Agricultural Pollution
Field Burning

Why Care about Agricultural Burning?

The practice of burning unwanted vegetation to prepare land for sowing crops or other farming activities is a worldwide and long-standing practice. Its tenacity, despite its harmful consequences for air quality, soil health, and the climate is a testament to its convenience and acceptance among farmers across a wide range of farming systems and agroclimatic zones. Burning is so broadly perceived as being natural that even its immediate toxicity is generally overlooked. Overall, there is no greater source of primary fine carbonaceous particles than biomass burning, and it is the second largest source of trace gases in the atmosphere. Yet while the polluting effects of burning are seldom a concern of agricultural producers, the act of burning often defies farmers' own understanding of the multiple benefits of biomass residues, which include nourishing and improving soils. That said, the embrace in the past two decades of alternatives such as no-till farming on a fairly wide scale in parts of Europe, Asia, and especially the Americas, demonstrates that change is possible with the right mix of public sector support and regulation.

Nature and Magnitude of the Problem

Around the globe, in farming systems large and small, burning is one of the most commonly used methods for removing crop residues after harvest. It is particularly prevalent following the cultivation of maize, but is also practiced with rice, wheat, sugar cane, and other crops (see figure 2). Burning is also a common way of preparing lands for cultivation after they have been fallowed.

In aggregate terms, China, India, and the United States are the top burners of crop residues, followed by Brazil, Indonesia, and the Russian Federation. In relative terms, however, Africa is home to some of the most intensive rates of residue burning per hectare of harvested land. It is also the region where burning is growing the fastest. Among the top 20 burners (in aggregate terms), Mexico and Tanzania stand out as the most intensive burners, followed by Brazil, the United States, and Nigeria. And over the past decades, burning has progressed significantly in countries including Brazil, Indonesia, Thailand, India, and China (see figure 3).[1]

Figure 1: Field Burning in the U.S. Great Plains

Source: © NewsNetNebraska.

To put the above in perspective, however, crop residue burning represents only a small fraction of overall, agriculture-related open burning of biomass (see box 1 and figures 4, 5 and 6). With regard to black carbon contributions, for instance, the burning of crop residues is estimated to represent only around 5 percent of overall open burning emissions (Bond et al. 2013).2 This note focuses primarily on crop residue burning because it is unambiguously related to agriculture, and represents a significant pollution abatement opportunity.

Impacts

The open burning of biomass releases a range of air pollutants that are known to contribute to the deterioration of air quality. This has especially harmful effects on human health and negatively affects crop growth, natural ecosystems, visibility (due to haze), and physical infrastructure. The key pollutant from a human health perspective is particulate matter (coarse particles of 2.5 to 10 microns, and fine particles of 2.5 microns or less), the impacts of which are mostly local and modulated by its concentration, by population density and exposure, and weather conditions. Other local air pollutants that result from biomass burning include carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NOx), ammonia (NH_3), sulfur dioxide (SO_2), carcinogens such as polycyclic aromatic hydrocarbons (PAHs), and multiple other toxic compounds. Short- and

1 These rankings are based on Food and Agriculture Organization estimates of kilograms of biomass burnt, and do not take into account all-important emissions factors.

2 Open burning is the largest source of global black carbon emissions.

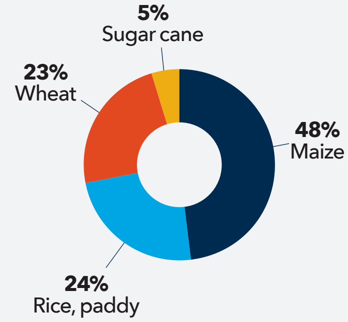
This note was written by Emilie Cassou. Full references and acknowledgments are available online.

long-term exposures to particulate matter and air pollutants more generally are strongly associated with a range of health responses including respiratory and cardiovascular disease, lung cancer, and premature death. In crops, ground level ozone (formed when NOx, CO, and VOCs react with sunlight) can reduce photosynthesis and prohibit plant growth. Acid rain resulting from the emission of SO_2 and NOx is also known to damage plants, affect soils, and corrode urban structures.

Biomass burning also releases several climate pollutants, including the greenhouse gases (GHGs) carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4),[3] and fine particles known as black carbon. The effects of these and other co-emitted species on climate are variable and complex.[4] Schematically, however, there are two major and unambiguous ways in which biomass burning contributes to climate change. One is a long-term warming effect linked primarily to CO_2 emissions, though also to other GHGs, from deforestation and other forms of land conversion during which biomass is burnt and not fully replaced. The other is a short-term warming effect attributed to the emission of black carbon from the burning of biomass in relative proximity to snow- and ice-covered regions of the planet (see box 2).

In addition to polluting, the burning of biomass amounts to destroying a resource that can be put to valuable uses that range from improving soils to controlling non-point source pollution, and reducing the use of substitute materials or products. Straw is a source of nutrients (nitrogen, phosphorus, and sulfur) and organic materials that, when returned to the soil through the process of decomposition, contribute to nutrient cycling and topsoil formation. These, along with the use of straw to maintain ground cover, generally improve soil properties, helping to slow runoff and erosion, enhance nutrient availability and plant growth, and mitigate yield risk. While burning returns some nutrients to the soil and can even result in a burst of fertility in the short run, most of the organic material and nutrient content of straw is lost under high temperatures. Burning, meanwhile, can perturb soil pH, moisture, and biota (for example, bacteria, fungi, algae, protozoa, earthworms, arthropods, and termites), resulting in imbalances. Beyond the farm gate, renouncing the recycling of biomass represents a lost opportunity to reduce downstream wa-

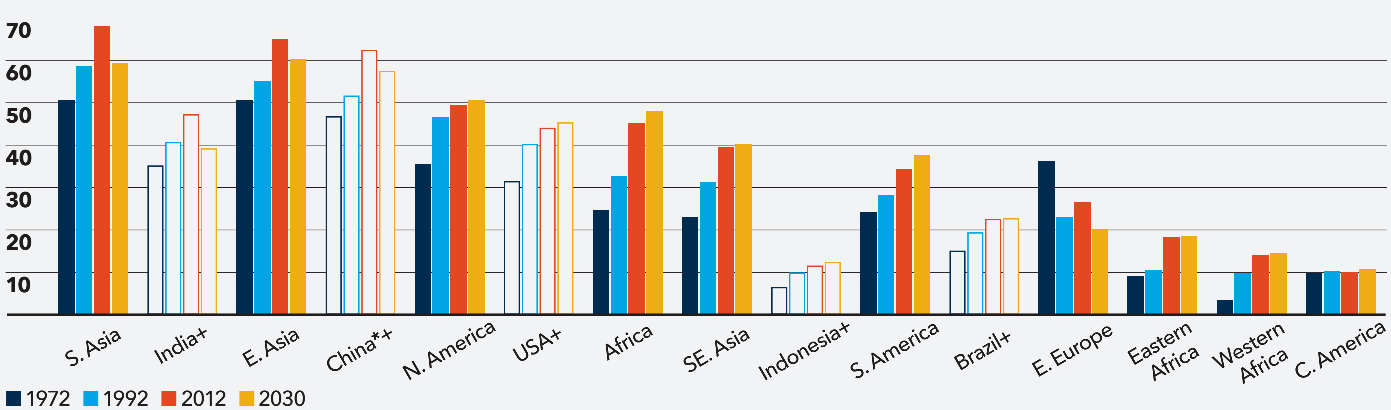
Figure 2: Burning of Crop Residues by Major Crop, 2014



Source: Based FAOSTAT data.
Note: Accounts for biomass dry matter.

Figure 3: Geography and Evolution of Crop Residue Burning

Millions of kg of biomass dry matter



Source: Based on FAOSTAT data. ***Note:*** Burning of residues, as measured by kilograms of biomass dry matter from rice paddy, maize, wheat, and sugarcane production. *Mainland China. +Overlaps with other categories shown in chart.

3 It also emits precursors to the GHG ozone (O_3).

4 The burning of "renewable biomass" is generally considered carbon neutral. Even though it can influence the climate for years before it is resequestered, the CO2 emitted in burning biomass is not considered a contributor to long-term climate change if the equivalent biomass is regrown, as in crop farming. Burning-related emissions of CH4 and N2O—GHGs that are respectively 25 and 298 times more potent than CO2—do contribute to radiative forcing even when the burnt biomass is replaced; however, biomass burning-related emissions of these gases are dwarfed by other global sources. Note that burning has also been found to increase biogenic soil emissions of CH4, N2O, and nitric oxide (NO)—that is, linked to soil microbial activity. The emission of pure black carbon has a potent and immediate ("near-term") warming effect on the climate. Depending on its source, however, its warming effect can be countered by co-emitted species such as organic carbon, which can have a cooling effect. As a result, the net, near-term effect of burning-related emissions on climate depends on a complex set of circumstances, including where burning occurs (box 2).

Box 1. What Is Agricultural Burning?

Agricultural burning refers to any open-air burning of biomass that is driven by agriculture and results from fires set intentionally in preparation for farming activities. Although this is conceptually straightforward, the challenge of empirically establishing this causal relationship makes agricultural burning exceedingly difficult to define in practice, as well as to measure. Whereas the burning of agricultural crop residues squarely fits the definition, other forms of open burning of biomass, including the combustion of forests, grasslands, and savannah, cannot all be traced to agriculture. A small minority of wildfires are provoked by natural causes such as lightning, for instance, and planned agricultural fires account for "only" 10–20 percent of open burning (ICCI 2014). The vast majority of open burning is believed to result from the uncontrolled spread of agricultural fires.

Figure 4: Burning Plantations and Rainforests in Indonesia

Source: © EPA/STRINGER (above); © Regina Safri/Antara Foto/Reuters (below).

ter pollution linked to soil erosion or the additional use of synthetic fertilizers for instance.5 Other valuable uses of straw precluded by burning include its use for energy, feed, construction materials, or bioplastics. The value of using biomass in these and other cases comes from displacing other sources of these (such as energy or materials) and associated externalities. In other words, the impact of burning is to not prevent these externalities.

Drivers

Burning patterns in the Andes and Himalayas were found to reflect multiple factors, and especially tradition, ease, timing, weather and location, and the practicality of alternatives—the latter being partly determined by access to appropriate tools or markets for biomass residues. Across regions, burning is widely seen as a quick and inexpensive way to manage crop residues while preventing pests and diseases. And burning crop residues can indeed be a rapid way to prepare fields for a second or third crop—an aspect that matters in certain farming contexts, where time and labor constraints factor into farming decisions. In parts of China, for example, there is a short window of typically one to two weeks for the removal of crop residues between harvests. Burning is often the preferred method of land preparation in such cases. In Russia, a sharp rise in residue burning has been linked to the virtual collapse, since the 1990s, of the country's livestock sector along with its appetite for stubble.

In general, while the cost-benefit reality of burning varies significantly and depends on many factors, burning is widespread because so many farmers perceive it to offer multiple benefits—and presumably ones that outweigh its costs. At the same time, farmers' favorable perception of burning is partly owed to the fact that they do not factor in the environmental and health costs of burning that are felt off-farm—its negative externalities. Meanwhile, in contexts where bans or regulations on burning are in place, weak enforcement means that there is little disincentive for farmers to carry on with the practice.

In parallel, a lack of awareness (that is, a partial awareness of the costs and benefits of burning and its

5 That said, the retention of straw on fields is often associated with higher reliance on pesticides to control unwanted species including weeds, termites, and rats. This is not an issue when residues are transformed into biochar, a soil amendment.

Figure 5: Global Open Burning of Biomass, 1997–2014

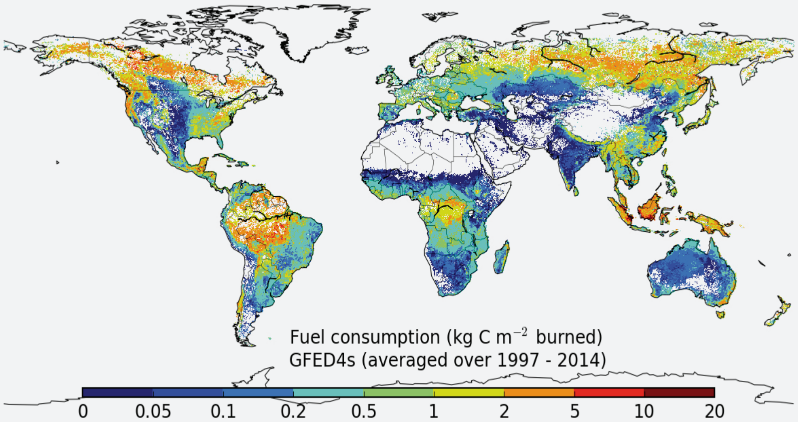
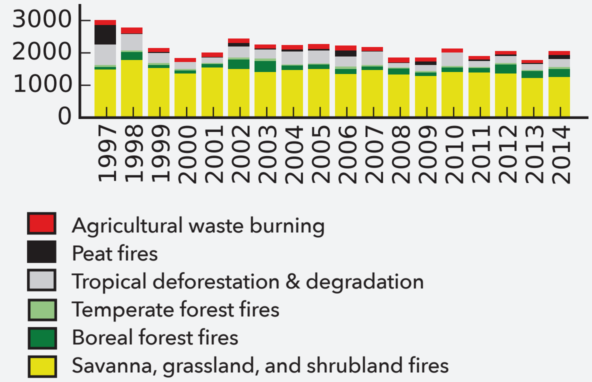


Figure 6: Annual Fire Emissions



Source: Giglio et al. 2013.
Note: Analysis of daily, monthly, and annual burned area using the fourth-generation global fire emissions database (GFED4).

alternatives) is no doubt part of the explanation for how widely burning is observed. In particular, the initial burst of soil fertility that can be gained from burning may obscure, for some farmers, the downsides of the practice, especially as those can be more drawn out over time, or entirely escape observation (counterfactual losses being the hardest to take in). Likewise, insects that are thought to be eliminated by fire can sometimes survive, hidden in the soil. Still, alternatives to burning are often cheap and beneficial enough over time, to farmers, that the breadth and frequency of burning cannot fully be explained by these externality and information failures.

Even where farmers perceive net benefits in alternative uses of crop residues, several factors can prevent them from pursuing these. For example, farmers sometimes lack the ability to pay for (or lack access to) the labor, equipment, or chemicals that would allow them to compost, switch to no-till farming, generate energy, move wastes off-field for alternative uses, or manage pests and diseases without burning. No-till farming, for instance, is greatly facilitated by relatively simple technologies for chopping crop residues into more manageable straw, sowing seeds through a thick carpet of straw, and managing weeds. Equipment for the production or biogas or biochar can require higher upfront investments and only make sense for operations above a certain scale, both in terms of feedstock availability and energy needs. In short, the investment can be too high or the payback period too long for farmers, and appropriate financial instruments are sometimes lacking to help

Box 2: Biomass Burning, Black Carbon, and Climate Change

Black carbon consists of extremely small particles that result from the incomplete combustion of fossil fuels and biomass. Commonly known as soot, it is one of the many types of particulate matter that influence the climate (alongside sulfates and volcanic ash). Fundamentally different from GHGs, black carbon remains in the atmosphere only for a few days to a few weeks before it is rained out or settles out of the air. Yet climate scientists now view black carbon as one of the largest warming agents after CO_2. Black carbon is similar to CO_2 and other GHGs in terms of light-absorbing properties that allow it to convert light energy to heat and warm the air around it. However, black carbon acts much more intensely than CO_2 for a much shorter time. In addition, and unlike GHGs, black carbon affects climate through its influence on cloud formation and properties, as well as through deposition on the earth's surface. The light-absorbing properties of black carbon particles can darken the earth's surface when settling on snow or ice. This increases snow and glacial melt, enabling strong feedback with land and ocean surfaces that may otherwise reflect sunlight.

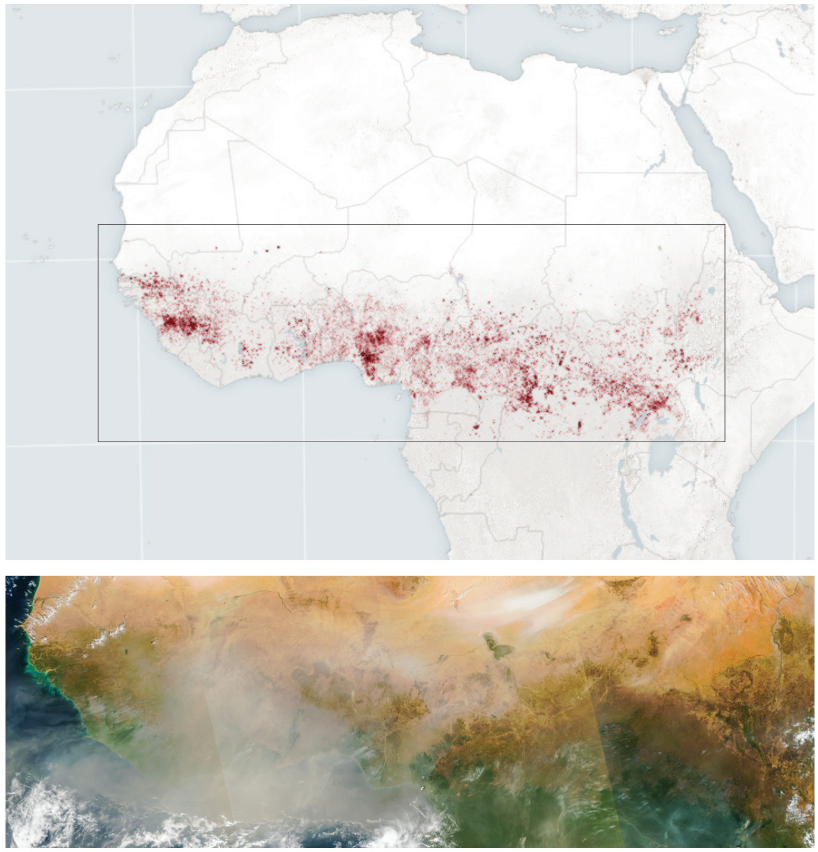
Total global open burning of biomass (including forest, savannah, and agriculture residue burning) accounted for nearly 37 percent of global black carbon emissions in 2000, with emissions estimated at 2,760 Gg per year (Bond et al. 2013). Although the figure of 2,760 Gg per year is an overestimate for agriculture (see box 1), the sector would be the largest emitter of black carbon even if only approximately 60 percent of these emissions were related to agricultural activities.

The effects of open burning on the climate are not straightforward, however. Open burning emits significant amounts of co-pollutants, including warming agents such as carbon monoxide and cooling agents such as organic carbon (which is lighter in color than black carbon, and can be reflective). As a result, it is possible that in some cases, biomass burning has a net cooling effect in the short run (that is, before the longer-run effects of GHGs are factored in). That said, when emissions are located near or transported to snow- and ice-covered regions (regions with a very light and reflective surface), the net effect of burning on climate is clearly to accelerate near-term warming, and with it, glacial melt and disruptions in water availability. This is notably the effect of burning in the Andes, the Himalayas, and parts of Russia and Central Asia.

them purchase or lease the equipment or inputs that are required. Investment can be further hampered by insecure land tenure, as seen in much of Sub-Saharan Africa and parts of Asia. Farmers also often lack the technical knowledge and know-how to adopt alternatives, and in certain contexts, collective action or markets are insufficiently developed to help farmers overcome some of these obstacles.

In addition, culturally produced mental models, social customs, present bias, procrastination, and other sociopsychological factors can play a role in perpetuating long-held practices. Burning, for example, can be held in place by the notion that crop residues are a form of waste, rather than a resource, and the customary belief that burning is the least costly way of removing a cumbersome waste stream. The idea that crop residues are a waste stream can also minimize the feeling of loss associated with burning. The central place of plowing, in many farmers' concept of land-preparation can deter their adoption of residue management practices that do not involve burning (box 3). A tendency to discount future gains and losses known as present bias can also interfere. In other words, farmers may pursue the short-term boost in soil fertility that burning offers, even while knowing full well that soils suffer from high temperatures, the loss of organic matter, and the excessive amounts of fertilizer that are often applied in compensation. And like all humans, farmers can simply procrastinate, intending to change practices but never actually implementing the change.

Figure 7: A Band of Fire Across Sub-Saharan Africa



Source: National Aeronautics and Space Administration (NASA), January 30, 2016.

What Can Be Done?

There are multiple alternatives to burning, many of which can be directly valuable to farmers.[6] Staying focused on crop residue burning—the broader question of open burning being beyond the scope of this note—major alternatives involve repurposing residues as ground cover, soil amendments (that is, mulch or compost), animal feed, or as feedstock for energy,[7] construction materials, paper products, bioplastics, and other artifacts. All of these can take on different forms, scales, and levels of sophistication. They can also take place on- or off-farm, with the latter relying on the aggregation of residues from multiple farms to achieve economies of scale. Off-farm solutions can also involve larger upfront investments, as well as additional costs and complexities associated with moving product around. At the front end, residues need to be collected from multiple farms, and at the back end, their byproducts distributed—processes that can involve varying degrees of commodification and market transacting.

Helping any of these become a reality, rests first and foremost on supporting the technical feasibility and economic attractiveness of alternatives to burning. Yet it also requires that the full range of drivers and barriers be addressed, including hidden costs of switching practices, farmer perceptions of crop residues and different possible uses of these, and such factors as present bias, action-intention divides, and even sociocultural constructs (that is, mental models or schemas). Thus, a range of instruments are needed to support alternatives to burning.

Laws and regulations. Through legal action, burning can be restricted or outright banned. Several U.S. states, for example, use a permitting system to limit burning to specific days, times, and atmospheric condi-

6 Besides alternative uses of biomass, increased combustion efficiency can also reduce burning-related pollution (especially particulates). Meanwhile, reducing the amount of residues that are generated in the first place, while theoretically possible, offers more limited options in practice. That said, reducing land clearing is a highly relevant though much larger topic that requires addressing the complex drivers of deforestation.

7 The use of crop residues to generate useful energy (for example, biogas, or fuel used in cement production) can mitigate burning-related pollution to the extent that burning can occur in more controlled conditions, thus resulting in lower particulate and methane emissions. Beyond this, its main benefit is to displace other forms of energy production and any pollutants associated with these.

tions; and the burning of straw and stubble is outlawed in most of the European Union's member states. Many have been able to manage or curb burning in this way, but evidently, legal action there and elsewhere has varied in effectiveness. In China and Russia, national and subnational bans on burning have yielded particularly limited results. The efficacy of legal measures generally rests on multiple nonlegal measures and circumstances, including efforts to make the law known to farmers, a rule-abiding culture, the capacity to detect and punish illicit burning, and not least, the alignment of economic incentives and other motivators with the law. Several U.S. states use a combination of fines, aerial photography, remote sensing, and tip hotlines for enforcement.

Information, knowledge, and innovation. Various forms of information and knowledge are needed to curb open burning. They are needed to support an understanding of, among others: the costs and benefits (both public and private) of burning and its alternatives; the existence and extent of these; legal and regulatory requirements pertaining to them; where, when, and why burning is carried out (satellite detection can help up to a point); and how to implement alternatives (that is, technical information). Where farmers' beliefs about the benefits of burning—or conversely, the inconveniences of not burning—are deeply rooted, and even socially or culturally reinforced, information alone may or may not counter these where they stand to be rectified. The above underscores the need for multidirectional flows of knowledge and information, as well as the importance of how information is framed and delivered. It also points

Figure 8: No-Till Agriculture in Brazil

Source: © Miguel Altieri.

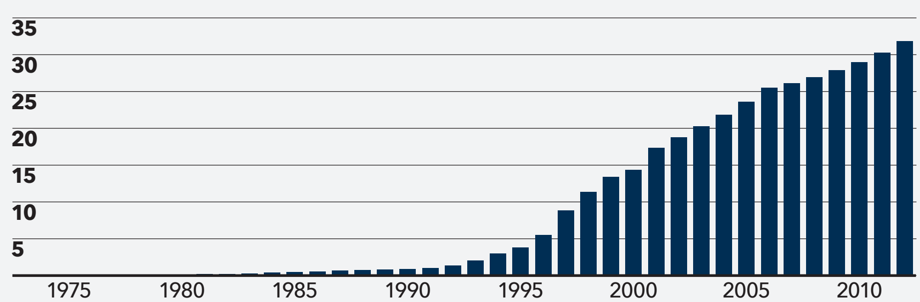
Box 3. Adoption of Conservation Agriculture

The global spread and acceleration of conservation agriculture over the past two decades–a largely farmer-led phenomenon to date–illustrates that alternatives to burning can become viable across a wide range of farming systems and geographies with appropriate forms of support. Conservation agriculture (CA) represents an exit from burning as two of its central tenets are to minimize soil disturbance (that is, by not tilling), and to maintain soil cover (the third is to diversify crop species). Approximately 155 million hectares, or around 11 percent of global arable cropland, were thought to be under CA in 2013 (data on CA are scarce). This represented an increase of 24 percent over 2010 penetration levels–and a 55-fold increase (that is, 5,400 percent) in 1974 acreage. Growth in conservation agriculture has particularly taken off in the past decade, driven by rising interest of small and large farmers in parts of North and South America and Australia, and most recently, large farms in Kazakhstan and small farms in India and China (Kassam et al. 2014).

Conservation agriculture has enjoyed high rates of penetration in certain geographies. In Brazil, for instance, at least half the area under annual crops (around 34 million hectares) was estimated to have converted to zero-tillage conservation agriculture as of 2012. In this case, the reality of massive and severe soil erosion, and the failure of prior attempts to manage it through landscaping techniques, were preludes to change. The launch of a national research program on conservation agriculture in the 1970s, and dogged, on-farm experimentation by committed lead-adopters, were critical for overcoming early technical barriers to adoption in tropical and crop-specific conditions. These helped to achieve and demonstrate profitability–first to large mechanized farms and later to smaller and less sophisticated ones–and provided fodder for the farmer organizations that disseminated and continued adapting the technologies and practices to evermore challenging conditions (for example, as in Brazil's Cerrado region). The spread of conservation agriculture was also a product of continued public sector support. In the early 2000s, for instance, the Brazilian Agricultural Research Corporation (Embrapa) set up a participatory platform that helped to sensitize and train farmers, but also to identify, from the bottom-up, persistent barriers to adoption ranging from financial to technological ones, in order to address these.

Figure 9: Evolution of Zero-tillage Conservation Agriculture Management Systems in Brazil

Millions of hectares



Source: Based on FEBRAPDPD 2013, in Freitas and Landers 2014. Permission required for reuse.
Note: Brazilian Federation of Zero Tillage in Crop Residues (FEBRAPDP), created in 1992.

to the need for a multiplicity of actors, including but not limited to traditional agricultural extension and advisory services, to be connected and engaged in generating and conveying information, knowledge, and technology to support alternatives to burning (see box 3). Without robust information and innovation systems in place, efforts to curb open burning are likely to be in vain.

Sticks, carrots, and nudges. In the Andes prior to the arrival of the Spanish and the introduction of the plow, the practice of burning fields carried a penalty of death because it damaged the soil, the lifeblood of high agricultural yields, reports a 2015 report by the International Cryosphere Climate Initiative. Today, gentler approaches to advocacy and enforcement are more in vogue—instruments such as fines, taxes, subsidies, and behavioral interventions known as nudges that ultimately let farmers decide for themselves. Whether or not they accompany legal action, these instruments can be used to correct externalities (that is, to expose farmers to the full costs and benefits of burning and its alternatives), and even to overcome sociopsychological barriers. For example, if it can be detected, burning can carry a fine, and alternative uses such as no-till, composting, and biogas production can be encouraged through concessional credit (for example, for the production or purchase of equipment), tax incentives (for example, for compost or biogas production), and supportive public investments. The effectiveness of different instruments is highly contextual and can be unrelated to their cost. The convenience of a residue pickup service, the persuasiveness of a community-based enforcement system, or even the influence of role models, may be more effective at dissuading burning than a cash incentive or fine. In sum, the complexity, persistence, and context specificity of the burning challenge needs to be mirrored by patient forms of public sector support that enable technological as well as social innovation—involving, serving, and motivating stakeholders at every level.