International Cryosphere
Climate Initiative

Addressing Open Agricultural Sector Burning:
A CCAC Global Transition Plan

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International Cryosphere Climate Initiative (ICCI)

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Introduction

Open burning in agriculture – defined as all intentional burning in the agro-forestry sector, including stubble and pastureland burning and use of fire to clear fallow lands, but excluding prescribed burns on wildlands -- is a practice with deep historical roots. Farmers burn for a variety of reasons, and rarely simply as a tradition. The practice for example occurs to cheaply remove excess straw that might otherwise snare or break plows; to remove insect pests and weeds; or to "fertilize" the soil with ash (a common misconception due to the black appearance of charred earth).

In reality, research beginning in the former Soviet Union in the 1930's and onwards repeatedly demonstrated that burning reduces damages soil structure by destroying organic matter. This "burned off" loss of fertility must be countered by greater use of expensive fertilizers to maintain crop yields, accompanied by greater erosion and soil run-off caused by the more brittle burned soil structure. Additional impacts of burning therefore include degradation of local water systems from added fertilizer and soil incursion, and greater need for water resources for irrigation, at a time when such resources already are under stress from climate change and glacial loss. These negative environmental impacts are accompanied by negative direct human health impacts from smoke, which in some cases (such as New Delhi, 2017, 2019) can be extreme.

In contrast, no-burn methods not only eliminate annual emissions of GHGs, black carbon and harmful pollution; but also provide some level of adaptation and resilience. This is particularly the case for low-till and especially, no-till methods, especially when combined with use of cover crops and injected manure (a suite of agricultural methods termed "conservation agriculture" or CA). In addition, there is increasing evidence that such methods also fix greater amounts of carbon in the soil (eg, negative carbon emissions). Other no-burn methods also aid adaptation, for example use of straw stubble for bio-energy or cookstove fuel to preserve local forest resources.

The negative impacts of burning, especially crop yield loss and increased fertilizer costs, translate into decreased income for farmers and puts into danger food security. Once demonstrated, this impact of burning on profits -- not initially understood by many farmers, who burn only because they believe it necessary – eventually drives demand for alternatives. In many regions of Latin America with large agri-businesses – Argentina, Brazil, eastern Bolivia – this transition to no-burn methods already has occurred entirely for economic reasons. In Western Europe and North America, human health impacts (including traffic accidents) together with regulatory measures and incentives have driven this transition more quickly, which does require some initial investment in no-burn equipment, methods and training. With EU accession, Poland and the Baltic nations decreased burning by 90% in just five years, showing that a transition to no-burn methods can occur rapidly with such supports (a combination of phasing in increasingly-strict EU regulations, with farmer subsidies to ease the transition).

This CCAC Open Burning Transition Plan draws on lessons learned in the 2016-2019 CCAC Open Burning Project and some earlier related projects, making connections with the needs to sharply decrease burning globally.

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Agricultural Open Burning: Definition and Characteristics

Open burning in agriculture – defined as all intentional burning in the agro-forestry sector, including stubble and pastureland burning and use of fire to clear fallow lands, but excluding prescribed burns on wildlands -- is a practice with deep historical roots. Farmers burn for different reasons, and rarely only “tradition.” Instead, use of fire in agriculture is seen as a dirty and dangerous, but necessary tool: to cheaply remove excess straw that might otherwise snare or break plows; remove insect pests and weeds; or “fertilize” the soil with ash (a common misconception due to the black appearance of charred earth). However, they rarely correlate burning with soil, air and health problems.

Burning damages soil structure by destroying organic matter. This “burned off” loss of fertility must be countered by greater use of expensive fertilizers to maintain crop yields, accompanied by greater erosion and soil run-off caused by the more brittle burned soil structure. Additional impacts of burning therefore include degradation of local water systems from added fertilizer and soil incursion, and greater need for water resources for irrigation, at a time when such resources already are under stress from climate change and glacial loss. These negative environmental impacts are accompanied by negative direct human health impacts from smoke, which in some cases (such as New Delhi in 2017.

In contrast, no-burn methods not only eliminate annual emissions of GHGs, black carbon and harmful pollution; but also provide some level of adaptation and resilience. This is particularly the case for low-till and especially, no-till methods, especially when combined with use of cover crops and injected manure (a suite of agricultural methods termed “conservation agriculture” or CA). No-till methods involve inserting seeds through the remains of the last crop’s stubble. The stubble roots preserve soil structure and slowly decompose, serving to fertilize the succeeding crop; and overall increasing soil organic matter. The leftover roots also provide resilience to both extreme droughts -- through preserving moisture content; and extreme rainfall events -- through holding soil in place. Both these weather extremes have become of greater concern for farmers in a changing climate. In addition, there is increasing evidence that such methods also fix greater amounts of carbon in the soil (eg, negative carbon emissions). Other no-burn methods also aid adaptation, for example use of straw stubble for bio-energy or cookstove fuel to preserve local forest resources.

Impacts of Burning

According to the “Status of the World´s Soil Resources. Technical Summary” (FAO, 2015), soil erosion is the removal of soil from the land surface by water, wind, or tillage. Water erosion occurs mainly when overland flow transports soil particles detached by raindrop impact or runoff, often leading to clearly defined channels such as rills or gullies. Wind erosion occurs when dry, loose, bare soil is subjected to strong winds and soil particles are detached from the soil surface and transported elsewhere. Tillage erosion is the direct down-slope movement of soil by tillage implements and results in soil redistribution within a field. Erosion is a natural process, but the rate of erosion is typically greatly accelerated by human activity.

Open burning exacerbates such impacts of tillage and erosion by making the soil more brittle. Soil is left bare and particles are prone to wind and water erosion, losing organic matter to burning in the surface horizon, which is the richest layer. Not only stubble or grass burns, in other words; also the organic matter in the soil is lost. This makes use of fire in agricultural systems a cause of net loss of carbon, either as CO_2 or methane. Loss of soil organic matter due to its combustion carries other consequences, such as decrease in soil fertility (organic matter carries nitrogen, phosphorus, etc.), reduction in soil infiltration rate and many other tangible economic impacts. In addition, a quarter of all living organisms exist in the soil; so when we burn, we impact global biodiversity. Finally, burning releases not only particle pollution, but also other air pollutants such as nitrous oxide.

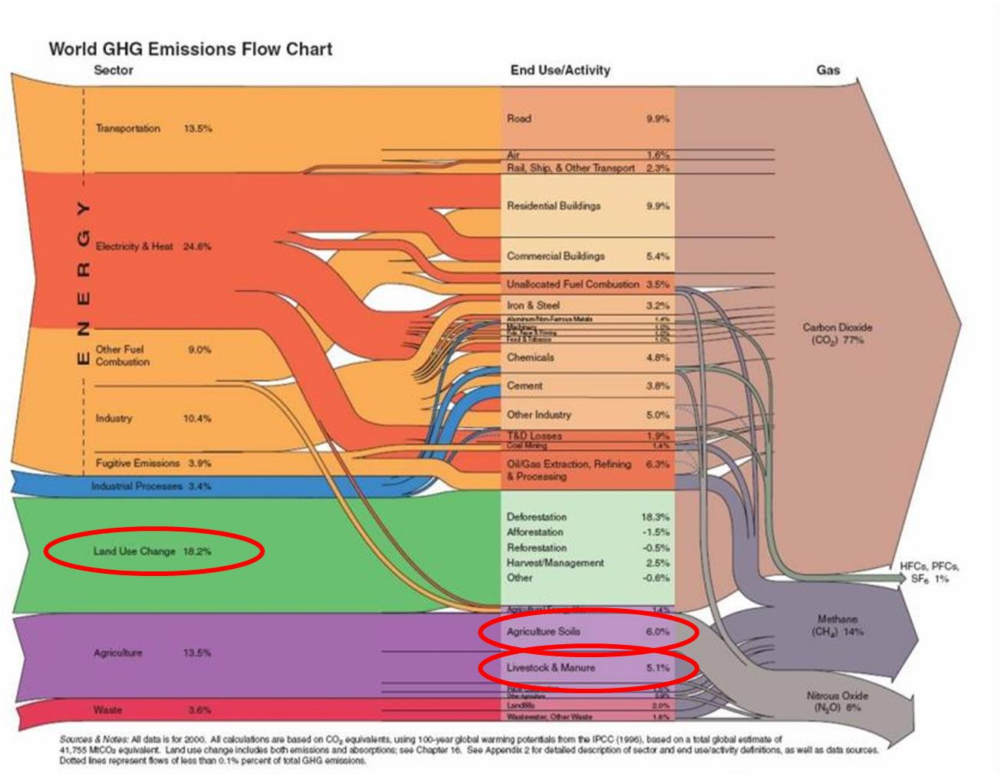
The summer 2010 fires in European Russian showed the degree to which smoke from open agricultural burning significantly and negatively impacts human health, with Russian authorities estimating that 25,000 additional deaths occurred that summer in Moscow alone. Later studies demonstrate that on a global basis, open biomass burning causes 5-10 percent of air pollution deaths (approximately 250,000 deaths annually). Lelieveld et al. (2015) note that PM2.5 from agricultural sources is the main contributor to premature mortality from air pollution for East and Southeast Asia, the eastern U.S., Europe and Russia/Ukraine. In Delhi during the November 2017 fire emergency, PM2.5 levels sometimes peaked over 1000ppm, well above rates with documented acute and severe health effects, especially among the very young and very old.

More recently, authorities have focused on the longer-term impacts of smoke exposure, even to a single exposure over a longer fire period. Much of this research interest has come due to more frequent wildfires in a drier and warmer climate, especially in the western U.S. When a wildfire raised PM levels in a small town in Utah during the month of July 2017, visits to the local emergency room increased for respiratory diseases, something also seen during other fires. However, local health authorities continued to monitor the situation, and discovered that rates for such visits remained higher than prior to the wildfire, for at least two years after the actual fire event. This indicates how the effects of a single exposure incident may be long-term, with the young (<age 6) as well as the elderly and those with existing respiratory conditions most seriously affected.

Accidents and direct fire-related injury and death comprise an additional health impact of open burning. Indeed, OECD nations first began addressing open burning due to its impact not only on health from an air quality standpoint, but accident mortality and morbidity. One of the first total burning bans anywhere was legislated as a result of a single severe accident in the U.S. state of Washington in 1988, when smoke from field burning so decreased visibility that a 24-car chain reaction accident took place on a large highway. Seven people were killed and 38 injured; with intense lobbying from relatives of the victims, the state legislature passed the ban a year later. Similar instances also contributed to regulation in other U.S. states and Europe.

Finally, direct injury and mortality from fires, occurring among both local inhabitants and firefighters is an annually occurring health impact of this practice, which becomes especially acute when set agricultural fires spread to become wildfires in a hotter and drier climate.

For climate, the following FAO chart shows that land use change accounts for 18,2% of GHG emissions. This includes lands that are burned and cleared because the lands already in use with traditional methods, including annual burning have become infertile or too eroded for continued agricultural use. In addition, another 6% of total GHG emissions come for agricultural soils (mainly with burn-and-till methods), with 5,1% arising from livestock and manure, the latter of which can also be used (and emissions reduced) through especially soil injection in no-burn, no-till systems.



Lessons Learned from Projects in the Andes, Himalayas and Eastern Europe

Since 2014, with the support of the UN Environment Program's Climate and Clean Air Coalition (CCAC), the International Cryosphere Climate Initiative (ICCI) has been raising awareness and ambition about tackling this problem, together with local partners; including two demonstration projects in Peru (with CARE and INIA) and Punjab, India (with the Punjab Agriculture and Management Training Institute (PAMETI)) from 2016-19. These projects built on earlier work, supported by the Oak Foundation, government of Sweden and Nordic Environment Finance Corporation (NEFCO) in Russia and Ukraine beginning in 2010 with the Bellona-Russia, and continuing to-date.

Despite the very different agricultural contexts in these three regions, these projects have all taken a "three legs" approach to introduction of fire-free agricultural systems: mapping and monitoring to define the problem, education of farmers, and expert policy support to state/oblast and national governments. Activities therefore have encompassed:

1) Mapping open burning patterns from the field- to regional-level and creating informational materials (https://www.openburning.org);
2) Demonstrating the available solutions to farmers through local partnerships with entities focused on more sustainable agricultural practices (NGOs, civil society, state and federal extension services, agribusinesses, among others);
3) Bringing together experts, policymakers, and progressive farmers for strategic support to discuss and troubleshoot practical solutions through conferences, meetings, and workshops.

Specific interventions in these projects have included:

- Distribution and publication of residue management strategies, farm literature, handouts/ brochures, billboards, media broadcast, using web and mobile technology through text messaging, formulation of social media groups;

- Organization of farmer awareness camps, farmers-scientists meetings, field days, school awareness camps, door-to-door contact, farmer training camps, village-level workshops, on and off campus farmers' trainings, exposure visits to demonstration plots and farms of progressive farmers associated with crop residue management

- Engagement of institutions such as oblast/rayon administrations, schools and universities, identifying and training of ambassador farmers/opinion leaders;

- Celebration and award ceremonies for farmers practicing no-burn methods and of progressive farmers to persuade the farmers about more sustainable ways to manage crop residue.

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Below, we outline challenges, solutions, and strategies worth scaling up in order to eliminate the practice of open burning, based on commonalities among these different project experiences.

Himalayas:

In the Himalayan region, the project has been replete with lessons. Technical and political challenges surfaced regarding monitoring and groundtruthing, practical implementation of sustainable no-burn practices, and factions in society interested in opposing priorities. PAMETI's pilot project in Punjab province has proven however that these challenges are solvable, with solutions such as engaging civil society at the grassroots level, including effective and timely communication; extension support to farmers; and financial incentives to adopt no-burn practices that are universally scalable thanks to new technologies (in Punjab, the Happy Seeder) and proven methods of residue management. Another important lesson is that enforcement of laws banning burning must be implemented only once these proven alternatives have been properly demonstrated to a critical mass of local farmers: showing that these no-burn practices lower costs for petrol and fertilizers, make crops more resilient to climate change, save water, and reduce climate and public health impacts – all while providing the same or improved yields during the 2017-19 Punjab project cycle. Indeed, this is the essence of climate-smart agriculture.

On monitoring and evaluation, the project has shown that satellite monitoring must be accompanied by third-party real-time groundtruthing from entities that have no incentive for enforcement. Satellite monitoring technology is affected by weather conditions, timeliness, and resolution. Groundtruthing can help to properly identify open burning as opposed to tilled plots, brick kilns, wildland fires, and/or pile burning. Using a data fusion approach of commercial very high resolution (< 5 m) Planet Labs imagery and open source moderate (10 – 30 m) Sentinel-2 and Landsat imagery and 375 m Visible Infrared Imaging Radiometer Suite (VIIRS) twice daily active fires, open burning can be detected in fields as small as ~150 m2 – or 0.015 ha. Additionally, community-specific geospatial data, like energy sites, is included as an augmentation to the validation provided by groundtruthing.

The extension and training component is often the key to success; simply making the technology available through subsidies is not enough and can lead to political backlash if governments fail to provide effective universal solutions while focusing primarily on enforcement. In Punjab, a market for residue management service providers is also developing in the region but must be properly and equitably regulated.

The project also observed some political challenges related to water resource management and factionalism. In Punjab, India, the Preservation of Water Subsoil Act of 2009 combined with subsidies for wheat and rice delayed planting and led to a shorter post-harvest residue management period and was at times subject to political pressure from farmers' unions and the whims of government authorities, which increased the amount of open burning in recent years. At the same time, engaging civil society through information campaigns and policy reform to include universal and holistic incentives for more sustainable practices can lead to better climate adaptation and mitigation of climate, air, and soil pollutants.

Andes:

Peruvian and indeed, Andean agriculture may be divided into three regions: the coastal region, with medium to larger farms and a variety of crops from grains to fruit orchards; the mountain regions, dominated by subsistence agriculture and pasturelands often farmed in cooperative “comunidades;” and the eastern region transitioning into the Amazon, with more recently established (often by burning) croplands dominated by cash crops such as soy and sugar cane. Mapping associated with the scoping project, covering over a dozen years has established that burning currently occurs in Peru in almost all regions and for all crops.

Conversely, no-burn alternatives proved almost unknown in Peru. These therefore were the subject of a project focused on no-burn demonstration plots and training in Huancayo region with the cooperation of CARE, INIA and IGP. In addition, as in the Himalayas an Andean regional Strategic Support Group (SSG) provided expert advice.

The Huaytapallana glacier is the main source of water supply for the Huancayo project area. During the past 20 years its snow and ice area has been reduced by 50%. According to the Geophysical Institute of Peru (IGP), Huaytapallana provides 40% of the water that flows by the Shullcas river, that is used by the population of Huancayo. In addition, Mantaro river basin has been suffering a reduction of 15% of rainfall, and an increase in temperature between 1 and 2 degrees by recent years. The main associated risks with these threats are the more recurrent periods of drought, as well as probable water scarcity that can bring changes in ecosystem, local economy and higher levels of rural poverty and vulnerability.

Open burning is a common practice in the area, both to get rid of weeds and crop residue and to “make pastures re-grow”. Cattle producers think that fire makes pastures grow stronger and healthier, though pasture fires decrease soil fertility; and the more palatable and nutritive species are prone to disappear, thus degrading pastureland and forcing farmers to increase area by deforestation if they want to keep the same amount of cattle. Huancayo crop producers think that fire is the only way to get rid of weeds and crop residue. Additionally, they believe that fire enriches the soil, thus conservation agriculture is a key practice to encourage farmers to stop burning. It has multiple benefits, not only for themselves, but also for the environment and subsequently Huaytapallana glacier.

Results from the Huancayo demonstration site generated high levels of interest in the no-till approach to corn cultivation under demonstration since November 2017, and a desire by participating farmers to expand the demonstration plots to additional crops after two years of experience. Interestingly, farmers in the Huancayo and nearby mountain regions themselves are increasingly concerned at the impending loss of water resources, and appreciate that burning -- in addition to its negative crop, soil and health impacts -- may be hastening the disappearance of glaciers and snowpack on which those water resources depend.

With regards to challenges ahead, financial incentives for larger farms will speed this transition to fire-free methods. More importantly, medium and small-size farmers, particularly the “comunidad” farms of the mountains will require support to make this transition, lacking the capital needed for initial investment in no-burn equipment such as direct seeders, cover crop seeds, or (on a more expensive scale) equipment for electricity, pellet or biogas production from harvested straw. While the overall project elements in future should include some policy elements to encourage a more rapid transition among large commercial farmers, and provision of training and education to farmers of all sizes; the main focus of project financial supports will be these small- and medium-sized farms.

Most of the community-level agricultural systems allow for a combined approach: where some stubble remains on the fields for the co-benefits named above, while some portion is harvested for fuel, animal food or bedding. Additional supported investments might include equipment to inject manure into the soil (for combined animal husbandry and crop production), harvest pasturelands for hay rather than burning off excess growth, or support purchase of initial cover crops (plants such as clover or legumes planted in-between cash crops, in essence providing a fertilizing function).

Eastern Europe:

Many landowners in European Russia and Ukraine continue to burn fields and forests in various seasons or stages of production. Reasons vary: to improve productivity for planting or pasture lands; clearing stubble or weeds, including in smaller summer 'dacha' plots; removing undergrowth in preparation for wood harvest; waste burning; or simply out of tradition.

In addition to the direct impacts of this burning, these fires often spread however to surrounding fields and forests, multiplying their negative impacts on health and air quality many times, and putting infrastructure and lives at risk. The Russian government has estimated that between 30-98 percent of all “wildfires” arise from these set agricultural fires associated with crops, small private plots or brush management. Russian public health experts have estimated that an additional 25,000 deaths occurred in Moscow and St.

Petersburg alone as a result of such wildfires during the summer of 2010.

In addition to the threats to human health and safety, these fires release large amounts of particle pollution and soot black carbon into the upper atmosphere, which may be carried thousands of kilometers to the Arctic. Over the last twenty years the Arctic has warmed twice as fast as the rest of the planet, and Arctic Council scientists have calculated that around 30% of this accelerated melting may be due to black carbon, especially from near-Arctic sources.

Since 2010, the Oak Foundation, Swedish government and NEFCO have supported a series of demonstration projects in Russia and Ukraine, beginning in Leningradskaya oblast and including the “black earth” regions of Krasnodar Krai and Rostov oblast; Tula oblast south of Moscow; and Zhytomir and Kharkiv oblasts in Ukraine. These projects aimed at first, understanding and characterizing burning; and then exploring potential alternatives applicable to the entire Eastern European region of Russia, Ukraine, Byelarus and Kazakhstan, all of which have similar crops and patterns of burning. Many of these methods are already in broad use in Europe, and produce much higher profits and yields than methods involving burning. The aim of this work is to support a transition to these methods in some pilot areas, adapting them to local conditions and needs in ways that improve yields, productivity and farmers' quality of life.

These projects have evolved to providing agricultural extension study tours to Sweden and follow-up local courses (“field days”) which have reached over 1500 farmers. The project also works with local governments on measures and regulations aimed at supporting cessation of burning. Rostov and Krasnodar both feature large and often well-financed agribusinesses in Russia’s “black earth” region. In Leningradskaya oblast, farms tend to be small and marginal “hobby farms” in many cases due to difficult soil and weather conditions. Tula exemplifies an in-between agricultural environment, with mid-sized farms of around 500-1000 hectares (still large by Nordic standards). Ukrainian agricultural experts indicate great openness to adoption of alternative methods to burning, perhaps even greater than that in Russia; but little knowledge or expertise on how to implement more “European” methods.

Financing emerged as a barrier to all but the largest farmers, as the alternative methods do require some initial purchase of equipment, which might range from a new and more effective plow for low-till methods (since many existing Soviet and post-Soviet plows are of poor quality steel and would break when exposed to thick stubble), to high-tech equipment that plants different crops in close proximity to one another using GPS locations down to the centimeter. Interestingly, even when the Russia project ceased funded operations, these larger farmers continued to spread the word and organized their own study tours even farther afield, for example to Kansas in 2018.

Common Conclusions:

- With proper extension/training, these methods help farmers save money on manual labor, fuel, and fertilizer by up to a net 50% and can equal or improve yields (by 10% for wheat within first two years, without effect on rice yields), while also helping to conform to laws banning open burning as well as water management (requiring less irrigation).
- There is a prevailing myth that burning is a quick, easy, and cheap option, but informing farmers about the economic benefits of resource conservation methods versus the economics of conventional ones can address the issue of open burning by 90% or more.
- No-burn alternative methods have positive impacts on public health (reducing smog events and local air pollution leading to reductions in cardiac and pulmonary diseases), safety (reduction in wildfires and air and traffic accidents, damaging infrastructure), environment and climate (reduction of black carbon, methane, and tropospheric ozone - short-lived climate pollutants affecting yields as well as melting of snow and ice covered regions), as well as nitrogen and water use (soils are more resilient and resistant to flooding and droughts).
- Maintenance of machinery and equipment for residue management must be supported, beyond simple financial support for purchase or rental. In Punjab, lack of support clearly presented a barrier to adoption for nearly two decades; with such support, demand for the technology grew substantially to include virtually all farmers in the target regions in just the two-year project period.
- If the required machinery and equipment is provided by the government under the subsidy scheme, increasingly large areas can be managed. With the proper resources (human and capital), burning can be all but eliminated.

Available Alternatives to Open Burning

Although no-burn technology and methods are available, not all plots, farmers, and weather conditions are created equal. Nonetheless, with appropriate extension networks and training, the systems for residue management can be effective at lowering costs and improving and/or not affecting yields. These systems can encompass in-situ (on-farm) and ex-situ (off-farm) residue management strategies. In-situ includes reincorporation into soil (although this has its own negative environmental externalities), conservation agriculture (no-till, minimal till, strip till, etc…), and use for feed and fodder. Ex-situ can involve third parties interested in using residue a primary material for energy production (biogas) or for construction (bricks, pellets, furniture).

Conservation Agriculture

Conservation Agriculture (CA) is seen as the most important alternative to conventional burning-tillage agriculture, replacing conventional globally at the annual rate of some 10 M ha of cropland because it offers many benefits to farmers and society. In 2016, CA cropland area covered some 180 M ha globally (12.5% of global cropland). CA systems are ecologically underpinned by three interlinked principles of:

- No or minimum mechanical soil disturbance (through the practice of no-till seeding and crop establishment and no-till weeding)
- Maintenance of soil mulch cover (through the practice of retaining crop residue, stubble and biomass from cover crops)
- Diversified cropping (through the practice of crop rotations or sequences or associations, involving annuals and perennials including legumes).

The above principles when put into practice with locally formulated adapted practices, along with other best management practices of integrated crop, nutrient, pest, water, energy, labor and farm power management, have shown in all continents the ability to address fundamental weaknesses of conventional burn-tillage agriculture.

According to the recent paper "Global spread of Conservation Agriculture" by SSG members Amir Kassam, Theodor Friedrich and Rolf Derpsch (all current or former FAO experts), CA represents is a new paradigm for farming worldwide, changing the production system and agricultural land management thinking. Originally, the adoption of CA was mainly prompted by acute problems faced by farmers, especially wind and water erosion, for example in southern Brazil or the prairies of North America, or by drought in Australia. In all these cases, the farmers' organizations generated knowledge that eventually led to mobilizing public, private and civil sector support. More recently, again pressed by erosion and drought problems coming with climate change, exacerbated by increase in cost of energy and production inputs, government support has accelerated the adoption rate of CA in Kazakhstan, China, India and Pakistan but also in some African countries such as Zambia, Zimbabwe, Malawi and Mozambique among others, and this is attracting support from other stakeholders. In Europe too, there has been greater concern shown by the EU towards soil degradation and the need for greater environmental and soil health management in agriculture. Thus, by means of the Common Agricultural Policy, member states of the EU have been able to provide incentives to farmers to adopt soil and water conservation practices that are also climate-smart.

The main reasons for adoption of CA can be summarized as follows: (1) better farm economy (reduction of production inputs of seeds, fertilizer, pesticides and water, and lower costs in machinery and fuel, and time-saving in the operations that permit the development of other agricultural and non-agricultural complementary activities); (2) flexible technical possibilities for sowing, fertilizer application and weed control (allowing for more timely operations); (3) equal yields or yield increases (depending on the starting level of soil degradation), greater yield stability (as long-term effect) and higher overall seasonal production; (4) soil protection against water and wind erosion; (5) greater nutrient use efficiency and retention; (6) fewer crop protection problems and costs; and (7) better water-use efficiency and retention, and better water economy including in dryland areas.

No-till and cover crops can also be used between rows of perennial crops such as olives, nuts and grapes or fruit orchards, and in palm oil plantation systems. CA can be used for winter crops, for traditional rotations with legumes, sunflower and canola and in field crops under irrigation where it can help optimize irrigation system management to conserve water, energy and soil quality, reduce salinity problems and to make fertilizer use more efficient.

Low-Till Practices

Low-till involves some use of plowing and tillage equipment, but this is minimized and residues are incorporated back into the soil. It shares some of the advantages of full CA, and for many farmers represents an intermediate step from tillage-and-burn agriculture. It also is possible in some ecosystems where organic matter does not decompose quickly enough, for example in very cold or dry winters.

Use as Animal Feed and Bedding

Crop residue can also be used as animal food and bedding. Even if its nutritional value is not the same as the one of a pasture, it can be also of great value for small-scale farmers who need to feed their cattle to survive. Indeed, loss of a viable livestock industry in post-Soviet Russia and Ukraine has been cited as one reason farmers may have begun to burn there, though this cannot be confirmed by lack of satellite records at the time.

Bioenergy

Research organizations and academic institutions such as the Asian Institute of Technology are actively pursuing pilot projects to look at viable ways to sustainably create demand for rice straw, allowing farmers to commoditize waste prone to burning. Rice straw can be converted into biochar, pellets, briquettes, and building materials. Cleaner cookstoves and bioheating technology can use rice straw as fuel, instead of traditional coal, dung paddies (large emitters of methane), and oil and gas. Compared to open burning, these techniques produce lower emissions of air pollutants and climate forcers, and at the same time can reduce the reliance on fossil fuel for cooking.

The use of agricultural residues for energy, unless it occurs directly on-farm requires refineries, transportation and a distribution network. Nevertheless, especially with subsidies this method is becoming increasingly practiced at both the on-farm and regional level, and depends upon the development of local/national markets.

The Transition: What's Needed

Extension Services

Education, training and demonstration plots are the key fact for success for a global transition to no-burn, fire-free agriculture. Results from all demonstration projects show high resulting levels of interest and demand for no-burn technologies and approaches. It is therefore highly important to develop an agricultural extension service, either public or private, to address every area and every farmer. This service should be capable of educating and training farmers in issues related to the new climate-smart agricultural paradigm to generate sustained change.

Equipment

According to FAO, mechanization covers all levels of farming and processing technologies, from simple and basic hand tools to more sophisticated and motorized equipment. Conservation agriculture equipment has been bought or modified with many of these projects to help communities make the transition. There are different options according to the size of the farm/plot: manual, animal-driven or tractor-driven. There are many options around the world as regards machinery. However, this is also a national opportunity to develop national equipment adapted to regional conditions.

In addition, other equipment for residue management can be used such as mowers, balers or windrowers so as to "harvest" residue for use as animal feed or fuel.

Community Engagement and Advocacy

Open burning is also a behavioral problem, and it can be addressed through regular social interaction, shifting the mind-set of farmers and society alike by providing timely and required training and information. Constant engagement and updated, timely, and concise knowledge about advancements in the field of agriculture brings changes in the attitude and behavior of farmers. Involving local institutions such as schools, religious places, and farmer cooperatives can also effectively address the issue of crop residue burning. Recognizing farmers through award ceremonies helps a great deal in motivating them about the importance of rice residue management.

Other examples of action items to be included in information campaigns include:

- Distribution and publication of residue management manuals for farmers, informative leaflets (e.g. through local post offices);

- Media broadcast, infographic video and website design, formulation of social media groups;

- Organization of seminars, press tours, distribution of small stipends for media to facilitate accurate solution-oriented coverage of open burning issues;

- Farmer awareness camps, farmers-scientists meetings, field days with exposure visits to demonstration plots and farms of progressive farmers associated with crop residue management;

- Engagement of institutions such as local administrations, schools and universities, identifying and training of ambassador farmers/opinion leaders.

Market Development

A number of academic and commercial start-ups, many of them associated with the Global Methane Initiative (GMI) and Global Alliance for Clean Cookstoves (GACC), have developed different systems that use straw, and/or biomass to produce bioenergy at the community level. The most effective systems seem to include both manure and stubble, and one of these is under active development in Punjab. Other kinds of alternate use may be possible. IKEA of India has offered for example to develop ways to use rice straw in household products; others have suggested use in brick manufacture; but these thus far appear to be in an early development stage.

In the ICCI/CCAC/PAMETI project in Punjab, it was observed that a promising industry of residue management service provision can be developed, either through public finance or private entrepreneurship. These custom hiring units of residue management and/or direct seeding machinery in the project villages face challenges, however. A training program can also be developed for potential residue management providers for use and upkeep of crop residue management machinery and equipment of the village level cooperatives, farmers' groups and other private enterprises operating such custom hiring units, so that these units become self-sustaining and economically viable models.

Financing

Farmers often need access, including potentially financial assistance, to appropriate equipment. Government subsidies for locally manufactured farming equipment that helps to avoid burning (among many other benefits) have often proven to be a useful tool, including as a component of the ICCI/CCAC/PAMETI pilot project in India, where the government subsidized up to 80% of the cost of the equipment such as the Happy Seeder.

Such financing is not a universal barrier and due to the greater crop yields and less fertilizers used, an issue of initial transition only. ICCI is aware of no instances of regions that have adopted no-burn, especially conservation agriculture techniques returning to use of fire. Farmers simply save money through higher yields and lower costs for fertilizers and fuel.

The potential role of direct subsidies for rapid conversion to no-burn methods should not be ignored. One study in India suggested that farmers might be convinced to cease burning with subsidies as little as $0.05/hectare. Current VIIRS satellite technology could serve a monitoring function for such programs, with subsidies paid out immediately upon planting with a new crop, regardless of the no-burn method chosen. If immediate cessation of burning is desired, this might prove the best initial approach, with more sustainable solutions introduced over time.

Financial incentives even for larger farms may therefore speed this transition. More importantly, medium and small-size farmers will require support to make this transition, lacking the capital needed for initial investment in no-burn equipment such as direct seeders, cover crop seeds, or (on a more expensive scale) equipment for electricity, pellet or biogas production from harvested straw. While some policy elements to encourage a more rapid transition among large commercial farmers will also be an asset, provision of training and education to farmers of all sizes is the desired alternative.

Additional supported investments might include equipment to inject manure into the soil (for combined animal husbandry and crop production), harvest pasturelands for hay rather than burning off excess growth, or support purchase of initial cover crops (plants such as clover or legumes planted in-between cash crops, in essence providing a fertilizing function).

The GCF may serve an important future source of funding for introduction of no-burn agricultural systems. These are especially attractive for several reasons related to GCF goals and requirements: they combine both adaptation and mitigation (most agricultural sector projects to-date involve adaptation alone); and measurement of both avoided emissions, and monitoring for compliance can be achieved in an unusually reliable, real-time, cost-effective manner through use of new satellite technologies and algorithms. Avoided emissions also include an unusually broad array of greenhouse gases, including CO_2, methane and N_2O; as well as black carbon and $PM_{2.5}$.

Additional avoided environmental impacts include avoided erosion, water pollution, eutrophication and flooding from more brittle burned soils. Adaptation benefits include enhanced resilience to extreme weather events (both extreme rain and droughts, due to higher organic matter in soils); and lower water use for irrigation (where appropriate), again due to more organic-rich soils with higher water retention. Economic co-benefits include lower costs for the farmer from lower fertilizer and petrol use (for alternatives that involve incorporation or no-till), and/or additional income from alternative straw use and sale (where applicable markets exist), with the GCF financing making technologies to realize these alternatives and provide education/training for their use.

Necessary pre-conditions for a successful GCF application however ca åresent signficiant barriers. In particular, support from both the national Agriculture Ministry and Finance Ministry (which is usually the GCF National Designated Entity, or NDA), as well as the Environment Ministry is needed. Basic mapping of burning patterns and identification of main burned crops and sectors, as well as alternatives to burning specific to that crop and environment is also a pre-condition.

Finally, inclusion of the need to address burning in some sort of national action plan, in particular climate or land use but also in terms of air quality, agriculture or SLCP action plans. The creation of national “fire-free agriculture action plans” should be seriously considered in this context.

In the meantime, this financing gap may be filled most quickly by bilateral donors and private foundation efforts, especially those aimed at improving health, climate and rural quality of life.

The Key Importance of Monitoring and Evaluation: New Era of Satellite Technology and Support

One key aspect to ensuring valid reductions in GHG and other emissions (black carbon, tropospheric ozone) and related co-benefits is the recent ability to characterize via satellite monitoring the crop vegetation in question, and therefore the related decrease in emissions arising from the farmer’s pledge not to burn over a given period of time.

Current VIRSS satellite technology has allowed for increasingly fine resolution not only of fires or burned areas (the older MODIS technology), but the existing crop prior to burning (or no longer burned). This allows for both verification of compliance with a no-burn pledge, and calculations of avoided emissions over time. Current resolution has been confirmed in 2017 studies as accurate down to the 5 m2 level. For example, three years of emissions from Ecuador open burning are shown below:

YEAR	Black Carbon	CO2	CH4	PM2.5
2015	5,223	13,210,533	41,201	75,531
2016	6,838	21,689,432	75,730	112,904
2017	3,752	11,758,688	42,829	59,089

Ecuador agricultural open burning emissions in metric tonnes (Mg or Mt) only from 375 m VIIRS calculated from 375 m VIIRS, using published emissions from Akagi et al. (2011) and fuel loadings from van Leeuwen et al. (2014).

Similarly, Peru's baseline CO2 annual emissions from all open burning average around 170 million metric tons. The past three years' emissions are shown below. Note that by comparison, Peru's reported total GHG emissions in 2012 were 146Mt:

YEAR	Black Carbon Mt	CO2 Mt	CH4 Mt	PM2.5 Mt
2015	54,605	170,856,059	537,797	940,285
2016	64,944	203,061,615	640,856	1,121,869
2017	45,189	141,136,684	446,023	772,418

Calculated from 375 m VIIRS, using published emissions from Akagi et al. (2011) and fuel loadings from van Leeuwen et al. (2014).

Although not easily quantifiable, some of these emissions occurred from wildland fires, rather than fires on agro-forestry holdings. However, the majority of wildfires and related emissions spread from set fires in the agricultural sector (published governments estimates range from 65-99%) or other human activities such as trash burning. Such wildfires, which are occurring with greater incidence given higher frequency of hot and dry conditions, will also be avoided through increased use of no-burn methods in the agricultural sector: an important co-benefit which would also be monitored at the regional and national level as use of fire in the agricultural sector decreases.

In addition, while negative carbon emissions within agriculture remain difficult to quantify with certainty, ongoing research in this field might make it possible to further characterize or monetize the benefits accruing from no-burn methods over time in terms of carbon drawdown into the soil, especially when conservation agriculture methods are used as the alternative to burning.

Final Note

With its many alternatives that are low-cost or even negative cost; and its many benefits, the shift to no-burn agricultural practices represents a true low-hanging fruit in the agricultural, climate, resilience, adaptation and public health contexts all.

Challenges to addressing open burning exist, but can and must be met with scalable solutions. The CCAC can serve a key role in their promotion and expansion with governments, IGOs and private stakeholders. A combination of development and climate financing, through expansion of capacity-building of extension and training services; with concurrent efforts to create financial incentives for farmers, agribusinesses, and throughout the supply chain is the main thread to ultimate and rapid success, with an aim to eliminate all unnecessary burning in the next decade as a key part of the CCAC's new decadal mission.