SPECIAL FEATURE

Future urban land expansion and implications for global croplands

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Urban expansion often occurs on croplands. However, there is little scientific understanding of how global patterns of future urban expansion will affect the world's cultivated areas. Here, we combine spatially explicit projections of urban expansion with datasets on global croplands and crop yields. Our results show that urban expansion will result in a 1.8–2.4% loss of global croplands by 2030, with substantial regional disparities. About 80% of global cropland loss from urban expansion will take place in Asia and Africa. In both Asia and Africa, much of the cropland that will be lost is more than twice as productive as national averages. Asia will experience the highest absolute loss in cropland, whereas African countries will experience the highest percentage loss of cropland. Globally, the croplands that are likely to be lost were responsible for 3–4% of worldwide crop production in 2000. Urban expansion is expected to take place on cropland that is 1.77 times more productive than the global average. The loss of cropland is likely to be accompanied by other sustainability risks and threatens livelihoods, with diverging characteristics for different megaurban regions. Governance of urban area expansion thus emerges as a key area for securing livelihoods in the agrarian economies of the Global South.

urbanization | global land use change | livelihoods | agricultural productivity | megaurban regions

Urban land expansion—the process of creating the built environment to house urban populations and their activities—is one of the fundamental aspects of urbanization. Urban land expansion modifies habitats, biogeochemistry, hydrology, land cover, and surface energy balance (1). In most parts of the world, urban land is expanding faster than urban populations (2). Whereas urban populations are expected to almost double from 2.6 billion in 2000 to 5 billion in 2030 (3), urban areas are forecast to triple between 2000 and 2030 (4). A defining characteristic of contemporary urbanization is the rise of megaurban regions (MURs): the merging of multiple urban areas into a contiguous and continuous urban fabric. These MURs differ from megacities with populations of 10 million or more in two important and fundamental ways: administratively, they consist of multiple contiguous entities with discrete governance structures; biophysically, they are a single continuous urban area whose absolute spatial size creates challenges for urban, land, and transport governance. The rate and magnitude of urban land expansion are influenced by many macro factors, including income, economic development, and population growth, as well as a number of local and regional factors such as land use policies, the informal economy, capital flows, and transportation costs (5).

More than 60% of the world's irrigated croplands are located near urban areas (6), highlighting the potential competition for land between agricultural and urban uses. Individual case studies show that high rates of urban expansion over the last three decades have resulted in the loss of cropland all around the world, with examples from China, the United States, Egypt, Turkey, India, and other countries (7–9). Although cropland loss has become a significant concern in terms of food production and livelihoods (10) for many countries, there is very little scientific understanding of how future urban expansion and especially growth of MURs will affect croplands. However, this knowledge is key given the potential large-scale land conflicts between agriculture and urban uses in an era of rapid megaurbanization.

Most of the future urban population and urban area expansion are forecast to take place in Asia and Africa (4), often in places with high poverty rates and potentially prone to systemic disruptions in the food system (11, 12). For many of these countries, agriculture is a crucial economic sector in terms of income generation, percentage of total national gross domestic product (GDP), and employment source. Thus, there is a need to assess the implications of urban expansion on croplands on global, national, and subnational scales to identify potential areas of conflict as well as strategies for shaping more sustainable forms of urban expansion.

This paper fills these knowledge gaps by addressing the following questions: (*i*) Where are croplands most vulnerable to conversion due to future urban expansion? (*ii*) What is the magnitude of cropland loss, especially of prime cropland, due to future urban expansion? (*iii*) How will the loss of croplands affect total cropland area and relative economic importance of agriculture for different countries? Sustainability in the era of megaurbanization will require understanding the "hidden linkages" between urbanization and food systems (13), including where and how to maintain croplands to grow food, the most basic of all human necessities. Here, we define food systems as "the chain of activities connecting food production, processing, distribution, consumption, and waste management, as well as all the associated regulatory institutions and activities" (14).

Significance

Urbanization's contribution to land use change emerges as an important sustainability concern. Here, we demonstrate that projected urban area expansion will take place on some of the world's most productive croplands, in particular in megaurban regions in Asia and Africa. This dynamic adds pressure to potentially strained future food systems and threatens livelihoods in vulnerable regions.

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SUSTAINABILITY SCIENCE

This study provides a global estimate of the loss of croplands to urban area expansion and its implications for crop production. We limit our discussion to croplands, which cover 12% of Earth's ice-free land area (15), but exclude pastures. We compare spatially explicit datasets on croplands (15, 16) and cropland productivity (17) for the year 2000 to gridded urban area projections for the year 2030 (4). Processing the cropland datasets, we generate a cropland map and intersect it with gridded data on the aggregated productivity of 16 major nutritional crops. We supplement this with a disaggregated analysis of four staple crops (maize, rice, soybean, wheat) and three cash crops (cacao, oil palm, sugarcane). We then calculate the cropland and crop production loss according to three different urbanization scenarios (low, medium, and high).

Results

Future urban expansion is highly likely to occur in areas currently under cultivation (Fig. 1). Globally, 46 Mha (medium scenario; range from low to high scenario: 43–55 Mha) of croplands in 2000 are located in areas that are expected to be urbanized by 2030, corresponding to 3.2% (3.0–3.8%) of existing cultivated land. However, urban agriculture is known to be significant in many cities. Hence, we account for urban agriculture by overlaying maps of urban areas and croplands for the year 2000, and find that, on average, 36% of all urban areas are used for crop production. We assume this percentage of urban agriculture to prevail when urban area expands but account for regional variation (for example, 41% in Asia and 32% in Africa; see *Supporting Information* for details). Accounting for these prevailing cropland fractions, total cropland loss amounts to 2.0% (1.8–2.4%) of the global total—around 30 Mha (27–35 Mha), with countries such as China, Vietnam, and Pakistan ranging between 5 and 10% (Table 1).

Although the aggregate impact of urban expansion on global cropland is modest, regional impacts will be acute and differentiated. In the medium urbanization scenario, Asia and Africa will experience around 80%, or roughly 24 Mha, of the total global cropland loss. The most affected regions in Africa include Egypt, Nigeria, and the region surrounding Lake Victoria Basin in Eastern Africa (Fig. 1). In Asia, the hot spots of cropland loss are river valleys and coastlines, many of which are in the vicinity of MURs, such as the Bohai Economic Rim and the Yangtze River Delta in China, or Java Island in Indonesia (Fig. 2).

One-fourth of total global cropland loss will occur in China. Urban expansion in China is taking place in the country's most productive farmland and over large areas. Therefore, urban expansion could pose a threat to domestic crop production. In contrast, India, the United States, and Brazil will also experience high losses in absolute terms, but here urban expansion leaves large expanses of croplands untouched, and is therefore less likely to threaten domestic crop production (Table 1).

Future urban land expansion will continue to take place on prime agricultural lands. We observe a total loss of crop production of 3.7% (3.4–4.2%) due to urban expansion. On average, the cropland lost to urban expansion is 1.77 times as productive as the average global croplands. Our results hence confirm evidence

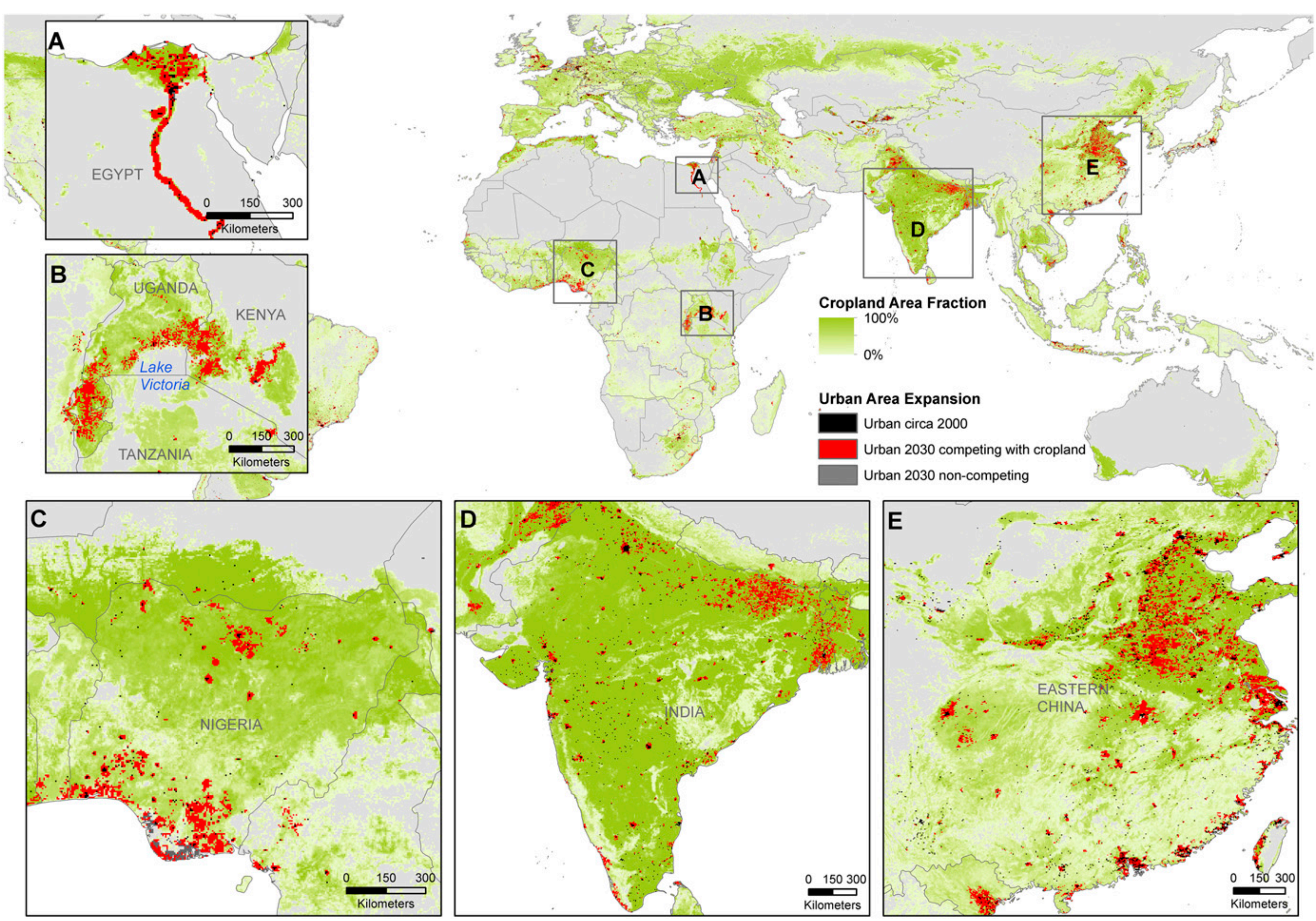

Fig. 1. Maps show where projected urban expansion until 2030 is expected to result in cropland loss. Competing areas (red) hold croplands but have a high probability (>75%; medium scenario) of becoming urbanized by 2030. (*A–E*) Close-ups of urban area expansion hot spots. Data on urban expansion are from ref. 4, and data on cropland are from ref. 16.

Table 1. Regional and national implications of urban area expansion on croplands and crop production

Region or country	Expected cropland loss, Mha	Relative cropland loss, % of cropland	Production loss, Pcal·y^{-1}	Production loss, % of total crop production	Productivity compared to domestic/regional average
World	30 (27–35)	2.0 (1.8–2.4)	333 (308–378)	3.7 (3.4–4.2)	1.77
Asia	18 (16–21)	3.2 (2.9–3.7)	231 (214–264)	5.6 (5.1–6.3)	1.59
Africa	6 (5–6)	2.6 (2.4–3)	49 (45–52)	8.9 (8.3–9.4)	3.32
Europe	2 (2–3)	0.5 (0.5–0.9)	17 (16–23)	1.2 (1.1–1.5)	2.18
Americas	5 (4–5)	1.2 (1.1–1.4)	35 (32–40)	1.3 (1.2–1.5)	1.09
Australasia	0.1 (0–0.1)	0.2 (0.1–0.3)	0.3 (0.1–0.3)	0.2 (0.1–0.3)	0.94
China	7.6 (7.1–8.6)	5.4 (5–6.1)	137 (128–153)	8.7 (8.2–9.8)	1.53
India	3.4 (3.3–3.7)	2.0 (1.9–2.2)	34 (32–38)	3.9 (3.7–4.3)	1.61
Nigeria	2.1 (1.8–2.5)	5.7 (5–6.9)	16 (15–17)	11.7 (10.7–12.6)	1.82
Pakistan	1.8 (1.7–2)	7.6 (7.2–8.6)	9 (9–10)	8.8 (8.4–9.9)	1.22
United States	1.5 (1.4–1.6)	0.8 (0.8–0.9)	11 (11–12)	0.7 (0.7–0.8)	0.90
Brazil	1.0 (0.9–1.2)	2.0 (1.7–2.4)	10 (9–12)	2.4 (2.1–2.8)	1.22
Egypt	0.8 (0.7–0.8)	34.1 (31.6–35.8)	25 (23–26)	36.5 (34–38)	1.07
Vietnam	0.8 (0.7–0.8)	10.3 (9.3–11.2)	15 (15–17)	15.9 (15.2–17.2)	1.41
Mexico	0.7 (0.6–0.8)	1.9 (1.7–2.3)	4 (4–5)	3.7 (3.2–4.4)	1.91
Indonesia	0.6 (0.5–0.7)	1.1 (0.9–1.3)	10 (8–11)	2.3 (2–2.7)	2.03

Cropland and production losses are generated using data from refs. 4, 15, and 17. We differentiate between different urbanization probability thresholds (50, 75, and 87.5%). Depending on the corresponding threshold, we define cropland loss scenarios as follows: low (>87.5%), medium (>75%), and high (>50%). Medium-scenario results are reported, and ranges indicate low- to high-scenario results. The 10 countries with the highest absolute crop production losses are presented in descending order.

from local case studies (7–9), indicating that urban agglomerations are surrounded by croplands with above average productivity.

Our analysis shows that 84% of global production losses are expected to occur in Africa and Asia (Table 1). The 3% cropland loss in Asia translates into a 6% production loss (Table 1). In Africa, the effects are tripled: a 3% cropland loss translates into a 9% crop production reduction, most of which will take place in Egypt and Nigeria. Only a few countries display urbanized cropland with below national average agricultural productivity, the United States being the most prominent example. China and India will continue to urbanize rapidly, but with different spatial patterns and development dynamics. China's croplands are concentrated along the coastal areas and in the east of the country (Fig. 1). By 2030, most of the urban land cover expansion is expected to occur in that region. The analysis reveals relative cropland losses of 5–6% (8–9 Mha) and productivity losses of 8–10% (128–153 Pcal) between 2000 and 2030 (Table 1). Results for India are markedly different. Total urban extent in 2000 is an order of magnitude smaller than in China (3 Mha compared with 8 Mha), and absolute urban area expansion until 2030 is expected to cover one-half as much area as in China (3–4 Mha compared with 7–8 Mha). This difference in urban expansion is in large part explained by very different urbanization and urban expansion trends (3). Whereas China's urban population exceeded its rural population in 2012 and is expected to be 75% of the total population by 2050, India's urban population is currently less than one-third of the total population and by 2050 will just be over one-half. Furthermore, as of 2011, 79% of India's total population resided in settlements of 100,000 or fewer, and 52% of the country lived in towns and villages with populations fewer than 5,000 (18). This is in stark contrast to China. Although cropland loss is currently not an issue in India (about 2% by 2030; Table 1), other studies corroborate that it is likely to become more significant in the future when the country's urban expansion begins to accelerate (19).

In African countries, there will be significant variation in the geographic distribution and rates of cropland loss. Croplands in less arid zones are expected to be relatively less affected by urbanization. Nigeria, Africa's most populous country, will experience high rates of urban expansion and 5–7% cropland loss (Table 1). Urban expansion will be concentrated along the continent's coastlines, whereas the majority of cropland lies inland (Fig. 1). The region around Lake Victoria will experience the highest rates of urban expansion. In particular, for Burundi and Rwanda, the high rates of expected cropland conversion to urban (~28 and 34%) reflect the limited availability of land in those countries.

Our disaggregated analysis for individual staple crops shows their relative importance in urbanizing areas. In 2000, 4% of maize, 9% of rice, 2% of soybean, and 7% of global wheat production were grown in areas that are forecast to be urbanized (Table S1). Although the results for Europe (range between 2 and 3%), the Americas (1–2%), and Australasia (all <1%) indicate low competition for these key staples, the findings for Asia and Africa suggest significant losses of specific crops. In Asia, 10% of maize, 9% of rice, 7% of soybean, and 13% of wheat production were produced in areas that will be urbanized by 2030. In Africa, these shares range from 11% of soybean production to 26% of the continent's wheat production (14% maize, 19% rice).

We further analyzed cropland loss for a selection of MURs, defined as continuous urban regions with multiple urban centers and a combined population greater than 20 million, often expanding over 10,000 km^2. Prime agricultural lands are especially vulnerable to conversion in MURs with estimated cropland losses between 0.1 and 1.2 Mha for the 11 case studies (Fig. 2 and Table S2). With the exception of the US Northeast, the productivity of the cropland converted in MUR is higher than national averages (Table S2). Notably, in MURs of India, Bangladesh, and Indonesia, the relative productivity is >2 (Fig. 2 *E*–*G*). In Chinese MURs, the relative productivity is 1.05–2.05 (Fig. 2 *A*–*C*).

To understand agricultural production patterns around these evolving MURs, we analyzed the harvested area fraction (HAF)—the ratio of harvested area of a specific crop over the total harvested area—in competing areas of the abovementioned staple crops and a selection of cash crops specific to some of the MURs (cacao, oil palm, sugarcane; Table S2). The aggregated HAF for these crops is high in most of the MURs. In the Yangtze River Delta around Shanghai, for example, the combined HAF of rice and wheat accounts for 50% of total area harvested in competing areas. In contrast, the combined HAF is very low for the United States, Brazil, and Japan, indicating that these areas are used to grow other crops such as vegetables. HAF is also low for the Greater Ibadan Lagos Accra (GILA) corridor in Western Africa, where these crops only contribute marginally to diets. The prevalence of the cash crops analyzed is comparatively low (the exception is sugarcane around Delhi with HAF of 18%).

The spatial pattern of urban expansion plays an important role in cropland loss. MURs are often characterized by multiple urban centers, with productive cropland distributed throughout the

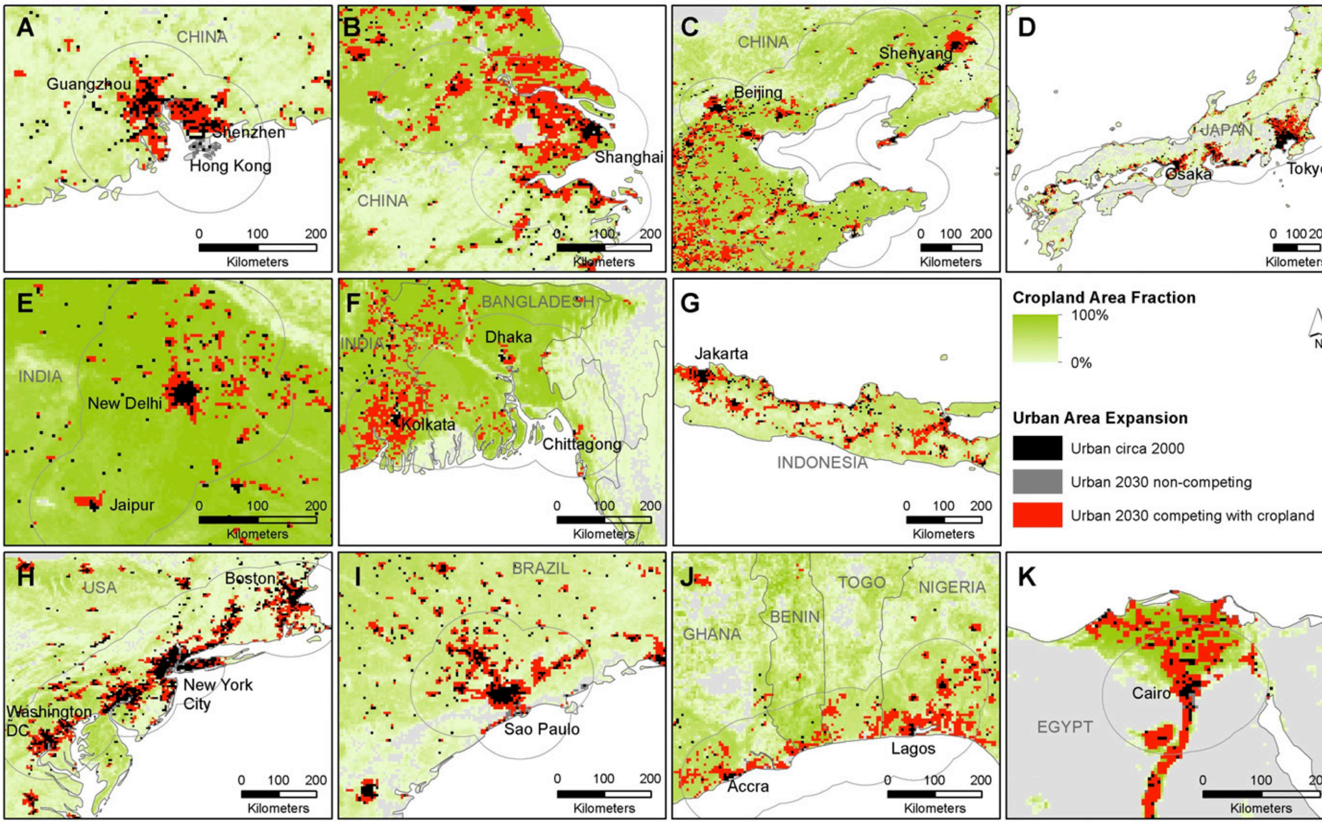

Fig. 2. Competition between croplands and urban expansion in select MURs. The maps show where projected urbanization until 2030 is expected to result in cropland loss. Competing areas (red) hold croplands but have a high probability (>75%; medium scenario) of becoming urbanized by 2030. MURs displayed are (*A*) Pearl River Delta, (*B*) Yangtze River Delta, (*C*) Bohai Economic Rim, (*D*) Tokaido Corridor, (*E*) Delhi National Capital Region and Jaipur, (*F*) Ganges-Brahmaputra Delta (Kolkata, Dhaka, and Chittagong Region), (*G*) Java, (*H*) Northeast Megalopolis, (*I*) Expanded Metropolitan Complex of São Paulo, (*J*) Greater Ibadan Lagos Accra Corridor (GILA), and (*K*) Greater Cairo Region. See *Supporting Information* for more details.

urban fabric. Although the aggregate amount of cropland in these regions may be high, each patch of cropland is relatively small and thus vulnerable to urban envelopment (Pearl River Delta, Fig. 2*A*). In regions with a single dominant urban center, such as Greater Delhi (Fig. 2*E*), urban envelopment of cropland is still contained around the urban core, with little evidence of large-scale continuous urban fabric development. Cropland in these regions will continue to be converted (19), but not at the same magnitude as in multinodal urban regions.

As urban areas expand, the remaining croplands and farmers at the periurban interface experience greater competition for water and increased exposure to climate hazards. The urban expansion into the Ganges-Brahmaputra Delta, for example, has resulted in the loss of wetlands and water bodies that serve as flood protection (20). In addition, cropland conversion led to a sinking of the delta due to a combination of sediment loading, compaction, ground water extraction, and reduced aggradation. This makes the delta increasingly vulnerable to hazards associated with climate change, such as sea level rise (21), and threatens not only urban areas but also the remaining croplands that were largely used to feed the regional population with rice (HAF of rice >83%; Table S2).

Sea level rise and subsidence are also significant concerns for Greater Cairo, because a considerable fraction of the Nile Delta is already near or below sea level and expected to sink further (22). Diminishing sediment discharge due to dams in the south will increase the pressure on the delta, which will eventually decrease in size (23). Our results show that urbanization converts precarious croplands at high rates along the Nile even though they are important for maintaining food supply of the urban centers [combined HAF for wheat and maize, 49% (Table 1 and Table S2)]. Efforts to divert urbanization away from the fertile lands into the deserts are underway but have been less effective than hoped (23).

Discussion

Our study shows that future urban expansion is expected to convert 27–35 Mha of croplands (1.8–2.4% of global cropland and 3.4–4.2% of the yearly production) globally between 2000 and 2030, adding an additional component to the emerging global consequences of land use (24). On average, this amounts to an annual land consumption of 1 Mha, which is almost a third of the annual agricultural expansion between 1961 and 2009 of 3.38 $Mha \cdot y^{-1}$ (25). Our study is limited by the spatial resolution of the analysis; although higher-resolution data would generate more detailed insights, these results provide a global assessment of the patterns of likely cropland loss due to urban expansion.

Compensating Cropland Loss. On aggregate, the loss of cropland can be compensated by the global food system, but the effects will not be distributed equally. Many less developed and emerging countries will face acute losses, both in absolute and relative terms (Table 1 and Table S3). In principle, cropland loss could be compensated by intensifying existing production or expanding cropland. However, the domestic adaptation potential varies substantially by country and may be limited. For example, many sub-Saharan countries have ample potential for extensification and could additionally aim to close their yield gap by improving agricultural management and technology (26). The option to expand cropland is constrained in other regions, such as Southern Asia, where much of the suitable land is already under intense, multicropping cultivation. Expansion in these regions is likely to occur in less suitable areas, thus requiring disproportionately more land (27). Other countries in arid regions, especially Northern Africa and the Middle East, have nearly reached their maximum potential (28). The option to expand is likely to be constrained further as climate change is expected to decrease the amount of suitable croplands throughout Africa, and Southern and Southeast Asia (29). Climate change is also expected to adversely affect yields (30), making it harder for countries in the tropical regions of Asia and Africa to compensate for cropland losses via intensification.

The loss of croplands and associated food production could also be offset by global agricultural markets and trade. Regardless of cropland loss to urbanization, the total volume of global trade is likely to rise, and many developing regions will see a decrease in food self-sufficiency (31). Many African countries as well as China have experienced a decline in the production-to-consumption ratio of food in the last decade, indicating rising imports (32). Countries with limited extensification and intensification potential, such as Egypt, are likely to resort to trade to compensate for cropland loss, which could make them more susceptible to international food supply shocks (12).

Food System Transition. Beyond the direct loss of cropland, the growth of MURs has other important implications for food systems, especially for smallholder farmers (33). Worldwide, there are about 500 million small farms and an estimated 2–2.5 billion smallholder farmers who cultivate farms of 2 ha or smaller. Large urban areas have seen a growth in supermarkets replacing locally owned or small-scale food retail stores (34, 35). This trend is occurring throughout the developing world, particularly in East Asia, where the growth of large cities and rising household incomes converge to create new demands for "modern" food retail supply chains. Additionally, supermarkets have gained greater market shares over traditional stores in big cities (36). Thus, as MURs continue to grow in number and size, food retail is likely to become increasingly dominated by large supermarket chains. This has important implications for traditional retailers, small-scale producers, traditional food brokers, and the entire supply chain. In larger cities, decentralized systems of food procurement (individual stores and their buyers work directly with producers or food brokers) shift to a more centralized system focused on large distribution centers. To protect small-scale producers and traditional retailers, governments may intervene. India, for example, has strictly regulated foreign direct investment into multibrand retail (the Indian equivalent to large supermarkets). Still, there is evidence of an "emerging supermarket revolution in India" (37), driven by domestic capital. The loss of local food chains might compromise food accessibility in markets as local food chains historically have shown to build resilience against price spikes (38). Local producers typically keep prices low, to maintain customers, a mechanism supporting resilient food security (39).

Livelihoods and Food Security. The dynamics of agricultural livelihood transformation are complex and involve dispossession of peasants by agrobusinesses (40). Urban land expansion also coincides with the loss of income and displacement of periurban livelihoods (41). However, economic development and the accompanying structural change are likely to provide sufficient job opportunities. The transformation of food supply chains around evolving cities, for example, offers ample nonfarm employment opportunities along the food chain— in processing, logistics, and wholesale (42). A study from Ghana shows that more than 50% of households that lost access to agricultural land engage in trading and other activities, such as construction, whereas 28% become unemployed (43). As only 11% of households try to replace the land they had lost, the overwhelming majority would aim to enter the nonfarm labor market. Livelihood and food insecurity could become an issue for the households that do not find employment. Generally, urban food security depends not only on the availability of foods in the markets, but ultimately on the ability of households to access food on their income (44). Hence, poor urban or periurban households, entailing the displaced farmers that are unemployed, are at risk of becoming food insecure (45). There is a myriad of other factors to account for to assess whether households would be better or worse off. However, such investigations are beyond the scope of this study.

Governance. To meet the twin goals of urban development to house the growing urban population and preserve prime cropland, it will be imperative to guide and shape future urban expansion to more sustainable forms. Different approaches to safeguard agricultural land have been tried around the world, with different outcomes. For example, despite numerous edicts from the central government to protect agricultural land from conversion, agricultural land in China continues to be converted (46). Regardless of approach, good governance is a necessary condition for sustainable urbanization and critical for successfully shaping urban expansion (47). The quality of governance in countries with important cropland losses, however, tends to be medium to low in emerging economies and low for developing countries (48) (Table S4). A factor specific to MURs is that they often consist of multiple contiguous entities with discrete governance structures. More comprehensive governance regimes could be helpful to mitigate pressures from urbanization on food systems and ecosystems in urban hinterlands (49).

Urban policy makers and planners play a crucial role in managing urban area expansion. Containing the expansion of urban areas is a well-established planning approach to encourage compact, public transport-oriented urban forms, crucial for securing long-term climate mitigation goals (50). The same approach also preserves agricultural lands in periurban areas (51). However, the effectiveness of urban containment strategies around the world is mixed, and its success depends on many factors, including the willpower of policy makers, and geographic and institutional contexts (52). An alternative approach involves selective protection of open space from urban encroachment (53). One policy instrument to use in this respect may be transfer of development rights that effectively redirects new growth from areas to be protected (e.g., prime agricultural fields) to areas where more development is desired (54). However, national policy makers are also important by designing crucial economic incentives. In particular, fuel taxes have also both empirically and theoretically been shown to induce more compact urban form and preserve open space (55, 56).

Conclusion. As Seitzinger et al. (57) argue, "Urban regions must take an increased responsibility for motivating and implementing solutions that take into account their profound connections with and impacts on the rest of the planet." Nowhere is this more evident than at the interface of urban areas and croplands. The next few decades will be a period of large-scale urban expansion, and in many parts of the world, this will take place on prime cropland. Our findings show that, for a few countries, the loss of cropland will significantly reduce the total share of national cropland. As most of the cropland expected to be converted is more productive than the global average, efforts will need to compensate for that loss, whether by intensifying remaining cropland or by expanding agricultural production into new areas. The results suggest that strategies and policies to effectively steer patterns of urban expansion will be critical for preserving cropland. In an increasingly interconnected world, the sustainability of urban areas cannot be considered in isolation from the sustainability of resources and livelihoods elsewhere.

Materials and Methods

We base our study on a spatially explicit urban area expansion probability dataset (4) and two gridded datasets on global croplands in 2000 (15) and 2005 (16). We use a dataset on gridded global crop yields in 2000 (17) to calculate the productivity of the displaced land. Yields of the 16 most important crops (listed in *Supporting Information*) are converted to calories and aggregated in a single dataset, weighted with area harvested. We supplement this with a disaggregated analysis of four staple crops (maize, rice, soybean, and wheat) and three cash crops (cacao, oil palm, and sugarcane). We assess the impact of urban area expansion by intersecting three distinct urbanization projections for the year 2030 with the cropland dataset for the year 2000. The resulting cropland and production loss scenarios are "low" (with a restrictive threshold including only grid cells exceeding 87.5% urbanization probability), "medium" (>75% urbanization probability), and "high" (>50% urbanization probability). As a "best guess," we assume that all grid cells with >75% probability of becoming urbanized (medium scenario) will be affected by urbanization until 2030. Please see *Supporting Information* for a detailed description.

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