a 4.67% (10.76%) decrease in farmer suicide count.

Figure 1. Relationship Between Farmer Suicide and Degree-Days



Note: Dotted lines are 95% confidence intervals.

The results, thus, suggest that it is prolonged, multi-year unfavorable economic conditions that increase farmer suicide rates. U.S. farms are often passed down through multiple generations. Multi-generational farm owners bear the pressure of preserving the family business. Loss or threat of loss of the business due to successive years of poor income is likely to exacerbate stress and self-blame emotions, which could lead to suicide.

Conclusion

Our study finds that extreme heat and chronic poor economic conditions are positively associated with farmer suicide in the United States. The effect of precipitation appears primarily due to the psychological impact of gloomy weather, not to precipitation's effects on farming operations. The high rates of both suicidal ideation and actual suicide among farmers create an imperative to understand suicide's causal factors in order to support appropriate and timely interventions by mental health professionals and agricultural service providers. We hope that our findings can support such efforts.

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Authors' Bios

Qi Wu is a 2022 UC Davis ARE department Ph.D. graduate. She is currently Xingnong Young Fellow Assistant Professor at China Agricultural University in Beijing. Pierre Mérel is a professor and Richard J. Sexton is a Distinguished Professor, both in the ARE department at UC Davis. They can be reached at qiiwu@ucdavis.edu, prmerel@ucdavis.edu, and rjsexton@ucdavis.edu, respectively.

For additional information, the authors recommend:

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ARE UPDATE
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Department of Agricultural and Resource Economics
UC Davis
One Shields Avenue
Davis, CA 95616

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Ria DeBiase
Giannini Foundation of Agricultural Economics
Department of Agricultural and Resource Economics
University of California
One Shields Avenue
Davis, CA 95616
E-mail: rwdebiase@ucdavis.edu
Phone: 530-752-3508

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