Cross-Cutting Policies for a Sustainable Food Future

The menu items for a sustainable food future described earlier in this report focus heavily on technical opportunities and solutions to help drive implementation. But menu items cannot be implemented in isolation, and they are all subject to (or need) a variety of cross-cutting public and private policies. Chapters 35–37 discuss policies relating to farm structure, productivity, and poverty reduction; agricultural emissions mitigation and climate funding; and agricultural research and development.

TABLE OF CONTENTS

CHAPTER 35

FARM STRUCTURES, LARGE LAND ACQUISITIONS, PROPERTY RIGHTS, AND CONTRACTUAL ARRANGEMENTS

Is there a conflict between the goals of increasing global food production and providing livelihood opportunities for the world's hundreds of millions of poor farmers and workers? Do large land acquisitions help or hinder these goals? Can the world sufficiently boost yields on smallholder farms or should large farms replace small farms? And if the world continues to support small farmers, what farm structures and property rights rules should policymakers support?

One of the challenges to answering these questions is the lack of a sound, quantitative definition for "small farms." Farm sizes and productivity per hectare (ha) vary greatly from one part of the world to another. Building on a 2008 landmark World Bank report,[1] this chapter addresses these often-contentious questions.

Large versus Small Farms

Public justification for consolidation of smallholder farmland is rooted in a perception among many analysts that large farms are more successful than small farms.[2] For example, although small farmers remain more numerous in Brazil, medium-sized and large farms dominate agricultural production, and their numbers and share of production and production value in the country have increased in recent years.[3] Brazil's large farms can be regarded as a model to replicate elsewhere. Small farms face many obstacles to improving their productivity:[4]

- Financial institutions face higher transaction costs when dealing with many small farms rather than one large farm, making access to capital more expensive for small farmers.
- Poverty traps arise when subsistence farmers must sell critical assets to survive periods of hardship, which undermines their future production or productivity gains.
- Smallholders face challenges in meeting quality, sanitary, and/or environmental standards or other demands made by large purchasers such as supermarket chains.

In 1998, the economist Paul Collier attracted great attention when he argued that small farmers in Africa were unsuited to cope with "investment, marketing chains, and regulation [of food quality]," and called for the gradual replacement of "peasant farms" with larger commercial farms.[5] In addition to pointing to the agricultural achievements of countries like Brazil, Collier pointed out that subsistence peasant farming is arduous and that farmers readily abandon subsistence farms when alternative job opportunities present themselves. To African governments faced with a history of poor agricultural production and limited resources, contracting with large-scale investors who will come in and upgrade agriculture therefore seems attractive.

In some countries, analysis supports the pure production advantages of larger farms. Yields of Brazilian maize and Chilean wheat, for example, have been significantly higher on large farms.[6] In Indonesia and Malaysia, large oil palm plantations have far higher yields than oil palms grown on most smallholder farms.[7]

However, Collier's argument touched off several counterarguments by agricultural economists:

- In China and India, comparatively small farmers have led agricultural improvements. According to data from the Food and Agriculture Organization of the United Nations (FAO), in India, farms smaller than 5 ha account for 70 percent of all farm area, and farms smaller than 10 ha account for 87 percent.[8] One 2011 study estimated the average farm size in China at 0.6 ha, and in India at 1.2 ha.[9] Yet, in both countries, small farms achieve yields at least as high as those of large farms.[10] In both countries, fertilizer use is high.[11] Based on Indian agricultural census data, the 2011 study found that small farmers actually used twice as much fertilizer as large farms per hectare, as well as more irrigation and high-yielding seeds. These findings reflect an intense effort on the part of small farmers to produce high yields, although there are environmental implications. Strong efforts by governments to support small farmers through credit programs, extension, and input subsidies played a major role in these developments.[12]
- In Africa, several studies have found that farms become less productive per hectare as they get bigger.[13] The typical explanation is that small farmers put in greater effort per unit of land. Because of the consistency of this finding, the main academic debate around this phenomenon has focused on whether it is explained by poor data, by failure to include very large farms in the analysis, or by some uncontrolled factor, such as soil quality. But a recent review of studies on this issue confirms that larger farm size generally does lead to lower yields per hectare.[14]
- Improvements on small farms contribute more to poverty reduction than improvements on larger farms—at least absent concerted government efforts to transfer income from overall

economic improvement. As one analysis notes, "Smallholdings are typically operated by poor people who use a great deal of labor, both from their own households and from their equally poor or poorer neighbors. Moreover, when small-farm households spend their incomes, they tend to spend them on locally produced goods and services, thereby stimulating the rural nonfarm economy and creating additional jobs."[15]

Yet the evidence in support of smaller farms in Africa has tended to exclude the largest farms. Studies showing higher productivity on small farms have typically focused on farms up to 10 ha.[16] There is some evidence of a "U-shaped curve" with productivities rising again on the largest farms.[17]

In addition, even if small farms are often more productive per hectare, studies around the world tend to find that larger farms are often more productive per day of work.[18] As a result, larger farms tend to have equal or lower costs of production per ton of crop.[19]

Good data are necessary to determine public policy but analyzing data on agricultural productivity is complicated. Some of the data on which researchers must rely are more than a decade old because national studies are expensive. The World Bank and FAO, both important sources of data, tend to analyze farm sizes and their characteristics on a rotating basis among different countries over many years. Although studies tend to group farms by area, area is a highly imperfect way of determining large and small farms. The size of farms as measured in hectares may not properly convey size from the standpoint of output or true scale of operation because agricultural lands have widely varying productivity. For example, "small farms" in grazing areas will often be larger than "medium-sized farms" in quality croplands.

Using the most recent available data—even though some national data may be more than a decade old—the best estimate placed the total number of farms around the world at 570 million.[20] Of these, farms smaller than 2 ha account for 80 percent of the total number, while they occupy only 12 percent of global agricultural land.[21] In surveys of 14 African countries in 2000, 85 percent of farms were smaller than 2 ha.[22]

Choosing any single size threshold to measure small and medium-sized farms is an imperfect approach, but the data suggest a few general developments:

- In most developed countries, farms are becoming larger.[23] This trend reflects the increasing role of mechanization, reduced labor requirements, and increasing opportunities for workers off-farm.
- In Africa and Asia, average farm sizes (measured by both mean and median) tend to become smaller over time because the number of farm households is increasing, meaning that small farms are divided into smaller and smaller units.[24]
- Although small farms are increasing in number, their average size is shrinking, and they do not appear to be increasing their share of farm area. In some countries small farms appear to be losing land to medium-sized or large farms. For example, one paper analyzing farms in Ghana between 1992 and 2012 found that even though the number of farms smaller than 5 ha grew by 37 percent, the percentage of farmland they occupied declined by 12 percent.[25] Meanwhile farms from 20 to 100 ha grew to occupy an additional 11 percent of the country's farmland. In Zambia, just between 2008 and 2014, the number of farms smaller than 5 ha grew significantly, but the percentage of farmland they occupied declined by 15 percent. By contrast, farms with 10 to 100 ha occupied an additional 10 percent of the country's land. A 2016 study in China also found that, while small farms continue to dominate, there is a growing class of medium-sized and larger farms.[26]

The growing share of agricultural land held by medium-sized and larger farms may reflect a number of increasing economic opportunities that are not available to small farms.[27] As new technology requires more expensive seeds, fertilizers, machinery, and pesticides, challenges in raising capital become more important. Some small farms cannot take advantage of large machinery, even if it is affordable.[28] As supermarkets become a larger part of the retail process and wish to deal with larger suppliers, and as quality and sanitary standards rise for high-value crops, small farms face more obstacles in accessing these markets.[29]

Beyond national food production goals, there is also a question of which strategies are best for helping small farmers, particularly because small farms are often too small to support their owners with adequate income. One recent study found that even if African and Asian small farms took advantage of opportunities for technological innovation, they could not escape poverty, although they could somewhat boost incomes and food security.[30] Another study found that in Kenya it was very difficult for mixed crop/livestock farms smaller than 0.4 ha to satisfy farmers' income and food needs.[31] The implication is that to escape poverty, small farms will generally need better market access and opportunities for off-farm incomes. One study across seven countries in Africa found that those two factors were strongly correlated with the food security of small farmers.[32]

Overall, the evidence suggests that small farms can be productive if governments support their development, and that strongly pushing their purchase by or consolidation into large farms has not been an effective strategy. At the same time, powerful forces do encourage eventual economies of scale in agriculture, particularly at higher levels of development. In addition, small farms in many countries are on a trajectory to becoming too small to provide more than supplemental income for their owners. Even strong advocates of smallholder farming therefore view appropriate public investments in small farms as part of a strategy to help people to transition out of small farming. "This is a paradox of early development: the need for agricultural development to allow people to move out of agriculture."[33]

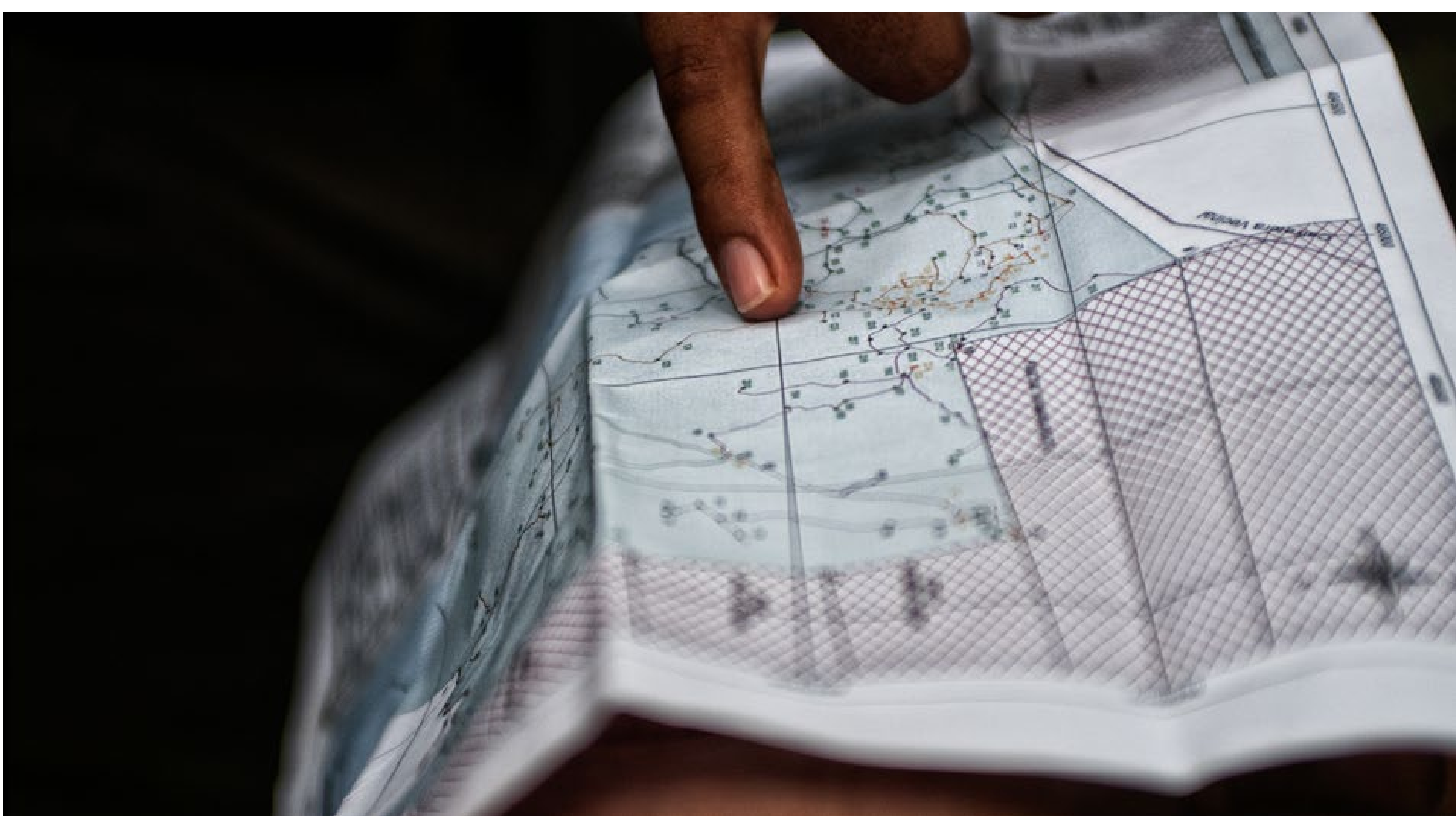
Recommended Policies Regarding Farm Sizes

The literature overall has a number of policy implications, the essence of which is to let the market play out—neither favoring large or small farms, nor blocking farms from reaching their appropriate size:

- In general, governments should not force small farms to consolidate or encourage large farms to take over small farms, as neither approach is likely to accelerate agricultural production or benefit the poor. Not only is the evidence of higher yields from even very large farms limited, there is even less evidence that pushing or forcing consolidation raises productivity. Oil palm plantations may be an exception, where large farms outperform small farms, but, at this time, clearing land for oil palm plantations contributes to large-scale deforestation and often has adverse consequences for indigenous people. The place of palm oil production in a sustainable food future will involve more protection of the rights of indigenous populations and targeting new production in the least environmentally harmful areas (as discussed in the next section).

- Even so, agricultural policy should support farms as they become more commercially oriented and increase their labor productivity. The aim of policy should be both to support productivity gains and allow farms to become more viable and not fight these developments as they occur. Policy should support these trends even though they might eventually result in less demand for agricultural labor. However, a fair and stable economic and social transition will depend on growth in other parts of the economy, particularly in the urban sector.

- Allowing farms to acquire smaller farms or to rent land—so long as transactions take place through market forces and are not pushed by governments—is a useful part of the economic growth process. As summarized by the World Bank study, the evidence generally supports the view that such transactions support rural incomes and often make it easier for small farmers to acquire land.[34] By contrast, restrictions on land sales "tend to drive transactions underground and undermine access to formal credit without addressing the underlying asymmetries of power, information, and access to insurance."[35] This World Bank study appropriately recommends safety nets and even land taxes to achieve equity goals rather than restrictions on sales.



Large Land Acquisitions ("Land Grabbing")

In Madagascar in 2008, the government entered into a deal with the Daewoo Corporation to lease more than 1 million hectares (Mha) of land for 99 years at a minimal price. Although the deal was sufficiently unpopular that it led to the collapse of the government and eventual cancellation of the deal,[36] deals such as this one attracted world attention and led researchers to study what was going on. "Land grabbing" is complex, with important regional differences, and some concerns turned out to be unfounded. However, a picture does emerge that many governments have not been following neutral policies regarding farm size. Instead, they have been favoring large acquisitions that often do not compensate local people for what they are losing and do not lead to significant productivity gains. This process has also tended to involve clearing of at least quasi-natural habitats.

Comprehensive analysis of recent, large-scale land acquisitions is difficult. Governments do not disclose the details of most deals, and many countries lack clear land registries that could reveal what is going on.[37] Despite these limitations, researchers have begun to tabulate large-scale land acquisitions and several themes have emerged from recent studies.

Concluded acquisitions are large but smaller than the original proposals

A World Bank study in 2011 found evidence of large-scale farmland deals, in various stages of development, amounting to 56.6 Mha—roughly the size of Kenya—just between October 1, 2008, and August 31, 2009.

More than two-thirds of these deals were located in Africa.[38] A 2013 study based primarily on analysis by GRAIN, a nonprofit organization, reported between 33 Mha and 82 Mha of large-scale land acquisitions between 2002 and 2013 conducted by foreign entities only. The wide range in the estimates of area of acquisitions reflects the level of deal completion, and roughly one-third of the verified deals were in Africa.[39]

Table 35-1 | Concluded and intended transnational agricultural deals, 2000–2016

REGION	FOOD CROPS (MHA)	NONFOOD CROPS (MHA)	MULTIPLE USE CROPS (MHA)[a]	TOTAL (MHA)	TOTAL (PERCENT OF WORLD)
Africa	1.5 / 4.0	7.7 / 0.9	8.2 / 5.7	17.3 / 10.6	47 / 70
Asia	0.2 / 1.8	1.8 / 0.6	3.5 / 1.9	5.5 / 4.3	15 / 28
Latin America & Caribbean	1.1 / 0.0	1.2 / 0.0	3.0 / 0.2	5.3 / 0.2	15 / 1
Europe (Eastern & Northern)	0.4 / 0.0	1.0 / 0.0	4.6 / 0.1	6.0 / 0.1	17 / 0
Oceania	0.1 / 0.0	0.2 / 0.0	2.1 / 0.0	2.3 / 0.0	6 / 0
Subtotal (all regions with information)	**3.3 / 5.8**	**11.8 / 1.6**	**21.5 / 7.8**	**36.5 / 15.2**	**100 / 100**
No information				7.4 / 3.1	
Total (all transnational agriculture deals)				**44.0 / 18.3**	

Notes: Concluded deals are shown in red, intended deals in black. Numbers may not sum correctly due to rounding.
a. "Multiple use crops" includes crops designated as "flex-crops" or "multiple use" in the Land Matrix database.
Source: Land Matrix n.d. Data shown as of 2016.

More recent updates show that many of these large proposed or announced deals have been scuttled and new dealmaking has slowed since 2012, but the total area of completed deals remains large. GRAIN's 2016 update of international land deals identifies 491 large agricultural land deals completed since 2006, extending over 30 Mha in 78 countries.[40] Similar results can be drawn from Land Matrix data, an ongoing collaborative project of two major research institutions and two international aid agencies.[41] By mid-2016, Land Matrix estimated that international investors completed deals to acquire or lease for the long-term 44 Mha of land between 2000 and 2016. As of 2016, these investors were at some stage of agreement to acquire another 18 Mha (Table 35-1).[42]

Land Matrix and other researchers have had to rely heavily on reports from others, and the area estimates are a combination of intended size, contract size, and final operations size. Some more detailed analysis suggests that these data may overstate what has actually occurred to date, at least in Africa.[43] For example, one research team put together a list of deals reported by Land Matrix and others and then conducted field research to try to verify those deals and assess their experience.[44] Of 6 Mha of potential Chinese deals reported by others from 1987 to 2014, the team ultimately found only 240,000 ha that were actually acquired.[45] Discrepancies emerged regarding financial sizes of transactions, too. A Chinese deal for rice fields in Nigeria reported as involving 2 billion U.S. dollars turned out to involve 2 billion Nigerian naira, equivalent to only about $17 million.

Although it is possible that the total area of land acquisitions has been overestimated, the reality remains that very large land acquisitions have been occurring, generally in the form of long-term leases. One more detailed study found that 2.4 Mha of land had been allocated to foreign acquisitions through some kind of legal agreement between 2004 and 2014 in Ethiopia, Ghana, and Tanzania alone, of which 1.4 Mha had resulted in actual leases.[46] Although some land had not been leased, the authors found that for those transactions they could track, the leases mostly reflected the original memoranda of agreement, and that additional leases might continue to occur where lands subject to the agreement had not yet been leased. In 2012, a government-commissioned report of the Lao People's Democratic Republic (Lao PDR) estimates that roughly 2,642 land deals totaling 1.1 Mha had been granted as foreign land-based investments, comprising roughly 5 percent of the national territory.[47]

The main reason many proposed deals fall through appears to be the difficulty of actually implementing them. Many of the original announcements were for much larger deals, and while public opposition has scuttled some—such as the large Daewoo proposal in Madagascar—many others collapse not because of governmental concerns but because they did not prove cost-effective, or because the investor ultimately lacked the capital required.[48] Because countries continue to try to enter into large land acquisitions, even if many are unsuccessful, the relative merits of these schemes remain an important area of policy inquiry.

Large-scale land acquisitions are made by a wide range of international purchasers and locally connected wealthy buyers

Although much press attention has focused on acquisitions by quasi-state entities, including sovereign wealth funds, private companies and investors also appear to be major players.[49] The latter include both domestic and international actors, though their roles vary by country. For example, a 2014 study found that companies from the United States and Europe have played the lead role in Ghana and Tanzania, while companies from India have played the lead role in Ethiopia.[50] In-country investors are playing a major role, too.[51] For example, national individuals and companies are acquiring land or associating themselves with major international land deals in Africa.[52] The Land Matrix database has inventoried about 602 large-scale domestic transactions covering 17.3 Mha[53]—but such domestic deals are greatly undercounted because information on domestic contracts is difficult to track. These land acquisitions spanned low- and middle-income countries (for which data were compiled) on all continents. While it is difficult to determine the exact location of completed deals, about half of them were likely in Africa.

National and local governments are playing a facilitating role, and international institutions may be playing an indirect supportive role

Even when investors are private, "the active role of governments in consumer and host countries . . . has also been instrumental in facilitating large-scale land acquisitions by providing financial, technical, and administrative support to investors; providing regulatory frameworks conducive to investment; and, in the case of host-country governments, assisting in land acquisition."[54] In Indonesia, oil palm development has occurred on lands originally zoned as part of the national forest estate, which are in effect reclassified by the national government on application, and all plantations require a series of permits from the regional land-use authorities.[55]

In Africa, land is typically state-owned, even if ownership includes some recognition of "customary rights," and large-scale acquisitions nearly always involve a government player. Many governments have adopted policies to encourage these acquisitions. Under Tanzania's Kilimo Kwanza (Agriculture First) policy, the government aims to increase land available for large-scale land acquisitions to 20 percent of present village lands.[56] Ethiopia's Growth and Transformation plan also calls for devoting millions of hectares to large-scale commercial agriculture, and the national government has played an active role in directly contracting with foreign investors in the Gambella region.[57]

By contrast with this supportive role, in a separate report, WRI reviewed government processes for recognizing rights to community lands in 15 countries and found them to be lengthy, filled with obstacles, and leading almost always to only a partial grant of rights at best.[58] For example, "In Chile, indigenous communities are not eligible for the procedure unless they possess a specified historic document. And in Uganda, communities must incorporate themselves into an association, elect officers, and write a constitution." The study found that procedures were unclear and that any disputes about lands or boundaries could easily halt the process. In all but one example, governments imposed "arbitrary caps" on the areas transferred, and, governments "retain the right to allocate overlapping concessions to high-value natural resources such as timber, and communities only had rights to exercise full free, prior, and informed consent to these transactions in 2 out of the 19 surveyed procedures." Although the study recognized that estimates are rough, it estimated that half of all land globally is community land but that only 10 percent is recognized as belonging to communities and 8 percent is designated for community use.

International institutions have played little role in directly supporting these large land acquisitions, but they may be doing so indirectly and sometimes unintentionally. For example, international institutions have been supporting specific agricultural improvement corridors in Tanzania and Mozambique. Even if their goals are to support small-scale farmers, large-scale acquisitions have also been occurring along these corridors.[59]

Although acquisitions are occurring on many continents, they mainly affect rural populations in Africa and Southeast Asia

Large-scale land acquisitions are occurring across the world. For example, of proposed international agricultural deals as of mid-2016, Land Matrix shows almost 50 percent in Africa, 17 percent in Eastern and Northern Europe, 15 percent in Asia, 15 percent in Latin America and the Caribbean, and 6 percent in Oceania (Table 35-1).[60] Yet these acquisitions appear to have quite different characteristics. For example, many of the well-publicized purchases in Australia have been of large preexisting ranches.[61] In the former Soviet Union, acquisitions have occurred at a large scale but appear primarily to have been takeovers of large areas of farmland abandoned after the collapse of the Soviet Union in areas with low populations. By contrast, acquisitions of land in Indonesia and Cambodia to produce palm oil or rubber, and acquisitions in Africa for agricultural uses, often occur in areas with substantial customary use by rural populations.[62]

Acquisitions have responded to effects of increased food demand, increased biofuel demand, farm price changes, and expectations for exports

Large-scale acquisitions accelerated after 2005 when crop prices started to rise; in 2008 and 2011, prices reached levels four times higher than they had been in 2005. As crop prices stopped rising, acquisition activity appears to have slowed as well.[63] Even though land acquisitions have occurred on extremely favorable terms—and sometimes with

no purchase price at all—these projects still require substantial investment and risk. Expectations of future high crop prices therefore play a major role. Although investments are sometimes blamed on "speculation," this term adds little to understanding the land-acquisition phenomenon. All land acquisitions are speculative in that they bet on future economic returns.

Although some entities have defended land leases as ways of boosting local food supplies, the evidence overall suggests that acquisitions which have gone through are focused on exports of nonfood crops, such as rubber or cotton, or of cash food crops, such as palm oil.[64] Even those few projects focused on staple food crops appear to be focused on exports.[65]

Much of the land rush in 2006–10, especially in Africa, focused on the production of sugarcane or jatropha intended to supply the European biofuels market.[66] Technical problems with growing jatropha reduced the prospects of those projects, and substantial political doubt about the future of European biofuel policies also appears to have reduced acquisition interest. However, as Table 35-1 indicates, at least 44 percent of foreign African acquisitions tracked by Land Matrix involved nonfood crops as of 2016, and the vast majority of the rest could serve multiple purposes.

In much of the world, acquisitions involve natural and seminatural landscapes that are valuable for biodiversity and ecosystem services

The primary focus of research into "land grabs" has been the social effects on rural populations, but effects on natural habitats are also significant. Most large land acquisitions do not appear to be occurring on farmland that is being intensively cropped by small-scale farmers. Although information on this point is mostly piecemeal, it appears that, in countries dominated by small-scale farming, land acquisitions target more natural habitats—including forests, savannas, and wetlands—and long-term fallow land. These are the types of land that are mostly managed on a community basis. The large acquisitions of existing farmland occur primarily in locations where farms are already large, as in the former Soviet Union.

In the Lao PDR, for example, a government-commissioned report found that 37 percent of large-scale land acquisitions involved forest land, and that 45 percent involved what the report categorizes as "unstocked forest and ray," which are areas of bush and forests created by shifting cultivation practices.[67] Three-quarters of the acquired forest land also fell under legal categories intended for protection.[68] In Paraguay, large land acquisitions are associated with the clearing of the biologically diverse Chaco forest.[69] In the Yala Swamp of Kenya, where the Yala River drains into Africa's largest lake, foreign investment led to large-scale clearing and drainage of a swamp rich with hippos, crocodiles, and leopards, and where local people used to fish, hunt game, harvest papyrus, grow vegetables, and graze cattle.[70] The Tana Delta, another wildlife-rich area of wetlands near the Kenyan coast similarly used by local people, is the subject of a large-scale, although highly contested, plan to grow sugarcane for ethanol.[71] In the Gambella region of Ethiopia, farming operations instigated by both Saudi and Indian investors have converted thousands of hectares of wetlands, used by local people to gather honey, hunt, and fish. Biofuel plantations in Zambia were established mainly on native Miombo woodland.[72] In Ghana, scholars found that biofuel developments were converting "large areas of secondary forest and rehabilitating fallow lands."[73]

Not all of these lands are pristine.[74] Much of the Miombo woodland in Zambia is land that has been cropped and has regrown woodland over time. One study concluded "that for every 1,000 ha of jatropha grown on smallholders' fields in the study site, an estimated 310 ha of mature forest and 196 ha of fallow land were cleared."[75] Similarly, in Indonesia, oil palm plantations were displacing not only primary forests but secondary forests, and often mixed landscapes of fallow, shrubs and grass, and cropland used by smallholders for rubber, pineapple, and maize.[76] Even in these disturbed landscapes, one can reasonably infer that lands cleared previously stored substantial quantities of carbon—or were rebuilding carbon—and provided other ecosystem services.

Analysis has shown that social and equity effects of land acquisitions differ among regions

Large acquisitions of preexisting large farms have occurred in the former Soviet Union and Australia. Although there has been some controversy about these acquisitions—including concerns about corruption and foreign ownership,[77] respectively—little scholarship has focused on local social consequences. The farms were generally large, supporting few farmers, and in the former Soviet Union many had fallen into disuse. There was little reason to believe that these acquisitions would displace farmers; rather, they had a large potential to boost overall production and the farm economy.

In contrast, both scholarship and press reports of impacts in Africa tend to find displacement, inequity, broken promises, and strong hints of corruption or self-dealing.[78] A summary of biofuel developments in Ghana by the Centre de recherche forestière internationale (Center for International Forestry Research, CIFOR) is illustrative of the conclusions:

> Large contiguous areas of suitable land were easily obtained by foreign companies through direct negotiations with Traditional Authorities, often through opaque, nonparticipatory and partially documented negotiations purportedly locking up large tracts of land for periods of up to 50 years. In this context, many affected households were forced to relinquish their land without any form of compensation or guarantees of future returns. Many land-losing households consequently experienced a marked decline in livelihood quality as a result of reduced incomes, increased food insecurity, and loss of access to vital forest products.[79]

In what may be the most socially advantageous case of biofuel investments identified by CIFOR, researchers found that a Tanzanian project followed "negotiations [which] were considered acceptable by affected communities" and produced "a number of early benefits," including "waged employment, full-time employees receiving considerably more than the minimum wage, water supply points, support for funeral costs." By 2009, however, an economic downturn had left wages "unpaid for long periods and promises to improve the school and hospital left unfulfilled." The authors concluded, "With approximately half of household landholdings converted in the process, this case represents an unacceptably high risk for communities."[80]

There are also clearly examples in which direct employees of new plantations reported improved or more consistent incomes, as one group of employees reported in Ghana.[81] However, even in that situation, CIFOR found greater returns both to land and labor from alternative, local uses, and concluded that "employment [on plantations] would compare far less favorably if the value of other displaced crops and forest products were considered."[82]

In Indonesia and Malaysia, researchers have found at least somewhat more mixed results:

> Some communities did enjoy economic and social benefits from oil palm plantations such as more stable and reliable income, road access, [and] better healthcare services. In Kubu Raya, some communities benefited both from employment opportunities and from sales of smallholder oil palm harvests. In Kubu Raya and Boven Digoel sites, some indigenous communities and migrants developed good interethnic relations, although this was not the case in Manokwari. Other communities experienced increasing restrictions on traditional land-use rights and outright land losses. . . . Conflicts over land between indigenous communities and oil palm companies were observed in all three sites.[83]

Similarly, in a series of case studies about oil palm in Thailand, Indonesia, the Philippines, and Malaysia, researchers at the Stockholm Environmental Institute found the consequences for local communities "were mixed, and that the espoused benefits for communities were not materializing as hoped."[84] It also found that "delivery of benefits at the local level was often highly skewed, with already marginalized groups being further disadvantaged, thus increasing inequity, societal fragmentation and social tensions."[85] Many communities have also found that oil palm developments led to serious problems with local water pollution and flooding.[86]

Indonesian law illustrates why transactions are likely to be unfair despite the fact that those seeking to build oil palm plantations must generally agree to a deal with local communities. To build a plantation, owners must first obtain permits, often first from the national government, to release land from status as national forest, and later from regional land authorities. These permits in effect give companies at least a temporary monopoly to buy rights to agricultural development. Only after obtaining a series of permits do companies negotiate with local communities, which therefore are not able to seek the best deal available from a choice of companies but must either agree or not agree to oil palm development with a single potential purchaser. Not surprisingly, although land for oil palm probably has a value of $4,000–$10,000 per hectare,[87] compensation for local communities rarely if ever approaches this level.[88]

By contrast, Tanzanian law applies a number of restrictions to acquisitions that would appear to mandate far more local potential for the interests of existing land users. But CIFOR found that

> the checks and balances in the law worked contrary to their intended purpose due to several factors. Both central and district governments are faced with strong incentives not only to generate revenues, but also to create conditions for enhanced economic growth and poverty reduction. Investment in the agricultural sector, which employs the majority of rural Tanzanians, is viewed as a promising pathway towards achieving these goals. Three factors exemplify the bias towards investors: land leases in excess of legal limits for the biofuel sector; the approval of flawed environmental assessments; and, ultimately, the overstatement of benefits of investments by politicians (including the President), which bolsters support from government officials and extinguishes critical debate on costs and benefits among villagers and local representatives.[89]

Recommended Policies for Land Acquisitions

Despite generally negative social and environmental assessments of the surge in large-scale land acquisitions, many critics have focused on procedural reforms.[90] One recommended reform is stronger recognition of customary rights, which we discuss below. These suggested procedural reforms for approving large-scale acquisitions typically highlight the following elements:

- Substantial consultations with affected communities
- Assurance of "informed consent" or true approval by a majority of local land users before deals go through
- More detailed contracts that specify the obligations of the investors
- Measures and procedures to oversee and assure enforcement of investor commitments
- Assurance of compensation for a wider array of customary uses and rights that recognize the real economic returns different people are now obtaining from them

We endorse these reforms. We also note that informed consent does not mean that every single user must consent. Assembling large-scale operations could involve high transaction costs even where benefits to all could be large, particularly if single holdouts can block the deal and demand a premium before others can benefit. This consideration explains why developed countries typically have procedures for government to seize land for eminent domain, but that ensure proper compensation. Informed consent instead requires rules that allow democratic decision-making by the community, with fair and transparent rules of thumb for compensation for the many different preexisting uses. Unfortunately, the evidence as marshaled by the reports we cite in this chapter is strong that these procedures are not widely or strictly followed.

Although these procedural reforms are worthy, the more fundamental questions are where, when, and under what conditions large land acquisitions should be encouraged or allowed because they benefit a country and its people and contribute to a sustainable food future.

When acquisitions involve large preexisting farms already converted to cropland, those acquisitions are less likely to displace and harm workers and natural habitats, and more likely to lead to valuable improvements in agricultural production. Some acquisitions in the former Soviet Union, Brazil, and Australia are more likely to fit these criteria, but, if benefits are to be realized, land purchasers must have the investment capital they claim to have and procedures must be in place to avoid corruption and political favoritism. In many land purchases, these conditions have not been met.

In general, other types of acquisitions rarely pass our criteria for a sustainable food future, such as ecosystem protection or climate change mitigation.[91] Large-scale land acquisitions tend to occur in forests, wetlands, or other natural or seminatural habitats. Although some governments and private companies have claimed they are merely acquiring "underutilized land" or "abandoned agricultural land," the evidence suggests that these lands typically hold more carbon and are more environmentally valuable than claimed, and that the labeling of land as "underutilized" or "abandoned" is an unjustified disparagement of secondary forests and savannas. Even when some of these areas are "degraded" from their purely natural state, they are typically being used by the poor and marginalized groups that rely on wetlands, grasslands, and trees (which in some locations may be common-pool resources) to diversify their livelihoods and increase their resilience to droughts and other shocks.

To truly support a sustainable food future, such acquisitions would have to meet one of two additional criteria: they occur on lands with relatively low environmental opportunity costs, including land for which the carbon costs per likely ton of crop are significantly lower than the global average; and they occur in countries where crop expansion is inevitable and are based on land-use plans consistent with the country's climate change mitigation obligations.

Cooperative, Contract, and Magnet Farming

What tools and contracting procedures can policymakers provide to help millions of smallholder farmers cope with the disadvantages presented by their size? What is necessary to help these farmers gain access to credit, buy inputs at low costs, acquire necessary technical understanding, and market their products at advantageous prices? Traditional tools involve three kinds of contractual mechanisms:

- Farmer cooperatives, through which farmers collectively own and run distribution facilities and input suppliers
- Contract farming, in which farmers agree to produce specific crops for future delivery at a set price and often receive assistance to do so
- Magnet farms, which typically involve contract farming around a central, large farm

Although these three mechanisms differ in detail, each involves an operational entity that works with smallholder farmers to increase access to inputs, expertise, and credit, and/or to process and distribute the final product.[92]

As countries' economies develop, and markets become increasingly long-distance and anonymous, these mechanisms are likely to become more important. Farmers working in these systems enjoy the benefits of branding,[93] gain expertise, spread risk, share costs of inputs and machinery, and access more remunerative and specialized markets.

Yet cooperatives, contract farming, and outsource farming by magnet farms also have costs. In the case of contract and outsource farming, larger farming enterprises may develop local monopoly power over purchases, and farmers can become particularly vulnerable to them once they have invested in the production systems needed to grow specialized crops.[94] In the case of cooperatives, there are administrative costs and risks that cooperatives will be managed unfairly. There is also the risk that a single cooperative may not prove to be as efficient at supplying farm inputs or marketing crops and livestock products as a competitive, private market of multiple businesses.

Contract farming is also vulnerable to cheating, either by the contractor or by the farmer. The core of contract farming is an agreement for farmers to provide and companies to purchase a quantity of a commodity at a predetermined price (or price range), at a specified time. For certain kinds of agricultural products, such as a highly processed tree crop, the contract may need to apply over several years to justify the upfront costs for either farmers or purchasers. By the time of the promised sale, changes in growing conditions worldwide or consumer preferences may have led to dramatically higher or lower crop prices, providing strong incentives either for a farmer to try to sell to someone else at a higher price or a company to try to avoid purchasing—perhaps by falsely claiming quality limitations—if market prices are lower. Overall, policing contracts is costly, and some products are harder to police than others.

The benefits of contract farming are hard to prove conclusively because there are many reasons why farmers who already have other advantages—whether these be better lands, better locations, or better training—are also more likely to be contract farmers.[95] There is evidence—gleaned from subtle statistical analysis—that studies of contract farming are subject to a publication bias in which studies that show benefits are more likely to be published.[96] Even so, and while the evidence can be conflicting, meta-analyses of studies generally find that contract farmers in developing countries tend to make more money than noncontract farmers and that contract farms tend to have higher productivity.[97]

The combined weight of the evidence and many studies indicate that contract farming should be able to provide valuable benefits, but there are several important caveats.

First, because of the mix of benefits and costs, these systems tend to evolve primarily for foods of higher market value.[98] For example, companies may pay a premium for vegetables or other high-value crops (e.g., cocoa, vanilla) of the right quality, or milk or poultry that meets the right sanitary standards and is reliably delivered year-round. If the quality cannot be assured through relatively quick and easy inspection, as with sanitary standards, for example, contract farming can provide a solution. Companies may also have special technical advantages—such as particular vegetable varieties, breeds of chicken, or feed formulations—which they can exploit only by maintaining some production control, particularly if goods are hard to store. Cooperatives may also evolve in similar circumstances, for example, to market milk because of the need for an assured buyer shortly after milk is produced. There are examples of contract farming for staple crops, such as rice, that seem to have economic benefits, but contract farming is less common for such crops, and there are also findings that efforts by aid agencies to promote contract farming for staple crops can make the costs of farming too high.[99]

Second, studies consistently find variability in results from different contract farming arrangements even where they tend to find benefits on average. The details therefore matter.

Third, the challenges of meeting the demands of contractors tend to favor somewhat larger farms (at least, the larger of small farms), and relatively few farmers tend to benefit from these arrangements. Today, fewer than 5 percent of smallholder farmers typically participate in some form of contract farming.[100]

Recommendations for Contract Farms

In general, the literature implies that governments can support smallholder productivity and livelihoods by supporting strategies that allow farmers to take advantage of these different contractual arrangements. We offer a few suggestions for policies to increase the benefits and reduce the costs.

Focus more development efforts on high-value crops

Agricultural development assistance to smaller farmers should be directed more toward high-value crops that carry a premium for quality because the benefits of collective action are more likely to apply to such crops. Many of these kinds of crops also tend to improve with heavier investments of labor. In general, our modeling analysis also projects larger growth in demand for these crops than for staple crops. Even farmers engaged in subsistence agriculture can raise cash crops to boost income, diversify production, and increase assets that may also be used to build staple crop production.

Provide basic social security

Because hunger is such a core risk, subsistence farmers are highly risk-averse and will often produce staples even if production of an alternative crop would on average provide more income and thus greater food security. For the same reason, farmers will typically avoid specializing in the most promising agricultural option unless the expected rate of return is extremely high relative to the increased risk. Government programs that provide an alternative form of income or food guarantee could therefore help farmers take more risks and make more profitable investments, such as growing crops likely to earn a higher return. Brazil's *Bolsa Família* program and Mexico's *Oportunidades* program, for example, provide small guaranteed incomes to the poor if they send their children to school, and both have had considerable success in alleviating hunger and poverty.[101] Research on the agricultural effects of these types of social security programs is limited, but it suggests that they allow farmers to focus more of their production on higher-value crops.[102] Both Brazil and Mexico are middle-income countries, and many countries in Africa probably cannot afford such extensive programs, but moving in this direction as soon as possible may also be a way to stimulate agricultural growth.

Ensure fair contracts and try to enforce them

A first step is to help ensure fair contracts up front, and small farmers would benefit from legal and marketing advice. The risk of cheating by either party poses a major barrier to mutually beneficial contract farming so efforts to make cheating harder are important. Such efforts can take advantage of improved remote and ground sensors and spatial tools to confirm production, which would increase the confidence level of companies. They should also enable faster and fairer arbitration and enforcement procedures, increasing farmers' confidence. Civil society organizations might provide these services. Governments should consider laws to facilitate such arrangements, including basic codes of conduct to help protect against abuses.

Build on sustainability commitments

Many major private food companies have committed to reducing deforestation and GHG emissions and improving the income of farmers in their supply chains. Deeper involvement with farmers through contract farming provides one opportunity for embedding these commitments further up supply chains and building longer-term relationships between companies and their producers.

Land Rights for Sustainable Intensification

Large-scale land acquisitions can occur in much of the world because traditional users of land generally lack full and protected property rights. In some parts of the world, neither smallholder farmers' rights nor common rights to community land are officially recorded in written form. In addition to increasing vulnerability to seizure of land by others, this lack of clear, full title—according to standard economic theory—undermines both the ability of farmers to borrow money and their desire to invest in long-term improvements because farmers may not be able to reap future benefits of their investments. Weak property rights therefore encourage short-term exploitation of land rather than longer-term stewardship. The resulting sustainability concerns have led international institutions and nongovernmental organizations to advocate secure land rights.

Property rights

Determining the best and most appropriate kinds of rights regime has proved challenging. The standard treatment of land rights in Western countries recognizes something similar to total rights of dominion over a parcel of land, subject to regulation but including the right to buy and sell and typically to exclude all, or nearly all, other uses. These rights are typically recognized in written documents recorded in government registries. International institutions have sought to mimic these types of property rights in countries without such systems, and many governments have made efforts in this direction.

These efforts have had some success but also many problematic results. From an equity standpoint, efforts to recognize rights in this way have sometimes led to failures to recognize a range of

traditional rights on common lands, ranging from hunting, wood gathering, and grazing to gleaning. By definition, if a piece of land has long been subject to overlapping rights but the new property rights system is oriented toward recognizing single ownership, then some people who have previously used the land will lose their rights (with or without compensation).

The process of recognizing rights has also provided an opportunity for political favoritism and unfairness. As the World Bank wrote in 2008, "Land policies were often adopted less to increase efficiency than to further interests of dominant groups."[103] In many contexts, granting recognition of individual property rights to people without experience of private land ownership and without establishing communal regulation has allowed elites to buy up rights and assemble vast complexes of land.[104]

The effect of individual property rights on agricultural productivity is complex. In theory, title should give farmers greater incentive to improve farms and greater means to borrow funds to do so. The ability to sell or rent land should make it easier for land to be transferred to more productive farmers. In studies of land reform effects in Latin America, Eastern Europe, and Asia, researchers have found productivity gains to be significant.[105]

But in studies of land reforms in Africa, researchers have generally found no particular gain, a result for which they have offered two possible explanations.[106] One is that customary land rights have been sufficiently secure that providing land titles has not provided much additional security—although there is evidence that customary land rights are generally not sufficient to use as collateral to obtain a loan.[107] The other explanation, in effect, is that while secure land rights are very helpful in promoting productivity investments, they are not by themselves sufficient, and the myriad other obstacles facing farmers in Africa have blocked improvement. Among these obstacles are poor soil quality; inadequate transportation, electricity, and financial infrastructure; weak marketing infrastructure and networks; and poverty traps.

As one critic has written about Africa, "In practice, many of the land policy reforms and titling programs of the 1970s and early 1980s failed to achieve the expected increase in agricultural investment and productivity, did not facilitate the use of land as collateral for small farmers, and often encouraged speculation in land by outsiders, thus displacing the very people—the local users of the land—who were supposed to acquire increased security through titling. The programs frequently exacerbated conflicts by ignoring overlapping and multiple rights and uses of land and led to or reinforced patterns of unequal access to land based on gender, age, ethnicity, and class."[108]

Customary rights

During the past decade, researchers, international agencies, and governments have learned from these lessons and begun to emphasize the recognition of customary rights. These are the complex rights recognized by many communities in much of the world (including Africa) to land uses that may accommodate both overlapping rights to the same piece of property and the process within a community of allocating rights. A number of African countries have taken steps to recognize customary rights, but the strength of measures varies. For example, Mozambique has recognized customary rights in general but still retains national ownership rights that may supersede the communal rights. As one study concluded, "A greater challenge to customary rights in Africa is not tenure conversion per se, but the fact that customary arrangements lack adequate constitutional and legal recognition in many countries."[109]

Customary rights, however, are not always completely fair. They may recognize the authority of local chiefs in the allocation of land, but decisions by the chief may be inequitable or may fail to prevent unbalanced deals with large investors seeking land. A study by CIFOR found that many of the large and inequitable land deals in Mozambique and Tanzania were the work of local chiefs, who directly received money as an incentive.[110]

Translating customary tenure rules into formal property rules also can institutionalize the inequality of women. For example, in southwest Ghana, women's ownership of land is customarily discouraged, and women often obtain land only by the license of their husbands.[111] One study by the World Bank concluded that in sub-Saharan Africa, "the vast majority of women, who are the primary subsistence producers, are locked out of landownership by customary laws."[112] Sometimes customary laws do recognize substantial rights for women, but they are hard to translate into property rights based on Western principles. For example, women in northern and eastern Uganda have many traditional land-use rights, but when sales transactions occur through the legal system, those rights are often lost.[113] Moves to recognize customary rights need, at a minimum, to recognize these rights. More broadly, recognition of customary rights should be seen as an opportunity to change those rights to increase fairness and broaden access to resources in ways that will simultaneously benefit productivity.

The development economics literature generally agrees that "(1) property rights need not always confer full ownership and be individual—they can, and should be, individual, common, or public, depending on the circumstances and (2) most important for sustainable development is that property rights are deemed secure."[114]

Beyond the challenge of determining the best system of rights, the sheer process of recording property rights has often proved to be expensive because it requires drawing precise property lines and settling potential disputes. That process has led some studies to question whether such efforts are always or even usually worth the cost. Modern information technology, however, seems capable of reducing this challenge. For example, Rwanda completed a national registration program of 10.3 million parcels in less than five years at a cost of $10 per parcel using aerial photographs and rectified satellite imagery.[115] Ethiopia implemented a similar program. Both countries used this process to improve women's rights by legally recognizing women's inheritance rights, elevating secondary rights so that they are equal to those of men, and allowing the joint registration of spousal land rights. Studies have found that Ethiopia's reform led to improvements in agricultural productivity.[116]

In addition to influencing equity and productivity, tenure arrangements have implications for forests and agricultural conservation. In some contexts, traditional property systems may discourage agricultural conservation practices. For example, the long-established principle of acquisitive prescription, common in Latin America, allows landowners who clear forests to obtain ownership and thereby encourages deforestation. In Africa, rights to use trees may be divided among those with the right to collect fruit and those with the right to cut the tree for timber, which in some cases may be the government.[117] This split in rights can reduce incentives for farmers to plant and care for trees. In many parts of Africa, members of the community may have the right to graze cattle on residues after the harvest, reducing incentives to return the carbon in residues to the soil.

Better recognition of the rights of indigenous users can help protect forests, however. Researchers have found that indigenous reserves in Brazil have been far more effective at preserving forests than other land ownership arrangements—although this may result in part from restrictions on deforestation built into the establishment of those reserves.[118] Overall, in Brazil, Bolivia, and Colombia, deforestation rates inside indigenous forest lands with secure tenure have been one-half to one-third those outside indigenous lands.[119] But many local people will also be attracted to the potential revenue from agricultural conversion, as long as the price is fair and other measures to boost their incomes are lacking. Recognizing land rights may help but will not always be an adequate measure to protect natural ecosystems from conversion to agriculture.

Recommendations for Land Rights

Despite the complexity of tenure issues, we offer a few general recommendations based on literature and our own conclusions:

- Governments should recognize and secure the rights of those who have used land (and water) under both formal and customary arrangements to protect against large-scale seizures by governments themselves and to provide sufficient security for farmers to obtain credit.
- Governments should use modern information technology to expedite the identification and recording of land boundaries and issuance of associated documentation. They can move the process along quickly by segregating parcels that are subjects of dispute (for subsequent resolution) from those that are not.
- Governments should eliminate rules that allow individuals to secure property by clearing forests and other natural landscapes.
- Where land ownership in the form of individual plots has a strong tradition, as in much of Asia and long-settled parts of Latin America, moving toward property rights systems similar to those of Western countries can work.
- Processes to formalize customary rights, because of their high potential to disadvantage those who are less powerful or whose rights are more transient, should specify rules and employ oversight systems to assure fair treatment.
- Where customary rights systems exist that recognize physical overlapping land uses, the systematizing process is also an opportunity to address fundamental unfairness, as in the treatment of women's rights, and to develop alternatives to traditional rules that impede productivity gains.

CHAPTER 36

CARBON-PRICING STRATEGIES AND FINANCING OF CLIMATE-SMART AGRICULTURE

Voluntary actions alone will likely not achieve climate goals. Economists generally favor pricing strategies that attempt to internalize climate costs, such as carbon taxes and cap-and-trade systems. Some policies would use carbon "offsets" to fund agricultural mitigation. We find that broad pricing strategies are likely impractical but that opportunities exist to apply them selectively as part of flexible regulations. Finding a limited role for offsets, we discuss reforming agricultural subsidies and increasing access to climate finance.

Carbon-Pricing Strategies

No one knows the precise changes in management or land uses that each farm should undertake to most cost-effectively boost production while reducing GHG emissions immediately today, let alone over time. In the same way, no one knows the precise mix of technologies most cost-effective for reducing emissions from factories and power plants. For these reasons, economists and most environmental organizations favor policies that target outcomes—by imposing costs or caps on emissions or possibly rewarding sequestration—rather than laws that mandate particular technologies or practices. Outcome-oriented approaches offer more certainty about the level of emissions that will ultimately be achieved and should be more cost-efficient because farmers and other emitters are given the flexibility to choose the most cost-effective ways of reducing emissions at any given time. But are such approaches politically or practically feasible for agriculture?

Carbon taxes and cap-and-trade systems

Governments can impose costs flexibly on emitters by imposing a tax on each ton of emissions, typically called a "carbon tax." They can also create a "cap-and-trade" system. In a cap-and-trade system, the government imposes a cap, or limit, on the total amount of allowable carbon dioxide equivalent emissions and allocates emissions "allowances," representing shares of the cap, to emissions sources that have been designated as entities under the cap. Cap-and-trade systems can allocate allowances at different parts of the supply chain, and participating entities can trade emissions with each other as long as total emissions from all entities remain under the cap. If applied in agriculture, for example, farms (or whatever entity is allocated allowances) that emitted more than their allowance would have to purchase more allowances from others, while farms that reduced their emissions below their allowance could sell credits for extra emissions reductions to others.[120]

Carbon taxes and cap-and-trade systems can create incentives that work their way through agricultural and food supply chains. For example, science and technology companies that develop more efficient fertilizers or feed additives to reduce ruminant methane would find a market for these innovations because farmers would pay for inputs that help them avoid taxes or the need to purchase allowances. Consumers would also have incentives to switch to lower-carbon foods, because the costs of high-carbon foods, such as beef, would rise to reflect their carbon costs. In such systems, markets can identify the most cost-effective sources of emissions reductions on their own.

These mechanisms can be implemented without imposing additional net costs on farmers or food consumers. For example, governments could refund farmers using taxes raised downstream from the food sector or by using funds from selling allowances. Such systems would work if those who reduced emissions ultimately received more of the economic benefits than those who did not, and if those advantages were proportionate to the reductions. Governments could also design either a tax or a cap-and-trade system to protect the interests of small farmers, including those who today generate high emissions relative to their production. The key need is to structure such a system to focus on improvements from a baseline, for example, by allocating carbon allowances to farmers who match their existing emissions levels. As small farms probably have some of the best opportunities to reduce emissions per ton of crop, meat, or milk, such pricing mechanisms could even favor them.

Despite their theoretical advantages, these pricing approaches face significant technical challenges in the agriculture and land-use sectors. In the energy sector, emissions generally track the amount of carbon in coal, oil, or natural gas. As a result, emissions are relatively easy to estimate per fuel type and form, so pricing the carbon in these fuels is a reliable proxy for emissions. In the agriculture sector, however, the quantity of emissions resulting from different farm practices can vary greatly. It is not practical to measure most agricultural emissions directly (such as the nitrous oxide released when using fertilizers or ruminant methane). Even if it were, monitoring millions of farmers globally would present enormous challenges in practice. Many mitigation options are relatively subtle—such as improving the efficiency of feed use for cattle—and it would be difficult to monitor how emissions change because of changes in management.

Land use also presents measurement and verification challenges, long acknowledged by the Intergovernmental Panel on Climate Change (IPCC).[121] Many natural factors, such as variations in rainfall and temperature, greatly influence how much carbon a forest or savanna adds or loses. As a result, holding landowners directly accountable for increases in land-use related carbon emissions that they cannot control may be unfair. Imposing penalties on owners for losing forests, for example, would raise questions about what to do and how to know when forest clearing results from natural fires or fires set by others. Monitoring carbon through remote sensing is not yet practical at the individual landowner level.[122]

Introducing carbon taxes or cap-and-trade systems likely faces even more significant political challenges than applying such approaches to other sectors of the economy. Neither agriculture nor forestry is part of Europe's emissions trading system, which applies only to large manufacturing sites and power plants. When the U.S. House of Representatives passed a bill to create an emissions trading system in 2009 (that ultimately was not introduced in the Senate and did not become law), the bill did not impose obligations to reduce emissions from agriculture or land use. In 2008, New Zealand established an emissions trading system[123] that was originally intended to apply both to agriculture and conversion of forests into agricultural use, beginning in 2015.[124] But the government suspended the law's application to agricultural production as the start date approached and replaced it with reporting obligations only—although the government did retain limitations on conversion of forests.

More selective pricing strategies

Given the technical and political challenges of these carbon-pricing strategies, agriculture may not be subjected to the same carbon-pricing mechanisms used in the energy and manufacturing sectors. However, the advantages in efficiency and flexibility afforded by pricing strategies should motivate governments to explore alternative, more limited variations. For example, although New Zealand's emissions trading system is not focusing on agricultural production emissions, it still requires those who cut down forests established before 1990 to have offsets for those emissions.[125] It might also be possible to tax the production of forest products, and to do so differentially based on the type of forest those products come from to influence the location, method, and quantity of wood products that are produced.

Creative pricing approaches could also apply to features of agricultural production that are measurable. For example, governments in countries where farmers have opportunities to apply fertilizer more efficiently could impose a tax on fertilizer that does not incorporate a nitrification inhibitor or time-release mechanism. The tax level would be based on the likely additional releases of emissions expected from use of conventional versus improved fertilizer. Different forms of manure management could also be taxed separately. Whether used to help set the level of a carbon tax or simply to monitor emissions more carefully, scientists need to develop useful proxy indicators to estimate emission levels and how emissions change with various mitigation practices. Taxes on high-emissions foods, discussed in Chapter 6 on shifting diets, represent another option.

In an ideal world, governments should impose taxes that reflect the costs of pollution, but political feasibility will depend in part on confidence in the technical feasibility and cost of mitigation options. Just as enhanced forest protection in Brazil was accompanied by increased confidence in the potential to intensify production on existing agricultural land, some method of taxing beef production that generates high levels of methane emissions becomes more plausible if scientists can demonstrate to farmers that safe, effective, and reasonably priced additives are available to limit methane generation from cow digestion.

Overall, given the complexities of the world's agriculture and land-use system and the scope of the climate challenge, it appears that taxing emissions would be the most efficient and effective approach to reducing them. Governments should explore selective application of this approach wherever practicable.

Carbon Offsets

Much of the interest in applying emissions trading systems to agriculture has focused on agriculture as a supplier of offsets to capped sectors. Energy users, for example, would pay farmers to reduce their emissions, creating credits that they could use to offset or cancel out their own emissions at less cost than any actions they could take in their own operations.[126] Similarly, some nongovernmental organizations and foundations have hoped that offsets could fund agricultural improvements by small farmers in developing countries, particularly through incentivizing measures that add soil carbon and improve soil fertility.[127]

To date, European companies capped under an emissions trading system have been able to pay farmers in developing countries for a limited number of mitigation measures under the Clean Development Mechanism (CDM).[128] The Canadian province of Alberta also established a system that allowed extensive use of offsets.[129] Interest in this approach in richer countries has been political as well as technical: trading systems could provide financial reasons for agricultural interests to support climate change efforts and reduce compliance costs for factories and power plants. In Alberta, for example, offsets have generated more reductions than those achieved by factories and power plants reducing their own emissions.

Despite these hopes, there are serious limitations and challenges to the use of offsets. The most obvious is that offset systems by themselves do not generate net greenhouse gas (GHG) emissions reductions from agriculture. The emissions reductions in agriculture are credited to the energy sector, which then reduces its emissions less than it would have done without the purchase of an offset. For years, climate mitigation policies have paid little attention to the need to reduce agricultural emissions. Given delays in taking action on climate change, it is now clear that by 2050, in addition to massive reductions in energy-generated emissions, agricultural emissions must also be significantly reduced to help stabilize the climate. This means that selling agricultural offsets to the energy sector can play at most a transitional role, perhaps stimulating progress in the agricultural sector. Large-scale agricultural mitigation is needed just as it is for other carbon-intensive sectors.

Beyond this need to limit both agricultural and energy sector emissions, other practical challenges limit the use of offsets:

Additionality

A critical requirement for offsets is “additionality,” which is proof that a mitigation measure would not have occurred anyway but rather results from the payment of the mitigation credit. To establish additionality, the CDM requires an analysis that the measure would not otherwise be economical and customary. But there is debate as to whether most CDM projects truly meet the additionality test.[130] One problem is that the more economical a mitigation measure—and therefore the more desirable and likely to be successful—the less likely it is to be additional. The additionality problem is so challenging to apply robustly in practice that many researchers and some policymakers have called for abolishing offsets altogether, thereby avoiding the additionality problem, and replacing offsets with an alternative mechanism that rewards countries for holding emissions below a projected baseline.[131]

Baseline

Related to additionality is the question of what baseline to use to assess mitigation. Should an offset require reductions from recent historical emissions, or recognize that emissions are likely to grow without additional effort (e.g., to improve livestock feeding efficiency or nitrogen use efficiency from fertilizers)? Although such improvements offer the best short-term options for reducing emissions while meeting growing food needs, it can seem odd to award offsets to farms for absolute increases in emissions (even though they are smaller increases than would occur under "business as usual" growth) and to use those activities to justify reduced mitigation by factories and power plants.

Administration

Developing offset agreements with millions of farmers is a major administrative challenge, as is monitoring the results. Solutions probably require a large "aggregator," which pays farmers for practices and then assesses progress over large areas using indirect means. But monitoring and payment require some entity to manage the process and probably assume much of the risk.

Leakage and permanence

When any activities claim mitigation, an important question is whether the activity truly reduces total emissions or just transfers emissions to other sources. For example, if some farmers plant forests on some of their land or reduce fertilizer use in ways that reduce yield, other farms may then clear more forest to meet demand for food. Efforts to estimate these effects are challenging and present large conceptual problems. For example, should carbon offsets reward producers if an economic model estimates that the amount of land-use change elsewhere to replace the food is less because higher prices cause people to consume less food?[132] Leakage is an issue for all emissions mitigation activities, but the likelihood of leakage is even greater when mitigation actions are counted at an individual farm level rather than at the national level. In addition, when the estimated reductions are sold as an offset to a purchaser, which can then increase emissions or avoid reductions itself, the consequences are even worse. Permanence is also an issue. Forms of mitigation that involve carbon sequestration might not store carbon over the long term.

Certainty and discounting

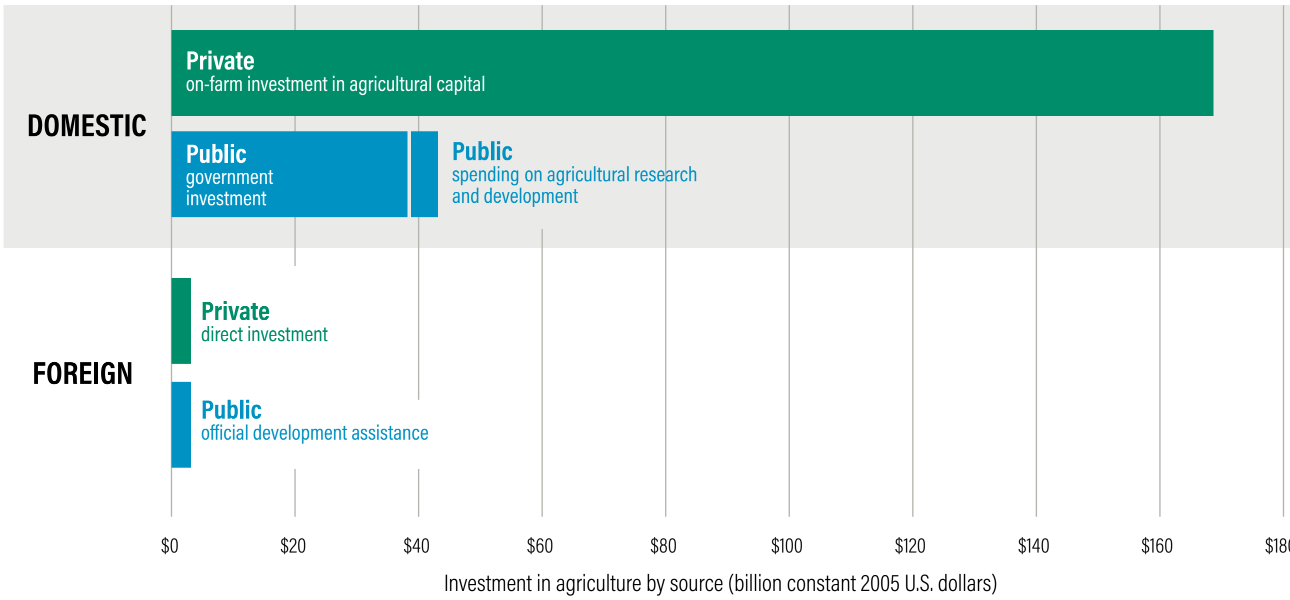
Accurately estimating emissions reductions in the agriculture sector is more challenging than in the energy sector. As a consequence, agriculture-based offsets are sometimes discounted relative to energy-based ones (e.g., of two tons of estimated reduction, only one ton can be traded). Such discounts reduce the financial incentives for agriculture-related offsets.

Small farmers

Participating in offset programs presents particular challenges for small farmers. Precisely because they are small, the amount of mitigation potentially available from any one farm is modest, although many of the transaction costs will remain. Small farmers also face timing and flexibility issues. For example, many offset projects only pay based on success, or after several years of operation. But many small farmers lack access to the capital necessary for up-front investments and cannot absorb the risk of failure. They also reasonably fear the multiyear commitments required by project designers, as those commitments reduce opportunities to adjust to changing personal, weather, or market realities.[133]

Because of these obstacles—and above all because the agricultural sector itself must achieve significant emissions reductions in addition to other sectors—agriculture-generated GHG emissions offsets have only a limited and short-term role to play in achieving a sustainable food future.

Figure 36-1 | Farmers' investments in agriculture are much higher than public investments



Note: Data on country-level sources of investment in agriculture vary among low- and middle-income countries. The number of countries covered by these data varies from 36 for foreign direct investment to 76 for on-farm investment in agricultural capital and government investment. See Appendix 1 in Lowder et al. (2012) for more detail on the country-level data included in this chart. Although the data are not comprehensive, they are sufficient to indicate that private on-farm investment far outweighs any other source of investment.
Source: Lowder et al. (2012), Figure 2.

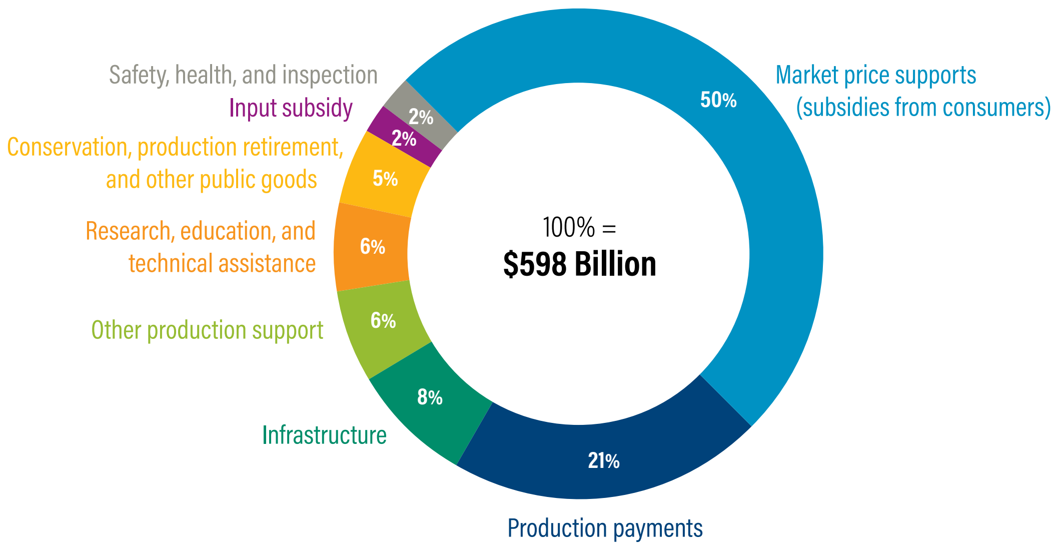
Funding Climate-Smart Agriculture

Agriculture is a major sector of the global economy, so is not surprising that estimates of the investment needed to maintain and improve it, as well as to address climate challenges, involve enormous sums of money. The private sector will likely provide the bulk of these funds. The great majority of those private investors will be farmers, who are primarily investing to replace and improve their own farm equipment, animals, farm roads, and irrigation and drainage systems. FAO estimates the total accumulated investment by farmers around the world at more than $5 trillion.[134] Despite assessing only 76 countries because of limited data, the FAO estimates that private investment per year of nearly $170 billion dwarfs public investments (Figure 36-1).[135]

The dominance of farmers in agricultural investment makes clear that a core role of government is to facilitate and guide their investments by internalizing environmental costs and establishing sound policies regarding tenure, land acquisitions, and cooperation or contracting. For example, in sub-Saharan Africa, much of the agricultural stagnation between 1980 and 2005 is attributed to an annual decline of roughly 0.6 percent of agriculture's capital stock compared to increases in all other regions of 0.7 percent more.[136] This decline was probably due to poor government policies, including policies that sought to tax agriculture to pay for industrialization.[137]

Nonetheless, there is still a need for government financial resources to support necessary infrastructure, research, and assistance to small farmers if they are to escape or avoid poverty traps. Classic poverty traps force farmers to sell off necessary assets in times of hardship or to avoid reasonable investments in productivity improvements because of an inability to cope with almost any level of risk. In the case of mitigating GHG emissions, such assistance to farmers is both advisable and fair. So where should these funds come from?

Figure 36-2 | The world's leading agricultural producers provided nearly $600 billion in public funding to support farms in 2015



Note: OECD assessment of 51 countries excluding India.
Source: Searchinger et al. (2018b), based on analysis of OECD (2016) data.

Redirecting subsidies

Government policies today already provide major financial support to agriculture. According to estimates by the Organisation for Economic Co-operation and Development (OECD), the 51 top countries in total agricultural production (excluding countries in South Asia, which the OECD data do not address) provided nearly $600 billion in farm support in 2015 (Figure 36-2).[138] This figure was equivalent to roughly 19 percent of total global agricultural production.[139] This level of support suggests that it would be difficult to obtain substantially higher levels of support from governments. Yet these funds, as a whole, are doing little to support the kinds of improvements outlined in this report.

Half of this total support takes the form of "market price supports," which are any kind of market barriers that raise prices to consumers. Examples include import limits, tariffs, or systems that limit production by farmers to increase prices. If these barriers benefit some group of farmers in a country, they do so at the expense not only of consumers but also of farmers in other countries. In fact, because these supports are more prevalent in higher-income countries, they offer little market protection for the world's poor overall. From a global perspective, reducing or redirecting the costs of these market interventions would reduce prices and benefit consumers.

The other half of farm support, about $300 billion, flows directly from governments, mostly through direct expenditures or tax credits. About $167 billion takes the form of direct payment to farmers for current or past production. This funding will only spur productivity to the extent that farmers decide to use these funds to boost investment rather than income, so it is an inherently diffuse way of boosting productivity. Another $14 billion is for input subsidies, which have modest benefits and often lead to environmentally damaging results (as discussed in the next section, on fertilizer subsidies). Approximately $46 billion supports infrastructure, including irrigation. These funds have probably boosted production in various ways. Finally, $74 billion is spent on research or technical assistance, conservation payments, or health and safety inspection.

This analysis indicates a real opportunity to redirect farm support toward the needs identified in this report. Redirecting market price supports would be most difficult administratively because these market barriers raise costs to consumers—and so are real costs—but generally do not create a pot of money that governments could transfer to other purposes. Both Europe and the United States, however, have experience in reducing these kinds of market barriers in return for increases in direct government subsidies. Subsidies could then be targeted more at the strategies and approaches necessary to close the food, land, and GHG mitigation gaps and achieve a sustainable food future.

Redirecting the $181 billion per year in direct payments to farmers—$167 billion for production and $14 billion for input subsidies—toward the priorities identified in this report provides the easiest administrative opportunity to achieve these objectives.

In recent decades, governments have been steadily reducing the extent to which their subsidies distort trade, in part because of trade negotiations. The most offensive subsidies from the perspective of trade are subsidies that pay farmers more as they produce more of a particular crop, known as "coupled payments." Researchers have estimated that coupled payments are often environmentally damaging because they encourage overuse of farm chemicals. However, their true impacts on land use and GHG emissions have rarely been estimated and are probably variable and complicated because of their effects on where crops are produced.

In the United States, there has been a major shift from direct price guarantees to "crop insurance." But crop insurance is highly subsidized and insures not merely against losses from bad weather but also against low prices. In effect, it serves as a revenue guarantee that is tied to the amount a farmer produces, and therefore has more similarities to than differences with traditional price guarantee programs.[140]

The United States has also seen modest movement toward imposing some kind of environmental criteria on farming as a condition of payments. Since 1985, farmers have been required to implement plans to reduce soil erosion and avoid draining wetlands, although enforcement has never been strong.[141] There is evidence that these requirements have had some effect although probably a modest one.[142]

Europe has done a little more to shift its agricultural funding toward conservation goals. The bulk of the Common Agricultural Policy's direct payments are now tied to conservation compliance, which involves two types of mandates. The first requires that farmers comply with applicable environmental and food safety laws that are already mandatory, such as an EU-wide directive on nitrogen use. This mandate also requires that farms comply with authorization requirements on irrigation use where they exist. The second mandate requires farmers to comply with Standards of Good Agricultural and Environmental Condition, which are set forth in general language at the European level and which member states are supposed to make more specific. For example, the standards protect against soil erosion, protect soil organic matter, and recommend the protection of important "landscape features" to provide some buffering of streams and hedgerows.

Unfortunately, the requirements are vague at the European level, and often minimally applied by national governments. For example, the United Kingdom protects streams, but it requires maintenance of only a one-meter buffer from the top bank of a stream. Ecologists recommend much larger buffers to effectively filter out pollutants or provide shade. In 15 of the 28 EU countries, the only soil carbon requirement is not to burn crop stubble. Europe also requires that 30 percent of total agricultural funding, or almost 13 billion euros per year, go only to farmers who meet three additional environmental requirements, but these criteria also are very modest.[143]

Probably the most important reform has been to direct roughly one-quarter of total agricultural support to rural development, which includes roughly 19 billion euros per year for conservation.[144] Approximately half was directed toward projects viewed as enhancing ecosystems or climate, and a small number of projects have truly focused on climate mitigation.[145]

China has also substantially changed its agricultural policies in the past few years. It has phased out its direct subsidies for fertilizer, which were as high as $21 billion in 2011.[146] It has also made hundreds of millions of dollars per year available for pilot projects to subsidize more efficient use of fertilizer and for agricultural research focused on environmental objectives.[147] China also devotes roughly $7 billion per year in funding to rehabilitate grasslands and restore forests on poor-quality agricultural land. These funds have done much to reduce soil erosion and have stored some carbon, although the focus on plantation forests, typically of a single species, has meant few gains and possibly even losses in biodiversity.[148] China also boosted agricultural research and development (R&D) spending heavily to roughly $12 billion per year between 2013 and 2016, more than doubling spending from 2006 to 2009. Even so, these funds represent only a modest share of China's total support for agriculture, which averaged $255 billion from 2014 to 2016 and was skewed heavily toward import barriers.

Agricultural subsidies are much lower in Africa and most of Latin America. One reason for Africa's poor agricultural development from 1960 to 2005 was low government investment combined with taxation or export restrictions designed to keep crop prices artificially low.[149] In 2003, the heads of state of most countries in the African Union pledged to increase the share of agriculture in government spending to 10 percent. An analysis by the International Food Policy Research Institute (IFPRI) in 2013 found that eight countries had met the target, and others had increased their spending, but that the overall goal had not yet been met.[150]

Overall, redirecting agricultural support provides a major opportunity for financing some of the needs identified in this report. Of course, all reforms of this kind are politically challenging. Even if agriculture would benefit overall, individual farmers who lose direct financial subsidies or market protections are likely to oppose such reforms. One prerequisite for these reforms will be increasing attention paid to farm programs by individuals and public officials who care most about climate change, biodiversity, and global poverty. These parties have an important stake in structuring farm support programs, though the connection is often not sufficiently recognized. Another opportunity may exist, however, by focusing on the linkages between agricultural productivity gains and climate protection. Even if some individuals would benefit by being allowed to clear more land, most farmers can benefit from programs that increase their productivity. So long as such programs are tied to protection of natural areas, they will contribute to a sustainable food future.

Reforming and redirecting fertilizer subsidies

The benefits and costs of fertilizer subsidies are particularly important questions for decision-makers allocating government spending because they can account for a large percentage of government support to agriculture. Fertilizer subsidies have been particularly large in Asia and in many parts of Africa, where fertilizer subsidies have consumed much of the government funding devoted to agriculture in recent years.[151] What is their proper role in a sustainable food future?

In Asia, the nonpolitical answer seems clear: fertilizer subsidies should be phased out. As Chapter 27 on reducing emissions from fertilizer use showed, farmers in both China and India overuse nitrogenous fertilizer (excess applications have little to no yield effects). Excess applications not only result in farmers spending more money than necessary but also cause high GHG emissions, particularly because much of the fertilizer in China is manufactured using power generated from emissions-intensive coal.[152] Studies have found that fertilizer subsidies contributed to agricultural growth and poverty reduction in the early years of introducing fertilizer but had little impact thereafter.[153] After the early years, fertilizer subsidies have contributed far less to raising agricultural productivity than other types of funding such as agricultural R&D, roadbuilding, irrigation, and education. Reforms in tenure and agricultural market liberalization have also had large effects.[154]

Subsidies encourage overuse of fertilizer. In China, one study estimated that fertilizer subsidies of all kinds—including many provided to manufacturers—reached $18 billion in 2010[155] although, as mentioned in the previous section, China has recently phased out fertilizer subsidies. A wide range of economic research supports the view, predicted by economic theory, that farmers' application rates of fertilizer reflect the ratio of fertilizer prices to crop prices.[156] If subsidies artificially lower the prices farmers pay for fertilizer, then farmers will use more fertilizer. This principle appears to hold true across countries, at least for cereals.[157]

In India, fertilizer subsidies have been especially distorting because they have been applied more heavily to nitrogen than to other nutrients, resulting in an inefficient balance of fertilizer application.[158] Reforms have tried to reduce support for some but not all nitrogen fertilizers, but the initial efforts may have had the opposite effect and led to more imbalanced nutrient application and higher costs.[159] By 2015, subsidy costs had reached $11.6 billion per year, roughly five times higher than 15 years earlier.[160] Although policymakers intend fertilizer subsidies to spur food production and to help small farmers, the evidence is strong that fertilizer subsidies are an economically and environmentally costly way of achieving these goals. There is also widespread evidence in China that average applications of synthetic fertilizers per hectare exceed efficient levels and could be reduced substantially with negligible impact on yields.[161]

In Africa, by contrast, fertilizer use is extremely low—around 9–10 kilograms per hectare on average in 2013, compared with an average of 150 kg/ha in Asia.[162] A World Bank publication in 2007[163] summarized the reasons for such low application rates, which still apply:

- Fertilizer prices are high in Africa compared to the rest of the world, which results in high prices of fertilizer relative to crop prices, a key determinant of how much fertilizer farmers use.[164]
- Exceptionally high year-to-year variation in fertilizer production and prices makes annual investments in fertilizer by African farmers risky compared to investments by farmers in other regions.
- The physical responses of crops to fertilizer are relatively poor, due in part to rainfall variability and in part to poor soil quality.[165]
- A variety of market imperfections, including poor access to credit for small farmers, make all agricultural investments challenging.

In efforts to overcome the market challenges, fertilizer subsidies in Africa were widely implemented from the 1960s through the 1980s. After that time, most countries phased them out or greatly reduced them in response to large balance of payments deficits and absence of foreign exchange reserves. Strong concerns expressed by the International Monetary Fund, the World Bank, and other international donors also played a significant role. These financial institutions worried about the cost of subsidies to governments, the challenges of targeting subsidies only to those who most needed them, and adverse effects on the development of private-sector fertilizer systems.[166]

However, the experience of Malawi helped change perceptions of what could be achieved by fertilizer subsidies.[167] Between the 1970s and the 1990s, Malawi went from producing a large food surplus to a large deficit. Three-quarters of the country's rural households experienced food shortages four to five months of the year and, in 2001–2 and 2004–5, Malawi faced severe hunger, exacerbated by an influx of refugees from civil war in Mozambique. In 2005, the country announced a subsidy program to provide 26 kg of fertilizer and 5 kg of improved seed to 2.5 million farmers. The program that year contributed to a 15–22 percent increase in maize production, restoring the national production surplus. Maize yields continued to grow in the next several years, and the program received considerable public attention.[168]

This apparent success in Malawi encouraged other African countries to reinstitute extensive subsidy programs.[169] As of 2013, subsidies supported roughly 40 percent of fertilizer use in sub-Saharan Africa.[170]

Faced with the Malawi example, international institutions and aid agencies to some extent modified their views, but they recommended that governments direct their efforts toward "smart" subsidies:[171]

- Subsidies should be structured to avoid displacing existing commercial sales, which means they should be tailored to support farmers who would not otherwise use fertilizer.
- Subsidies should encourage development of private markets, for example, by the use of coupons that can be used to purchase fertilizer from any supplier, rather than through government distribution channels.
- Subsidies should be temporary.

Nonetheless, economists have done much analysis of fertilizer subsidy programs and have expressed a high level of skepticism about their merits based on several considerations:

- Due to the difficulty of targeting fertilizer subsidies only to farmers who would not otherwise use fertilizers, several studies have found that farmers use much of the money not to increase fertilizer use but to purchase fertilizer they would have bought anyway. One reason is that even programs based on vouchers distributed to the poor may result in poor farmers selling the vouchers to better-off farmers.[172]

- One study showed that the quantities of fertilizer imported by the government to be sold in subsidized form was much larger than the quantity ultimately purchased by farmers in subsidized form, indicating that one-quarter to one-half of subsidized fertilizer was actually diverted to intermediaries before being sold to farmers.[173]

- Due to political favoritism, corruption, or simply the difficulty of truly targeting programs, many of the funds have supported wealthier farmers and have not been targeted at those who are most vulnerable.[174] In Zambia, one study found that the 73 percent of farms cultivating less than 2 ha, with 78 percent of those smallholders in poverty, received only 45 percent of the subsidies. Farms of 10–20 ha were significantly more likely to receive fertilizer subsidies.[175]

At least some of the fertilizer subsidy programs have not worked to encourage the emergence of private fertilizer distributors and retailers and therefore have had negative impacts on the development of the private sector and competition.[176]

Moreover, more recent studies of Malawi's experience have started to shed some doubt on initial claims that the subsidy program boosted production. Some researchers have pointed out that official estimated growth in maize yields in Malawi appeared inconsistent with farm-level studies and other data, and there was little evidence of declines either in rural poverty or in maize prices after the new subsidy program, both of which should have declined if production had increased.[177] Weather also played a large role. Maize yields that reached roughly 2 tons per hectare per year from 2007 to 2009 fell back to roughly 1.5 tons in 2010–12 even with continuation of the subsidy program. At least one study, however, has found small positive effects on agricultural wages.[178]

Ultimately, the biggest issue remains cost. In 2011, 10 African countries spent $1.05 billion on input subsidies, mostly fertilizer, which represented 29 percent of their collective public expenditures on agriculture.[179] In 2004–5, Zambia devoted one-third of its entire public budget to fertilizer subsidies.[180] In Malawi, the cost reached 60 percent of the entire national budget in a peak year. As FAO noted, fertilizer subsidies "are too costly and, as such, unsustainable in the long-term."[181]

Recommendations

A key question is what alternative policies exist for judiciously boosting fertilizer use. One set of options involves efforts to make fertilizer less expensive because evidence shows that farmers in Africa, as elsewhere, respond to lower fertilizer prices.[182] Reasons for high fertilizer costs identified by the World Bank include the small market (which inhibits economies of scale), lack of access to credit by importers, high transportation and handling costs, excessive differentiation of fertilizer products, and poor dealer networks.[183] Policies to boost fertilizer use could address these challenges through several measures:

Encourage private fertilizer markets

Public policies have often contributed to the high cost of fertilizer through measures that restrict or tax fertilizer imports, limit credit, or use government agencies to control fertilizer sales, all of which tend to lead to high prices.[184] A first set of advisable measures is therefore to eliminate these barriers and encourage private fertilizer markets. Kenya successfully boosted fertilizer use largely by avoiding government competition and eliminating import and price controls. Between 1993 and 2007 fertilizer use doubled, despite the elimination of subsidies.[185] Between 2002 and 2009, fertilizer use in Kenya averaged almost 30 kg per hectare,[186] fertilizer applied to maize rose from 84 kg/ha to 111 kg/ha, and maize yields increased by 18 percent. In the more productive areas of western Kenya, fertilizer use now rivals that of Asia and Latin America.[187]

Reduce transportation costs

High transport costs appear to be the single most important factor explaining high fertilizer prices in much of Africa.[188] High costs start with inefficient ports and then quickly rise with distance from port. Kenya's port of Mombasa is the primary port in Eastern Africa, and fertilizer is roughly 20 percent less expensive in Mombasa than in western Kenya and roughly half the price it is in Malawi.[189] Road improvements are therefore valuable.[190] Although roads are also expensive, the International Fertilizer Development Center has argued that substantial fertilizer price reductions could be achieved in parts of Africa by changing port management systems, arranging two-way truck transport, and incorporating some feasible improvements in rail management.[191] Major improvements in road infrastructure in Ethiopia from 1997 to 2011 appear to have played a substantial role in increasing fertilizer use and boosting yields.[192]

Increase the yield benefits of adding more fertilizer

A third set of measures increases the yield effects of adding more fertilizer. Researchers have demonstrated that farmers' decisions to use little fertilizer are often rational in light of the low crop response. For example, in good farmland in western Kenya, the response of maize to fertilizer is high, and farmers use high levels of fertilizer.[193] But in other parts of Kenya and most of sub-Saharan Africa, crop responses are low, and thus farmers use little fertilizer.[194] As one study emphasizes, "The evidence from agronomic and soil science disciplines indicates that increasingly continuous cultivation, associated soil degradation, low soil organic matter, and soil acidity problems will lock a growing proportion of African farmers into low crop response rates to fertilizer use."[195]

Unfortunately, as we discuss in Chapter 13 on soil and water management, no one has developed a silver bullet for improving soil fertility or otherwise facilitating the use of fertilizer. Options include everything from agroforestry and other measures to improve levels of soil carbon (organic matter), to improved credit access, crop breeding, irrigation, and pest control.[196] Many African governments have developed agricultural investment lists in reports prepared with the African Union as part of the Comprehensive Africa Agriculture Development Programme. But there is no simple, proven list of alternative investments.

In this context, fertilizer subsidies will remain attractive to governments. Even when misused, funds do go directly to large numbers of farmers. In Kenya, despite its success in increasing fertilizer use without the use of subsidies, the government reinstituted subsidies in 2008–9 in response to rising global fertilizer prices at the time and political upheaval following contested election results. These subsidies have continued.[197] Although the research arguments against fertilizer subsidies are strong overall, the case against fertilizer subsidies rests on proof that funds can be better spent elsewhere. Researchers could strengthen their case by costing out specific, alternative agricultural investment strategies and likely results.

Earning Dedicated Climate Funding

At the international climate conference in Copenhagen in 2009, developed countries pledged to provide $100 billion per year in assistance to developing countries, both to adapt to climate change and to mitigate GHG emissions. This funding has been slow to materialize, and the economic downturn in much of the developed world that started in 2008 did not help. To date, developed countries are not on track to meet their goal.[198] But they have begun to raise their funding commitments, some of which they will distribute directly and some of which will pass through the Green Climate Fund (GCF). As of September 2017, the latter had received funding of roughly $10 billion in total for all climate-related work, not merely agriculture.[199] The GCF has adopted policies to allocate roughly half to adaptation and half to mitigation.

Before countries or the GCF distribute large sums of money for mitigation, they demand clear plans showing how funds will be spent and estimates of what will be achieved. Agriculture will probably find itself at a disadvantage compared to other sectors. It is much easier to estimate the GHG emissions savings from a project to replace a coal-fired power plant with a wind power system than it is to estimate the savings from efforts to improve the livestock sector. And it is easier to guarantee construction of the wind farm than to guarantee those livestock improvements. Focusing on energy alone, however, ignores the largest source of emissions for many developing countries.[200]

The best way for agriculture to claim a reasonable share of climate funding for mitigation will be to generate highly specific mitigation plans that are persuasive, detailed enough to guide implementation, and measurable enough to be monitored. Throughout this report, we have highlighted ways to meet these criteria when addressing particular sources of emissions.


Fireboy

CHAPTER 37

STRENGTHENING RESEARCH AND DEVELOPMENT

This report has consistently emphasized the need for additional research to overcome the many obstacles to achieving a sustainable food future. It has also stressed adequate funding to pursue research into the most promising leads. Meeting these needs will require increasing the quantity of funding well beyond what is currently available, putting more effort into the direct application of research, and pursuing critical technological breakthroughs.

Funding for Research and Development in General

The period since 2001 has witnessed some modest growth in agricultural R&D funding. Global public research spending grew from $26.1 billion in 2001 to $31.7 billion in 2008,[201] the last year for which we can obtain truly comprehensive information. Spending on public and nonprofit R&D grew modestly in 30 of 39 countries in sub-Saharan Africa for which data are available. The increase between 2001 and 2014 was roughly 30 percent (from about $800 million to $1.06 million).[202] However, growth has been uneven and spending in many food-insecure regions remains inadequate. Roughly half of the total agricultural R&D growth from 2001 to 2008 occurred in China and India.

Private sector research has also experienced growth. Total private food sector R&D reached $20 billion globally in 2010,[203]and in the United States and Europe the private sector has taken over the incremental improvement and production of many seeds. But globally, only $3.7 billion of these private R&D funds were directed at crop breeding.[204] Abundant evidence indicates that agricultural R&D generally pays off, with estimates commonly in the range of annual returns of 40 percent.[205] China and Brazil, recent global leaders in agricultural R&D, saw their agricultural productivity between 1979 and 2009 increase by 136 percent and 176 percent, respectively.[206]

With agricultural research underfunded in general, and agricultural research related to climate mitigation barely funded at all, the world is unlikely to solve the challenge of achieving a sustainable food future without a large increase in R&D. Viewed more optimistically, the current low levels of research suggest that new investment has a good potential to produce high returns.

A reasonable initial goal would be to raise agricultural R&D in low- and middle-income countries from the current 0.5 percent to 1.0 percent of their agricultural output production value. This would involve an increase of roughly $15 billion per year. The burden of this growth should be shared by high-income countries. The growth should occur in ways designed to guarantee continuity, development of infrastructure, and advancement of partnerships that allow low- and middle-income countries to benefit from newer breeding methods.

Funding the "D" in R&D

Many strategies for boosting agricultural production while reducing GHG emissions require detailed technical assessments of farm practices, land-use characteristics, and infrastructure in a given area. These assessments must be continually updated and improved over time. Such analyses involve science and engineering, not basic research, and are therefore analogous to the "development" portion of "research and development." At this time, however, no entities appear responsible for these assessments, nor are governments funding them at the level of detail required.

For example, our assessment of flooded rice farming (in Chapter 28) found that various strategies for reducing or interrupting the periods of flooding could dramatically reduce emissions, reduce on-farm water use, and potentially boost yields—at least modestly—for most farms. Yet rice farmers cannot practically implement improved management practices unless they can control their water enough to drain and fill fields when needed. The capacity of farmers to do so varies by irrigation district and farming system. Mitigating GHG emissions from rice therefore requires reasonably detailed engineering assessments, irrigation district by irrigation district. Yet to our knowledge no entity is responsible or funded for this task.

Similarly, as we described in Chapter 11 on sustainable intensification of livestock farming, several global studies have shown that beef and dairy systems around the world can greatly reduce their GHG emissions through more efficient feeding and grazing practices, reduced mortality, and improved fertility of pastureland. Yet actually encouraging these changes at the local level requires detailed understanding of the type and location of beef and dairy operations, how feeds are used, how feeds are produced, how cows are managed, and the economic and technical options for improvements. This information can form the basis for changes in infrastructure and new financial incentives to encourage improvements, but such innovations must be tailored to the locale and farm type.

These are just two examples of the type of detailed planning efforts that must occur to take advantage of technical opportunities to boost production and reduce emissions. Reducing land-use change emissions, improving the efficiency of fertilizer uptake by crops, and improving the water- and land-use efficiency of aquaculture all require these kinds of detailed assessments to animate coordinated efforts. And, as planning moves forward, specific needs for new technologies are likely to become clear—such as a lack of knowledge of soils in a particular location or the lack of an appropriate grass or legume variety necessary to implement a promising grazing system. When a company develops a new product, a university develops a new educational initiative, or a health service addresses a particular public health challenge, they require coordinated planning efforts, technical assessments, and specific studies to address revealed information gaps. Mitigating agricultural emissions while boosting production will require the same type of coordinated effort.

Technical planning efforts may focus on a whole country or on a portion of a country. Based on our assessment of what is needed for detailed decisions on spending and other policies, technical plans should share the following characteristics:

- Start with detailed assessments of representative farm types sufficient to assess farm performance and opportunities.
- Include information about farms and land use that is both disaggregated to the local level and aggregated to the provincial and national levels.
- Assess land use and recent patterns of land-use changes using more detailed and reliable methods that can typically be undertaken at global levels.[207]
- Estimate GHG emissions using methods that are detailed enough to assess how they would change under promising changes in management.
- Include mechanisms for assessing the economics of these management changes, including benefits and costs to farmers and other actors.
- Organize information in easily accessible and understandable formats that allow analysis of improvement scenarios.
- Host online systems that incorporate changing and improved information.
- Integrate work of national and global researchers.

As international development institutions move to support climate-smart agriculture, the lack of funding for this kind of technical planning presents a major obstacle. For example, countries typically use World Bank agricultural loans exclusively for direct agricultural investments and aid. Countries must themselves cover the costs of administering the loans and any technical planning efforts. The World Bank and other funding institutions should develop systems to ensure that at least a small percentage of agricultural project costs support the planning and analytical work necessary to make agricultural plans truly climate-smart. Such systems could include dedicated grant funds or project/loan requirements to apportion, for example, 2–3 percent of funding for this kind of work.

Funding Needed for Breakthrough Technologies

The steady, incremental growth of crop and livestock yields, and recent improvements in input efficiency in developed countries, reflect the continuous development by researchers of a wide range of new seeds, new breeds, and new management techniques. As discussed previously, we assume continued incremental improvement in our 2050 baseline projections. We also call attention to many breeding opportunities to reduce environmental impacts.

In order to achieve a sustainable food future, the world's food system will need to develop and deploy a number of breakthrough technologies as well. Table 37-1 summarizes some of the innovations identified in this report.

These research efforts require dedicated and coordinated funding, directed with intelligence, just as funding institutions support multiyear efforts to cure specific diseases or to develop new energy technologies. Private sector research should be adequate in some areas; developing improved meat substitutes from plant-based ingredients is one such example. But the private sector is unlikely to devote serious funding to most of the items in Table 37-1 and will likely ignore them unless GHG emissions regulations, taxes, or strong financial incentives are in place to assure a market for innovative new products or techniques.

Additional, coordinated funding is therefore needed. In 2009, several governments agreed to form the Global Research Alliance for Agricultural Greenhouse Gas Mitigation precisely because of this need. New Zealand hosted the first meeting and provided much of the motivation, reflecting its commitment to reduce its emissions under the Kyoto Protocol and the fact that almost half of the country's GHG emissions come from agriculture. By 2017, 46 countries had joined, and the alliance now comprises a series of scientific working groups. Although on the right track, the alliance has limited resources. In the absence of additional resources, only limited coordination and development is possible. Another challenge is that in many countries, agricultural agencies are the primary agricultural researchers. Notwithstanding the strong motivations of the individuals involved, these agencies were historically established to promote agricultural production. It will take real effort to expand their missions to include GHG emissions mitigation.

The alliance provides a structure for international coordination but requires additional funds to effectively support the development and deployment of the kinds of breakthrough technologies listed in Table 37-1. In addition, research agencies with a broader mandate than agricultural research should become involved along with climate-focused institutions such as the Green Climate Fund, the World Bank, and international development agencies. International efforts should adopt good research grant-making procedures, such as professional administration and panels of outside scientists to review and rank proposals.

Table 37-1 | **Critical research needs for breakthrough technologies**

SELECTED MENU ITEM	RESEARCH NEED	COMMENT
DEMAND-SIDE SOLUTIONS		
Course 1: Reduce growth in demand for food and other agricultural products		
Reduce food loss and waste	Development of inexpensive methods to prevent decomposition without refrigeration	Companies are investigating a variety of compounds, such as spray-on films that inhibit bacterial growth and hold water in.
Shift to healthier and more sustainable diets	Development of inexpensive, plant-based products that mimic the taste, texture, and experience of consuming beef or milk	The private sector is making significant investments in various plant-based substitutes including imitation beef containing heme, which appears to bleed like real meat.

Table 37-1 | **Critical research needs for breakthrough technologies (continued)**

SELECTED MENU ITEM	RESEARCH NEED	COMMENT
SUPPLY-SIDE SOLUTIONS		
Course 2: Increase food production without expanding agricultural land		
Increase livestock and pasture productivity	Breeding of better, high-yielding forage grasses that can grow in "niche" production areas	In much of Africa and Asia, with limited land available, quality forage for cattle depends on producing high-quality grasses and legumes in restricted land areas, such as underneath forest or banana plantations.
Improve crop breeding to boost yields	Breeding of cereals to withstand higher peak temperatures	Recent research has shown that high peak temperatures, particularly at critical growth periods, can greatly restrict cereal yields, and that climate change may push temperatures to exceed peak thresholds.
Course 4: Increase fish supply		
Improve productivity and environmental performance of aquaculture	Development of fish oil substitutes from microalgae, macroalgae (seaweeds), or oil seeds for aquaculture feeds	Research groups have developed initial breeds of rapeseed containing oils nutritionally equivalent to fish oils and promising seaweed varieties. Work is also proceeding on more economical production of algae.
Course 5: Reduce GHG emissions from agricultural production		
Reduce enteric fermentation through new technologies	Finding feed compounds, drugs, or breeds that lower methane emissions from cows, sheep, and goats	Several research groups are working on feed compounds to reduce methane emissions. After years without promising results, a private company has claimed 30 percent emissions reductions from a cheap compound that does not appear to have significant impacts on animal health or environmental side effects.
Reduce emissions through improved manure management	Development of lower-cost ways to dry and consolidate manure, stabilize nutrients to reduce methane and nitrous oxide emissions, and make them easier to use efficiently with crops	Technologies exist to dry manure and turn it into energy, but costs and leakage rates reduce viability and GHG emissions reduction benefits.
Reduce emissions from manure left on pasture	Breeding of traits into pasture grasses to inhibit formation of nitrous oxide or developing safe, ingestible nitrification inhibitors for livestock	Researchers have discovered one variety of Brachiaria that significantly inhibits nitrification and thus nitrous oxide formation.
Reduce emissions from fertilizers by increasing nitrogen use efficiency	Development of more effective, lower-cost, and integrated compounds such as improved nitrification inhibitors to reduce nitrogen losses associated with fertilizer use and breeding nitrification inhibition into crops	Various compounds exist and appear to be effective but improvements should be possible, including more tailored understanding of which compounds are most effective under precisely which conditions. Researchers have now identified traits to inhibit nitrification biologically in some varieties of all major grain crops that can be built upon through breeding.
Adopt emissions-reducing rice management and varieties	Development of rice varieties that emit less methane	Researchers have shown that some common rice varieties emit less methane than others and have bred one experimental rice variety that reduces methane emissions by 30 percent under scientifically controlled conditions, although its effects on yields are unknown.

Note: This table is not intended to be exhaustive and does not include all courses or menu items.
Source: Authors.

ENDNOTES

1. World Bank (2008).
2. Collier (2008).
3. Farms of more than 500 ha, including pasture, controlled 63% of Brazilian farmland in 2013 but accounted for only 1% by number of Brazilian farms. Farms of more than 500 ha of crop-land only accounted for 2% of all farms but generated 50% of production (de Souza Ferreira Filho and de Freitas Vian 2016).
4. Hazell et al. (2007).
5. Collier (2008).
6. World Bank (2008), 91, Figure 3.7.
7. Ser Huay Lee et al. (2014).
8. Lowder et al. (2016).
9. Chand et al. (2011).
10. Chand et al. (2011).
11. SAIN (2011).
12. Fan et al. (2008).
13. Deininger et al. (2011); Ali and Deininger (2014); Larson et al. (2014).
14. Holden and Otsuka (2014).
15. Hazell (2007).
16. Jayne et al. (2016).
17. Place (2009).
18. Chand et al. (2011); Jayne et al. (2016a).
19. Chand et al. (2011).
20. Lowder et al. (2016).
21. Lowder et al. (2016).
22. HLPE (2013).
23. World Bank (2008); Lowder et al. (2016), Table 3.
24. World Bank (2008); Lowder et al. (2016).
25. Jayne et al. (2016a).
26. Ji et al. (2016).
27. Hazell et al. (2007).
28. Hazell (2011).
29. Hazell et al. (2007); Poulton et al. (2010).
30. Harris and Orr (2014).
31. Waithaka et al. (2006).
32. Frelat et al. (2015).
33. Wiggins (2009).
34. World Bank (2008); Holden and Otsuka (2014).
35. World Bank (2008).
36. Borger (2008).
37. The International Institute for Environment and Development has done a large series of investigations and papers on land acquisitions, many of which can be found at http://www.iied.org/understanding-growing-pressures-land-land-grabbing-beyond.
38. Deininger et al. (2011).
39. Rulia et al. (2013), Table 1.
40. GRAIN (2016). GRAIN focused on an important subset of land deals that were initiated after 2006, have not been canceled, are led by foreign investors, are for the production of food crops, and involve large (> 500 ha) areas of land.
41. Information on acquisitions is being acquired by Land Matrix, a cooperative venture of many respected institutions. Members include the International Land Coalition, CIRAD, the Centre for Development and Environment of the University of BERN, GIGA, and GIZ.
42. Land Matrix database, accessed July 2016. This chart shows completed land acquisitions for agriculture. To meet criteria, deals involve land use for any purpose that must "entail a transfer of rights to use, control or ownership of land through sale, lease or concession; have been initiated since the year 2000; cover an area of 200 ha or more; imply the potential conversion of land from smallholder production, local community use or important ecosystem service provision to commercial use." See more at http://www.landmatrix.org/en/about/.
43. As one study explains, estimates vary substantially by research group, which may in part reflect the sources of information and kinds of transactions being counted, which may range from announcements in the press, to applications, to memoranda of agreements, to completed leases (Cotula et al. 2014).
44. Brautigam (2015).

45. According to the most recent figures in Land Matrix, Chinese interests acquired 437,000 ha in Africa. Land Matrix Online DataBase, accessed July 14, 2016.

46. Cotula et al. (2014).

47. Schönweger et al. (2012).

48. Many examples are described in Brautigam (2015); and Pearce (2012).

49. Pearce (2012); Cotula et al. (2014).

50. Cotula et al. (2014).

51. Cotula et al. (2014).

52. Farmland held by large-scale domestic owners is underreported, and anecdotal evidence suggests that national elites and the urban middle class are involved in land acquisitions in several African countries. See, for example, Cotula et al. (2009); Jayne et al. (2016a); Blas and Wallis (2009); and Koussoubé (2013).

53. The 17.3 million ha included 500 deals.

54. German et al. (2011).

55. Rosenbarger et al. (2013).

56. German et al. (2011).

57. Cotula et al. (2014); Pearce (2012).

58. Notess et al. (2018).

59. German et al. (2011); Cotula et al. (2014); Feed the Future (n.d.).

60. Land Matrix database, accessed July 2016.

61. Pearce (2012).

62. An image of land deals around the world is provided by Pearce (2012). For Indonesia, see Obidzinski et al. (2012). For Africa, see Cotula et al. (2014); and German et al. (2011). For Cambodia, see Colchester and Chao (2011).

63. Cotula et al. (2014).

64. Examples include descriptions of land acquisitions in Ethiopia in German et al. (2011).

65. For example, in the Gambella region of Ethiopia, where Saudi and Indian companies have cleared and drained thousands of hectares in part to grow food crops such as rice, maize, and sorghum, the goal of exporting down the Nile appears to have been important (Pearce 2012), 7.

66. German et al. (2010a); German et al. (2011).

67. Schönweger et al. (2012).

68. Schönweger et al. (2012).

69. Veit and Sarsfield (2017); Pearce (2012).

70. Pearce (2012), 55–63.

71. Neville (2015); McVeigh (2011).

72. German et al. (2010b).

73. German et al. (2011).

74. Global databases on land deals do not provide comprehensive summary statistics on existing land use, land cover, and land tenure. Where data are available, they do not clearly and consistently differentiate between cropland and less intensively used land. For example, a Land Matrix newsletter summarized data for September 2015 that covered 38.9 Mha, of which 26.3 Mha had no information on existing land use. Land use was known for deals covering 12.6 Mha, of which 4.2 Mha were former commercial (large-scale) agriculture, about 3.9 Mha were smallholder agriculture, 3.6 Mha were forestry, 0.6 Mha were for pastoralists, and 0.3 Mha were for conservation. Land cover data for these deals indicated 6.4 Mha of forest, 4.5 Mha of cropland, 2.6 Mha of shrubland/grassland, and 1.8 Mha of marginal land. Land cover data were not available for 23.5 Mha.

75. German et al. (2011).

76. Koh and Wilcove (2008).

77. Thomson Reuters Foundation (2017); Hemphill (2017).

78. Deininger et al. (2010); German et al. (2011a); Cotula (2011).

79. Schoneveld et al. (2010).

80. German et al. (2011).

81. German et al. (2010b).

82. German et al. (2010b).

83. Andriani et al. (2011).

84. Larsen et al. (2015). This short paper cites to the underlying studies.

85. Larsen et al. (2015).

86. Larsen et al. (2015); German et al. (2010a).

87. Butler (2009); Budidarsono (2012), 6.

88. There is no good dataset for the compensation typically provided to communities, but extensive contacts between WRI staff and local communities over the years indicate that payments do not approach these estimated oil palm values.

89. German et al. (2011).

90. German et al. (2011); FAO (2010a); FAO (2010b).

91. For further discussion on this report's criteria for a sustainable food future, see the first section of this report, "Scope of the Challenge and Menu of Potential Solutions."

92. Bellemare (2015).

93. For Africa, for example, see Kherallah et al. (2002).

94. As Key and Runsten (1999) noted, "Contract farming has also been critiqued as being a tool for agroindustrial firms to exploit an unequal power relationship with growers. While farmers usually enter into contracts voluntarily, they may, over time, invest fixed resources into production or alter their cropping patterns so as to become overly dependent on their contract crops. When this is the case, growers face limited exit options and reduced bargaining power vis-a-vis the firm and forced to accept less favorable terms."

95. This is a consistent finding of studies and summarized in Ton et al. (2018) among other meta-analyses.

96. Ton et al. (2018).

97. Ton et al. (2018). Minot and Sawyer (2016) found that contract-farming in developing countries improves farm productivity and incomes, with income effects mainly in the range of 25 to 75%. Otsuka et al. (2016) and Wang et al. (2014) also found income and productivity gains in meta-analyses of contract farming in both developed and developing countries. Bellemare and Novak (2017) found benefits for contract farming from six regions in Madagascar. For examples of the variety of experiences even in limited regions, Narayanan (2014) found high variability in the income effects of contract farming in Southern India although average benefits overall.

98. Bellemare (2015).

99. Maertens and Vande Velde (2017) found that benefits from an aid agency promoted effort to support contract farming in Benin. Ragasa and Kufoalor (2018), however, found that donor-supported efforts to promote agricultural intensification of maize in Ghana resulted in higher costs to farmers that were not fully justified by higher prices and production.

100. Minot and Sawyer (2016).

101. For papers on the effects of the Bolsa Família program, see Soares et al. (2006); Vaitsman and Paes-Sousa (2007); and Fernald et al. (2008).

102. For example, Todd et al. (2009) found that cash transfers enable small farmers to increase the diet diversity and nutritional quality of what they grew for themselves.

103. World Bank (2008).

104. World Bank (2008); Place (2009).

105. For China, see Jacoby et al. (2002). For Eastern Europe, see Rozelle and Swinnen (2004). For Latin America, see Deininger and Chamorro (2004); and Fort (2007). For Thailand, see Feder et al. (1988).

106. Place (2011).

107. See the discussion of Tanzania in Notess et al. (2018), 23, Box 3.

108. Peters (2009).

109. Lawry et al. (2014).

110. German et al. (2011).

111. Adedipe et al. (1997); Adekanye et al. (2009).

112. Byamugisha (2013), 1.

113. Veit (2011).

114. Place (2011), paraphrasing Van den Brink (2005).

115. Byamugisha (2013), 8.

116. Deininger et al. (2011); Bezabih and Holden (2010).

117. Marfo et al. (2012).

118. Nolte et al. (2013).

119. Ding et al. (2016).

120. For more on how carbon pricing works, see Kennedy et al. (2015).

121. IPCC (2003); INPE (2009).

122. Tollefson (2016).

123. New Zealand Government (2013).

124. New Zealand Government (2013).

125. A basic description of New Zealand's emission trading system is available at the website of Te Uru Radau at https://www.mpi.govt.nz/growing-and-harvesting/forestry/forestry-in-the-emissions-trading-scheme/ (last accessed August 15, 2018).

126. Examples include Koper (2014); and Parkhurt (2015).

127. De Pinto et al. (2010).

128. The CDM allows European companies responsible for cutting their emissions to obtain credit as an alternative for paying for actions in developing countries that cut their emissions. Only a few potential agricultural practices have qualified under CDM methodologies, mostly including managing of manure or wastes, or planting trees on agricultural land. As of 2011, one study found that agriculture or other land-use projects were expected to generate less than 1% of total CDM projects. Larson et al. (2012).

129. The Alberta system allows offset credits for changes in cropping systems, three ways of increasing feeding efficiencies, various efforts to reduce nitrous oxide, improvements in dairy cow efficiency, and capture of biogas from manure. Stockholm Environment Institute and Greenhouse Gas Management Institute (2011).

130. Vasa and Neuhoff (2011).

131. Haya (2009).

132. Searchinger, Edwards, Mulligan et al. (2015) showed that government models estimating greenhouse gas emissions reductions for grain-based biofuels are estimating large reductions in food consumption, which are the source of the greenhouse gas benefits through reduced breathing out and generation of wastes of carbon by people and livestock.

133. De Pinto et al. (2010).

134. FAO (2012c). This figure is an estimate of the total value of agricultural capital stock.

135. Lowder et al. (2012), Figure 2.

136. FAO (2012c), Figure 8.

137. World Bank (2008).

138. Analysis by the authors from OECD database on agricultural price support. OECD (2016).

139. According to the World Bank, total agricultural value added in 2015 was $3.175 trillion (World Bank 2017e).

140. Smith et al. (2017).

141. GAO (2003).

142. Claassen et al. (2004) estimated that the wetland programs had probably reduced wetland drainage based on the continued status as wetlands of several million acres that the study estimated were profitable to convert. Since that date, there have been no comparable studies offering estimates. USDA/ERS (2017b) also estimated that the erosion control provisions had achieved some reduction of water erosion, and possibly of wind erosion as well.

143. Hart et al. (2017). Farmers are required to follow crop diversification, but that only means they must grow two or three separate crops somewhere on their land. They are required also to devote 5% to ecological focus areas, but that can include any kind of cover crop grown on 5% of their land. Finally, national governments must protect 95% of existing grasslands, which may not result in any restrictions on individual farms.

144. Based on data from the OECD, the combination of funding from the European Union and member states for individual farm payments was roughly 61 billion euros per year in 2014–16, and the two combined provided 19 billion euros for rural development. See Searchinger et al. (2018b).

145. Searchinger et al. (2018b); Hart et al. (2017); Jongeneel et al. (2016); European Network for Rural Development (2017).

146. Huang et al. (2017).

147. Email communication with Jikun Huang, March 2017.

148. Hua et al. (2016) found that plantation forests reestablished in one province actually had less biodiversity value than the forests they replaced. For papers estimating soil carbon gains from the reforestation programs, see Persson et al. (2013); and Song et al. (2014). Anna et al. (2017) found that grassland rehabilitation programs had not consistently sequestered carbon.

149. World Bank (2008).

150. IFPRI (2013).

151. Gulati and Narayanan (2003); Gale (2013).

152. Li et al. (2014).

153. Fan et al. (2007); Morris et al. (2007).

154. Fan et al. (2008); Gulati and Narayanan (2003); Gale (2013).

155. Li et al. (2014).

156. See papers discussed in Jayne and Rashid (2013) finding that African farmers tend to apply fertilizer at rational rates given prices. For China, see Zhou et al. (2010).

157. Zhang et al. (2015b).

158. Gulati and Banerjee (2015).

159. GKTODAY (2012); Himanshu (2015).

160. Gulati and Banerjee (2015).

161. Qiu (2009).

162. See also AGRA (2013).

163. Morris et al. (2007).

164. World Bank (2008), Figure 6.2.

165. Morris et al. (2007) lists this as only one factor, but researchers since have given it an even heavier emphasis.

166. An excellent summary of experience with African fertilizer programs is set forth in Morris et al. (2007). See also Druilhe and Barreiro-Hurlé (2012); and Jayne and Rashid (2013).

167. Future Agricultures Consortium (2008).

168. Jayne and Rashid (2013).

169. Wanzala-Mlobela et al. (2013). Also see Morris et al. (2007).

170. Wanzala and Groot (2013); Lunduka et al. (2013).

171. World Bank (2008), 152.

172. Holden and Lunduka (2012).

173. Jayne and Rashid (2013).

174. A large number of studies are summarized in Jayne and Rashid (2013).

175. Jayne and Rashid (2013).

176. Druilhe and Barreiro-Hurlé (2012).

177. Pauw and Thurlow (2014).

178. Jayne and Rashid (2013).

179. Jayne and Rashid (2013).

180. World Bank (2008).

181. Druilhe and Barreiro-Hurlé (2012).

182. Ariga and Jayne (2011).

183. Morris et al. (2007).

184. Morris et al. (2007).

185. Ariga and Jayne (2011).

186. Druilhe and Barreiro-Hurlé (2012), Figure 1.

187. Ariga and Jayne (2011).

188. Morris et al. (2007), Table 4.7.

189. Druilhe and Barreiro-Hurlé (2012).

190. Kiprono and Matsumoto (2014).

191. IFDC (2013).

192. Bachewe et al. (2015).

193. Morris et al. (2007).

194. One summary of the whole region found a yield of 8 to 24 kg of maize for each kilogram of nitrogen. This estimate means that even if there were a linear relationship and yields responses were toward the high end of the response to nitrogen, an addition of 50 kg of nitrogen on a hectare would only raise yields by 1 ton. Those yield gains would be meaningful but far less than the response to nitrogen use in developed countries. In addition, in Malawi, the poorest households tend to obtain the lowest response, presumably because they have the poorest-quality land. See Ricker-Gilbert and Jayne (2012).

195. Jayne and Rashid (2013). For additional discussion of fertility problems, see Marenya and Barrett (2009a); Marenya and Barrett (2009b); and Giller and Tittonell (2013).

196. When economists analyze farmer willingness to apply fertilizer, they typically assume high discount rates, which means that farmers must anticipate high returns on investment to take the risk of purchasing fertilizer. See, for example, Druilhe and Barreiro-Hurlé (2012). Reducing the riskiness to farmers of these investments by reducing the consequences of crop failure should therefore increase farmer investments in fertilizer. See the discussion of risk and fertilizer use in Morris et al. (2007).

197. Andae (2015).

198. Roberts and Welkmans (2016).

199. Green Climate Fund (2017).

200. WRI (2016).

201. Beintema (2012). The most recent year that we found with available global figures is 2008.

202. This analysis is based on data provided by the Agricultural Science and Technology Indicators downloaded from the IFPRI website in March 2019. This analysis assumed $1 million of spending in Eritrea in 2011, the last year reported, continued in 2014. The omitted additional countries, which lacked reported data from 2001, contributed roughly an additional $90 million of spending in 2014, although the data do not allow assessment of how that changed from 2001.

203. Fuglie et al. (2011).

204. Fuglie et al. (2011), Table 1.1.

205. Alston et al. (2000).

206. Fuglie (2012).

207. The best way to assess land use change is to combine satellite images with use of more detailed aerial photographs, such as those available from Google Earth to verify the findings from satellite images.

REFERENCES

To find the References list, see page 500, or download here: www.SustainableFoodFuture.org.

PHOTO CREDITS

Pg. 434 CIAT/Flickr, pg. 436 Mokhamad Edliadi/CIFOR, pg. 439 Axel Fassio/CIFOR, pg. 441 Marco Simola/CIFOR, pg. 445 Marlon del Aguila Guerrero/CIFOR, pg. 451 Jeff Walker/CIFOR, pg. 454 PXHere, pg. 458 PXHere, pg. 465 Icaro Cooke Vieira/CIFOR, pg. 468 Dean Calma/IAEA.