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Agriculture Practice

What climate-smart agriculture means for smallholder farmers

McKinsey research identified more than 30 measures that smallholder farmers can pursue to adapt to and mitigate climate change.

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Smallholder farmers[1] generate an estimated 32 percent of global greenhouse-gas (GHG) emissions from agriculture.[2] They are also one of the populations most at risk from climate change. Our analysis shows that in three countries—India, Ethiopia, and Mexico—nearly 80 percent of all smallholder farmers could be affected by at least one climate hazard by 2050 (Exhibit 1). Moreover, climate change will affect land suitability for crop production. For example, by 2050, India could lose 450,000 square kilometers of land currently suitable for rainfed rice cultivation (Exhibit 2).

Stakeholders have focused on climate-smart agriculture for the past two decades. Nonetheless, there is no clear road map for the types of mitigation and adaptation measures smallholder farmers can adopt and how to prioritize investments and efforts to support those measures. In this article, we try to fill this gap. Our work is informed by a geospatial analysis of climate risk in key smallholder markets; an extensive review of current technologies and tools that smallholder farmers can deploy to adapt to and mitigate climate change; and a prioritization of those measures based on agroecological and farming systems in different countries.

Identifying adaptation and mitigation measures that the world's 510 million smallholder farmers can adopt is critical to the protection and support of their livelihoods in the face of climate-related hazards.[3] They are also key to global food security. Smallholder farms produce a third of the world's food, and global food demand is expected to increase by 60 percent by 2050.[4] Meanwhile, climate change has already led to a 21 percent loss of agricultural productivity globally since 1961.[5] In a world where temperatures could rise another 2°C by 2050, there could be large reductions in crop yields if no countermeasures are taken. For example, in Africa, pest-driven losses are expected to increase by 50 percent (compared to the baseline) for staple crops such as maize, rice, and wheat.[6]

These measures are also important for countries with large smallholder populations and those that are making low-carbon pathway commitments, given that they will likely need to help farmers transition to less carbon-intensive agriculture. For example, Kenya has announced a nationally determined contribution (NDC) of reducing 32 percent of emissions by 2030, relative to the baseline. Kenya's agricultural sector is the country's largest source (58.6 percent) of total emissions.[7] So reaching its carbon reduction goals will require the participation of its 4.5 million smallholder farmers (about 80 percent of all farmers) and 600,000 pastoralists.

We identified more than 30 measures smallholder farmers can adopt to help adapt to and mitigate climate change. We also noted several approaches that governments, development partners, and the private sector could pursue to help scale those measures. We found that implementing a prioritized set of three measures at scale in each country could mitigate 45 percent of smallholder farmer–driven carbon emissions. For adaptation, almost every smallholder farmer can adopt at least one on-farm adaptation measure. But about 75 percent can adopt at least three—and the more measures they adopt, the more likely that greater climate resilience could be achieved.

How smallholder farmers can adapt to and mitigate climate change

Adoption of adaptation and mitigation measures among smallholder farmers is complex. Smallholder

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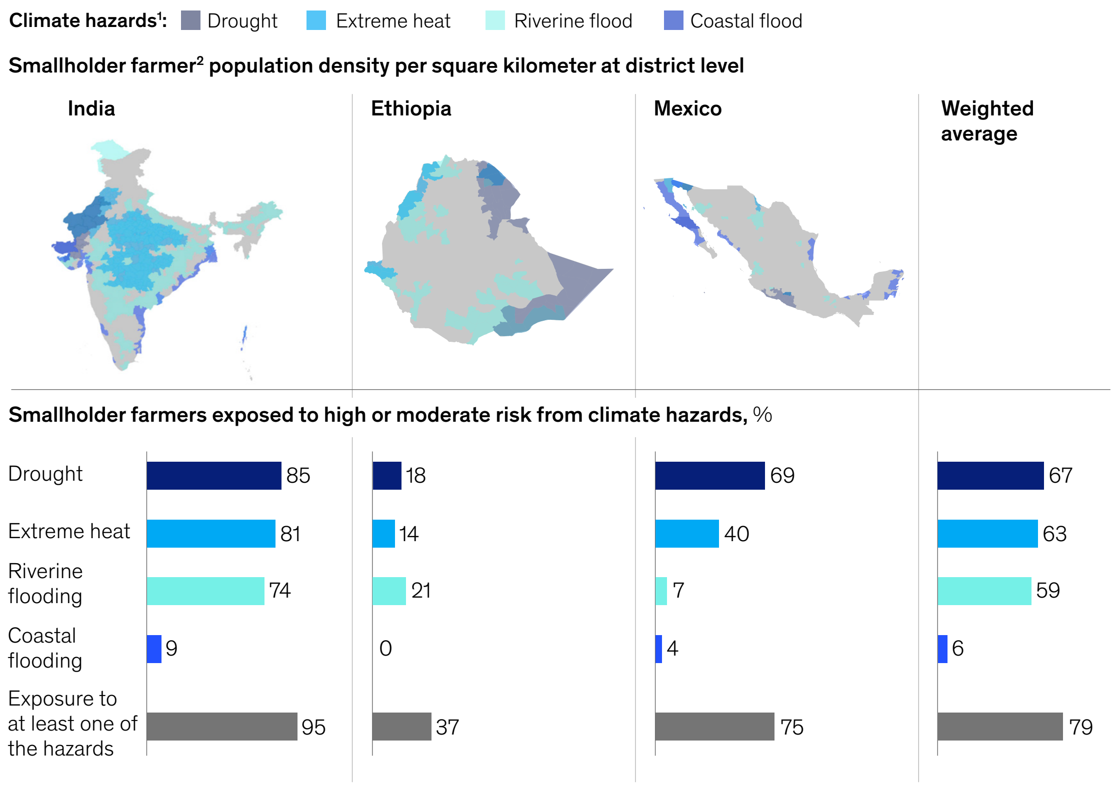
[1] For the purposes of this article, we define smallholder farmers as crop farmers with land sizes of two hectares or less and small-scale livestock producers, including those in extensive livestock systems, such as pastoralists.
[2] Emissions include those from agriculture as well as from agriculture-driven land-use change. Sonja Vermeulen and Eva Wollenberg, "A rough estimate of the proportion of global emissions from agriculture due to smallholders," CGIAR, April 2017.
[3] The 510 million represents the global number of farms of two hectares or less based on Raffaele Bertini, Sarah K. Lowder, and Mario V. Sanchez, "Which farms feed the world and has farmland become more concentrated?" *World Development*, June 2021, Volume 142. Note that this number does not include pastoralists.
[4] José Graziano Da Silva, "Feeding the world sustainably," *UN Chronicle*, June 2012, Volume 49, Number 1 and 2.
[5] Ariel Ortiz-Bobea et al., "Anthropogenic climate change has slowed global agricultural productivity growth," *Nature Climate Change*, April 2021, Volume 11.
[6] C. H. Trisos et al., "Africa," in *Climate change 2022*, February 27, 2022.
[7] "Climate-smart agriculture in Kenya," CIAT, CGIAR, and The World Bank, October 2015.

Exhibit 1

Nearly 80 percent of smallholder farmers in India, Ethiopia, and Mexico could be affected by at least one climate hazard.



Note: The boundaries and names shown on the maps do not imply official endorsement or acceptance by McKinsey & Company.
[1]Denote an area's exposure to climate hazards of drought, extreme heat, riverine flooding, and coastal flooding in a 2°C scenario. Based on a high-emission RCP 8.5 scenario, reaching 2°C global warming in year 2050.
[2]Includes crop farmers and extensive livestock farmers. Based on 2020 population estimate.

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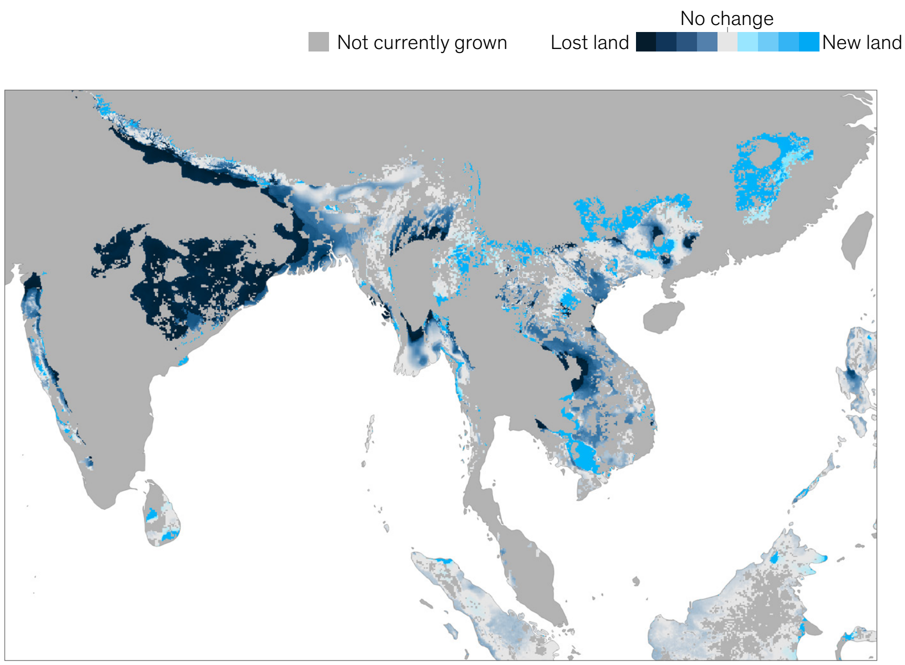
We identified more than 30 measures smallholder farmers can adopt to help adapt to and mitigate climate change.

Exhibit 2

By 2050, India could lose 450,000 square kilometers of land currently suitable for rainfed rice cultivation, while Southeast Asia will gain suitable land.

Change in land suitability for rainfed rice at 2°C global warming (2050 vs 1990) across production regions[1]



Note: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.
[1]Future suitability was calculated at RCP 8.5 for each of five Coupled Model Intercomparison Project (CMIP) phase-5 general circulation models, chosen based on performance in temperature and precipitation metrics and accessed via WorldClim: CCSM4, GFDL-CM3, MPI-ESM-LR, HadGEM2-ES, and NorESM1-M. The ensemble mean of the five climate models is presented here. The mean is over the 1981–2000 vs 2040–59 period. The land suitability map is masked by the 2010 rainfed production areas (MapSPAM).
Source: European Space Agency, Climate Change Initiative Land Cover website (ESACCI-LC), land-use data; FAOSTAT agricultural production data; Food and Agriculture Organization of the United Nations (FAO) Crop Ecological Requirements Database (ECOCROP); Integrated Biodiversity Assessment Tool (IBAT) World Database on Protected Areas (WDPA), protected areas data; International Soil Reference and Information Centre (ISRIC) soil depth data; ISRIC soil pH data; Shuttle Radar Topography Mission (SRTM) elevation data; WorldClim climatic data; McKinsey ACRE Land Suitability Model

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farms are fragmented and often have limited access to inputs, new agricultural technologies, and financing. However, as previously mentioned, we identified more than 30 measures smallholder farmers can pursue for adaptation and mitigation. We divide these measures into five categories: animal production practices, rice-based measures, other crop-based measures, land-use change and intensification, and postharvest and processing loss (Table 1). We separate rice measures from other crops because emissions from rice production are anywhere from five to 30 times higher per hectare than those from other crops.[8]

Of these measures, some are limited to climate adaptation, such as eco-engineering reefs to protect coastlines from flooding and the introduction of pest-tolerant crop varieties. Others are exclusively mitigation measures, such as GHG-focused livestock breed selection and scaling solar-powered irrigation. But many measures have both adaptation and mitigation benefits. For example, introducing irrigation to increase productivity has an indirect mitigation effect, allowing farmers to grow more crops on less land and therefore reducing the amount of land needed for agriculture. But irrigation also has an adaptation benefit by allowing farmers

[8] This range depends on the type of crop with which rice is compared.

Table 1. Thirty-three mitigation and adaptation measures relevant to smallholder farmers

Theme		Measure	Mitigation	Adaptation
Animal production practices	**1**	Improve breeding systems (breed selection and breeding or insemination timing management) for increased productivity and reduced greenhouse-gas (GHG) emissions (with GHG-focused breed selection)	●	
	2	Intensify fodder production to reduce extensive grazing for dairy cattle and reduce emissions from land-use conversion	●	
	3	Expand use of feed processing for improved digestibility to reduce methane emissions from enteric fermentation	●	
	4	Optimize animal feed composition and transition to diets that reduce methane production from enteric fermentation	●	
	5	Integrate livestock and crop systems to reduce nutrient losses (ie, management of farm-level nutrient flows and losses from manure) to reduce further input requirements and related emissions	●	
	6	Improve animal health monitoring and illness prevention to control disease outbreaks (predicted to increase with warming climates), thereby increasing productivity and creating emissions savings	●	●
	7	Improve timing of livestock sales (eg, by weight, age, and time of year) to maximize productivity and reduce GHG-emissions footprint per head	●	
	8	Optimize stocking rate (livestock heads per hectare) according to land capacity to minimize land degradation and maximize grassland and livestock performance		●
	9	Scale rotational grazing and rangeland restoration to improve grassland health and increase soil carbon content	●	●
Crop production practices: Rice	**10**	Utilize dry direct-seeding technology and optimize rice variety selection (eg, aerobic rice that grows in nonflooded fields) to increase productivity and reduce methane emissions from rice paddies as well as reduce reliance on water	●	●
	11	Improve water management to reduce methane emissions in rice paddies	●	
	12	Improve placement of fertilizer (eg, urea deep fertilization) to reduce emissions from nitrogen fertilizer use	●	
	13	Improve rice straw management by incorporating crop residues into paddy soil to maintain and enhance soil fertility and carbon storage	●	●
Crop production practices: Other crops	**14**	Expand use of new pest management practices (eg, seeds, IPM[1]) to maintain productivity in the face of projected increased pest and disease threats in a warming climate		●
	15	Expand use of drought-tolerant crop varieties to maintain productivity in the face of projected increased rainfall variability		●
	16	Scale low- or no-tillage farming to minimize soil disturbance and retain organic soil cover	●	●
	17	Intercrop[2] to improve soil health, reduce pest and disease outbreaks, and optimize fertilizer use	●	●
	18	Expand use of crop rotations and cover cropping using legumes or a mix that includes a legume to improve soil health and reduce nitrogen application	●	●

Theme		Measure	Mitigation	Adaptation
Crop production practices: Other crops	**19**	Expand use of soil testing to guide fertilizer application, increasing yields, improving soil health, and reducing overall fertilizer application	●	●
	20	Reduce overapplication of nitrogen fertilizers in India and China to reduce emissions associated with fertilizer losses	●	
	21	Expand use of soil amendments (eg, manure, compost, crop residue, lime, biochar, and various inoculations) to improve soil health	●	●
	22	Switch to other crops better suited to climate-related land suitability changes to ensure long-term sustainability		●
Land use change and intensification	**23**	Expand adoption of effective rainwater harvesting (eg, with earth or stone-works) to prolong access to water and reduce runoff, improving soil health and reducing fertilizer losses	●	●
	24	Introduce irrigation (from exclusively rainfed farming) to increase productivity and resilience in relation to increased rainfall variability, and reduce risk of land use change and related emissions	●	●
	25	Transition to drip or sprinkler irrigation (from flood irrigation) to improve water efficiency and reduce soil erosion, improving soil health and reducing fertilizer losses	●	●
	26	Scale solar-powered irrigation (from petrol pump irrigation) to reduce emissions from fossil fuel–powered alternatives	●	
	27	Electrify on-farm machinery and equipment (except scaling solar-powered irrigation) to reduce fossil fuel–powered alternatives	●	
	28	Develop eco-engineering (use of ecology and engineering to restore and protect ecosystems) of reefs to protect mangrove forests to provide coastal flood buffers, protecting coastal agriculture		●
	29	Expand agroforestry (integrating trees into cropland for firewood, forestry-based land restoration, and diversified income) to improve ecological functions, improve soil water storage, increase soil productivity, reduce erosion, improve the microclimate, and buffer against climate variability—all while increasing carbon sequestration and reducing the need for deforestation for fuelwood	●	●
Postharvest and processing losses	**30**	Improve loss management in meat and dairy production (eg, through solar cold-chain storage)	●	
	31	Introduce mechanization in rice farming to reduce food loss and associated emissions	●	
	32	Reduce on-farm postharvest crop loss through improved storage and packaging	●	
	33	Utilize crop waste (eg, for animal feed, biomass energy production, biochar production, biofuel generation and composting), particularly in lieu of burning, to reduce related emissions	●	

[1] Integrated pest management. This is application of a combination of all available pest control techniques (biological, chemical, physical, and cultural) that discourage the development of pest populations and minimize the use of chemical pesticides.
[2] Intercropping is growing two or more crops together in a field, where the combination results in higher yields due to making use of ecological resources or processes that a monocrop cannot produce (eg, through increased water retention and provision of shade).
Source: McKinsey ACRE geospatial analysis; McKinsey Marginal Abatement Cost Curve (MACC) model

to continue to grow certain crops despite climate change–related increases in water stress and drought. (See sidebar, "About the research," for an explanation of adaptation and mitigation and the methodology under which these measures were derived and prioritized; see the technical appendix for the case studies on which each measure is based.) While we focus on carbon emissions and climate adaptation in this article, it is important to note that these measures also have important nature-related benefits. These include reducing land-use change, decreasing nutrient runoff into waterways by moderating fertilizer application, and adopting integrated pest management practices.

Each measure is based on a proven trial in a smallholder farming environment. For example, one measure related to animal production practices focuses on improving livestock breeding systems for increased productivity and reduced GHG emissions. The approach was used in Malawi and Uganda for a community-based goat-breeding program with 269 farmers. In the program, goats reached a higher average weight (from 16 kilograms to 19 kilograms with the improved breeding) and survival rates (from 72 percent to 91 percent); emissions were also reduced.[9]

As another example, in rice production, straw management can be used to maintain and enhance soil fertility and carbon storage. One case from Vietnam showed that the direct incorporation of rice residues into soils after harvest led to increased soil organic carbon by about three metric tons per hectare. The approach also significantly reduced the amount of chemical fertilizer required to achieve the same yields by returning nutrients to the soil.[10] For other crops, greater use of a combination of six tillage, residue management, and intercropping practices in legume–rice–wheat cropping systems in India resulted in the lowest emissions. The practices led to 823 to 3,301 kilograms of CO_2-equivalent sequestered per hectare per year compared with 4,113 to 7,917 emitted per hectare per year in typical farming practices, as well as a 29 percent decrease in water usage.[11]

Prioritizing investments in adoption of on-farm adaptation and mitigation measures

The choice of measures to invest in depends on multiple factors, including a country's farming system; farmers' access to markets, which is an indicator of their ability to access other actors such as sales agents for seed companies that sell new drought-resistant seed varieties; cost of adoption; and capabilities required. Taking these factors into account, we prioritized measures using geospatial analysis in three countries: India, Ethiopia, and Mexico. Together, they are home to more than 40 percent of the global smallholder farmer population and generate about one metric gigaton of GHG emissions from agriculture.[12] The results highlight not only areas of commonality across smallholder systems but also the importance of a differentiated approach by country and subnational region.

How adaptation measures vary by country

Priorities for adaptation differ by country. These differences are mainly driven by varied exposure to climate change hazards and by the farming systems used in the exposed areas (Table 2). For example, using drought-tolerant seed varieties is much more applicable in drought-prone India or Mexico than in Ethiopia. This is because pastoral livestock systems dominate the drought-prone regions of Ethiopia rather than crop production. Moreover, as shown in Exhibit 1, more farmers in India (95 percent of the total) are exposed to at least one risk, and most are exposed to multiple risks, which requires the adoption of multiple adaptation measures. In Ethiopia, on the other hand, 37 percent of farmers are exposed to at least one risk, and few

[9] Wilson Kaumbata et al., "Experiences from the implementation of community-based goat breeding programs in Malawi and Uganda: A potential approach for conservation and improvement of indigenous small ruminants in smallholder farms," *Sustainability*, February 2021, Volume 13, Number 3.

[10] Dao Trong Hung et al., "Rice-residue management practices of smallholder farms in Vietnam and their effects on nutrient fluxes in the soil-plant system," *Sustainability*, March 2019, Volume 11, Number 6.

[11] Tek B. Sapkota et al., "Global warming potential through sustainable intensification of basmati rice-wheat systems in India," *Sustainability*, June 2017, Volume 9, Number 6.

[12] Calculation based on indicators found on the FAOSTAT Emissions Totals database.

About the research

In our research, we looked at adaptation and mitigation levers that smallholder farmers could adopt.

This research involved geospatial and land suitability analytics from McKinsey's ACRE team (our agriculture advanced-analytics center) and geospatial climate hazard analysis from our Climate Analytics team.

Adaptation addresses the impact of climate change. It refers either to actions taken to reduce vulnerability to the current and future effects of climate change or to taking advantage of opportunities created by climate change. These actions include switching to other crops better suited to climate-related land changes, expanding the use of drought-tolerant crop varieties, and using dry direct-seeding technology for rice.

Mitigation measures focus on the causes of climate change. They are actions taken to reduce and curb the increase of greenhouse-gas (GHG) emissions. Mitigation is achieved either by reducing the sources of these gases or by enhancing the storage of them—for example, by increasing the size of forests. Some measures include reducing the overapplication of nitrogen fertilizers (especially in China and India), scaling rotational grazing and rangeland restoration, or optimizing animal feed composition to reduce methane produced from enteric fermentation.

We followed a three-step process to determine priority measures that smallholder farmers could adopt:

— We identified 33 climate adaptation and mitigation measures through a comprehensive literature review to determine measures that have been tested with—or are actively being implemented by—smallholder farmers in different countries and that have been demonstrated to be effective.

— We evaluated the theoretical scale of adoption of these measures for India, Ethiopia, and Mexico. We chose these countries because they contain more than 40 percent of the global smallholder farmer population, they come from three regions (Africa, Asia, and Latin America) where smallholder farms are dominant, and they have strong data availability. We based the evaluation on a geospatial analysis at a ten-by-ten-kilometer resolution of crop and livestock production types (using more than 30 crop types and dairy and meat from cows, goats, sheep, and buffalo) and four production systems (irrigated high-input production; rainfed, high-input, and commercial production; rainfed, low-input production; and rainfed, low-input, and subsistence production). We also layered on measure-specific factors such as access to surface water, distance to a coastal ecosystem, and soil type.

— We prioritized measures based on impact and feasibility criteria:

  - For adaptation, we based prioritization on the scale of exposure to the most relevant climate hazards, such as drought, extreme heat, and coastal and riverine flooding.

  - For mitigation, we based prioritization on two factors: impact and feasibility. Impact was measured using GHG-emission-reduction potential. This was determined by calculating the area of farmland where measures could technically be implemented—or calculating the number of livestock heads for which measures could be implemented based on the theoretical scale of adoption described above—and multiplying it by expected GHG reduction potential per hectare or per livestock head based on findings from research trials. Feasibility was evaluated based on three criteria: cost (a qualitative assessment of whether the measure is capital intensive; requires an increase in operational expenses, including labor or inputs; or is cost neutral); capabilities required to implement a measure (an assessment of whether the measure required a single agronomic practice change with standard technical assistance or a more complex multiprocess change with specialized support); and access to market (a sliding scale, with "good" market access defined as a one-day round trip, four hours each way, from the nearest large market center).

Table 2. Priority adaptation measures

Percent of smallholder farmers (for all nonlivestock levers) and livestock heads (for all livestock levers) exposed to climate hazards and for which measure is applicable

Rank within lever type: ● Soil health ● Adaptation of crop varieties ● Irrigation or water ● Other ● Livestock

Nonlivestock levers

Rank	India			Ethiopia			Mexico		
1	17	Intercrop to improve soil health	95%	17	Intercrop to improve soil health	37%	17	Intercrop to improve soil health	75%
2	19	Expand use of soil testing to guide fertilizer application	95%	19	Expand use of soil testing to guide fertilizer application	37%	19	Expand use of soil testing to guide fertilizer application	75%
3	14	Expand use of new pest management practices (eg, seeds, IPM[1])	91%	14	Expand use of new pest management practices (eg, seeds, IPM)	33%	23	Expand adoption of effective rainwater harvesting	69%
4	23	Expand adoption of effective rainwater harvesting	85%	21	Expand use of soil amendments	19%	14	Expand use of new pest management practices (eg, seeds, IPM)	59%
5	15	Expand use of drought-tolerant crop varieties	83%	23	Expand adoption of effective rainwater harvesting	18%	15	Expand use of drought-tolerant crop varieties	55%
6	29	Expand agroforestry	78%	15	Expand use of drought-tolerant crop varieties	16%	16	Scale low or no-tillage farming	38%
7	21	Expand use of soil amendments	66%	16	Scale low or no-tillage farming	13%	18	Expand use of crop rotations	23%

Livestock levers

Rank	India			Ethiopia			Mexico		
1	6	Improve animal health monitoring and illness prevention	96%	6	Improve animal health monitoring and illness prevention	52%	6	Improve animal health monitoring and illness prevention	63%
2	8	Optimize stocking rate (livestock head per hectare) according to land capacity	65%	8	Optimize stocking rate (livestock head per hectare) according to land capacity	50%	8	Optimize stocking rate (livestock head per hectare) according to land capacity	62%
3	9	Scale rotational grazing and rangeland restoration	65%	9	Scale rotational grazing and rangeland restoration	50%	9	Scale rotational grazing and rangeland restoration	62%

Note: Lever 22 ("Switch to other crops better suited to climate-related land suitability changes") is applicable to all countries but is not shown here because it is not sized, given the complex analysis required to determine land suitability changes and optimization of crop mix for each country and subnational area.
[1] Integrated pest management.

face multiple risks. Nonetheless, resilience is likely to increase for any farmer who adopts multiple measures. Our analysis shows that about 75 percent of smallholder farmers in these three countries could adopt the three highest-priority measures.

How mitigation measures vary by country

From a technical point of view, the breadth of application of all the measures combined would allow the vast majority (90 percent) of farmers in the three countries to adopt at least one mitigation measure. However, the applicability of measures varies across and within countries, driven by different farming systems and practices that lead to different emission mixes (Exhibit 3). For example, fertilizer application rates are more than five times higher in India than in Ethiopia, which means that soil- and fertilizer-related mitigation measures are much more applicable in India.[13]

When layering on feasibility criteria, the top ten mitigation measures highlight important differences by country (Exhibit 4 and Table 3). In India, given its large crop production (and rice production, in particular), rice- and crop-based measures account for nine of the ten priority measures. About 50 percent of smallholder farmer–driven agriculture emissions in India could be mitigated by scaling agroforestry and transitioning to more sustainable rice production practices on smallholder farms. Agroforestry alone represents the largest opportunity, with a mitigation opportunity seven times that of the next most impactful measure of incorporating rice straw into soils.[14] This is consistent with the launch of India's National Agroforestry Policy in 2014. India is the first nation to introduce such a plan to mitigate climate change and increase the resilience of smallholder farmers.

In Ethiopia and Mexico, where cattle production systems are more common, livestock-related measures dominate and could collectively mitigate up to 25 percent and 35 percent of emissions, respectively. In Mexico, 60 percent of land is considered arid or semiarid, with a substantial area dedicated to the range farming of livestock. As a result, one of the largest mitigation opportunities[15] lies in regenerative rangeland management. In Ethiopia, the livestock sector is responsible for 60 percent of agricultural emissions.[16] Thus, Ethiopia's emission-reduction potential is mostly associated with livestock-based measures (eight of the top ten), with rangeland management, improved timing of livestock sales, increased adoption of veterinary services, and feed-based measures making up a significant proportion of the opportunity.

In aggregate, these countries could achieve about 455 metric megatons of CO_2-equivalent emissions savings—collectively about 45 percent of the total smallholder farmer–driven agriculture emissions from India, Ethiopia, and Mexico—by implementing only the top three prioritized levers across smallholder farms in a comprehensive and widespread manner.

Driving adoption of these measures will require solutions at the farm and agriculture-system levels.

[13] "Fertilizer consumption (kilograms per hectare of arable land)," The World Bank, accessed December 20, 2022.

[14] We define agroforestry as land suitable for trees to grow in a range of grass- and crop-based systems and with a tree density of 45 or more trees per hectare.

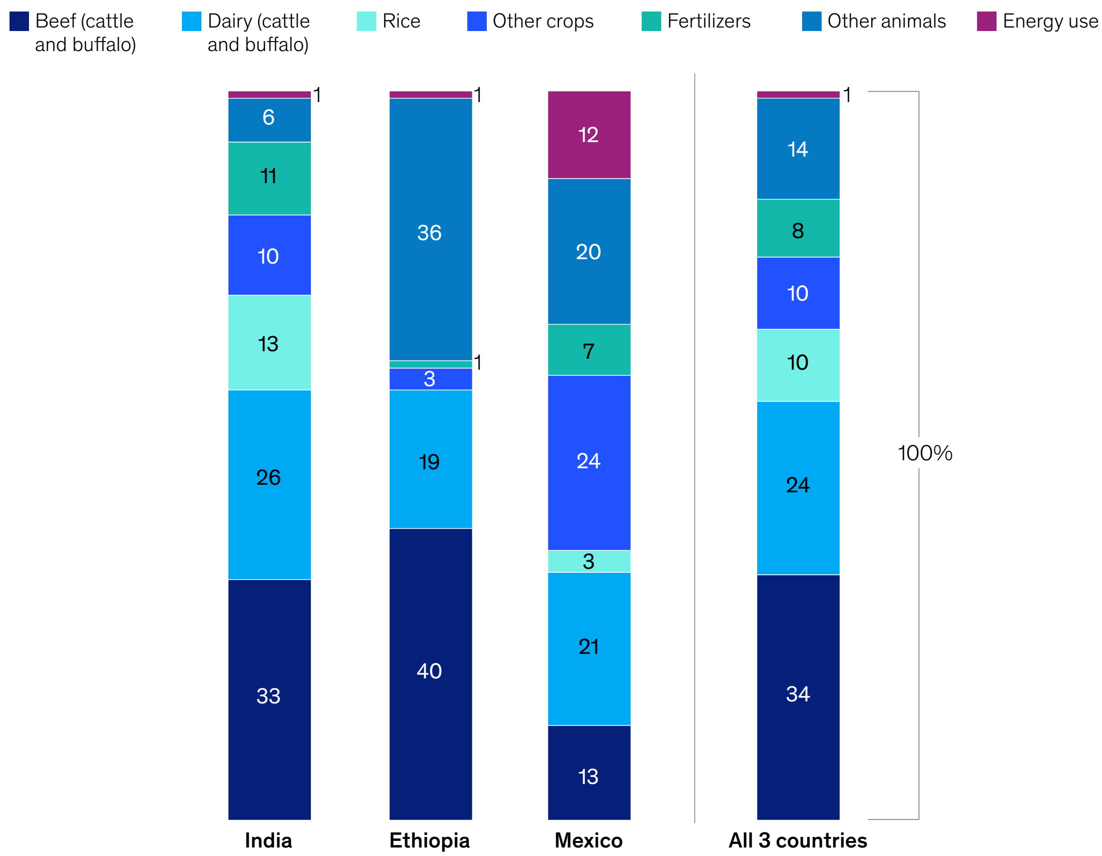
[15] Paulina Alejandra Pontifes et al., "Land use/land cover change and extreme climatic events in the arid and semi-arid ecoregions of Mexico," *Atmósfera*, August 2018, Volume 31, Number 4.

[16] Andreas Wilkes et al., *Inventory of greenhouse gas emissions from cattle, sheep and goats in Ethiopia (1994-2018) calculated using the IPCC Tier 2 approach*, CGIAR, 2020.

Exhibit 3

Smallholder farmer–driven emissions across India, Ethiopia, and Mexico differ greatly.

Percentage breakdown of smallholder farmer–driven emissions[1]



Note: Figures may not sum to 100%, because of rounding.
[1]Percentage breakdown is directional and not inclusive of land use, land-use change, and forestry (LULUCF) and fires.
Source: McKinsey analysis

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These countries could achieve about 455 metric megatons of CO_2-equivalent emissions savings … by implementing only three levers.

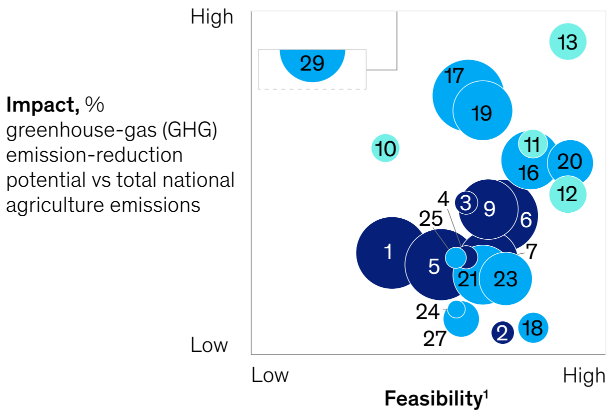
Exhibit 4

India's mitigation opportunities are highest for crop measures (especially rice), whereas Ethiopia's and Mexico's are with livestock.

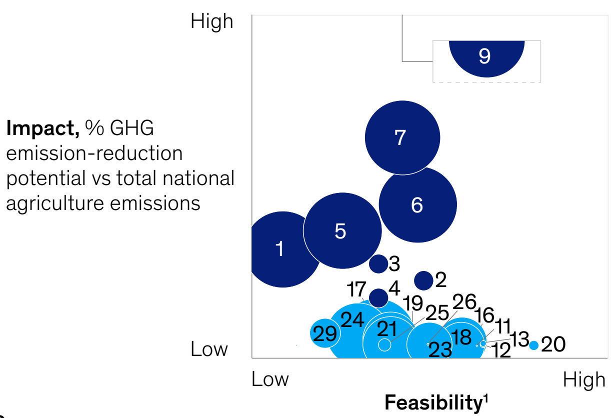
Emissions mitigation potential plotted against feasibility of measure implementation across the three focus countries

- Livestock: Size = % livestock head measure is relevant for
- Crop or land (nonrice): Size = % smallholder farmer population measure is relevant for
- Rice: Size = % smallholder farmer population measure is relevant for (rice measures)

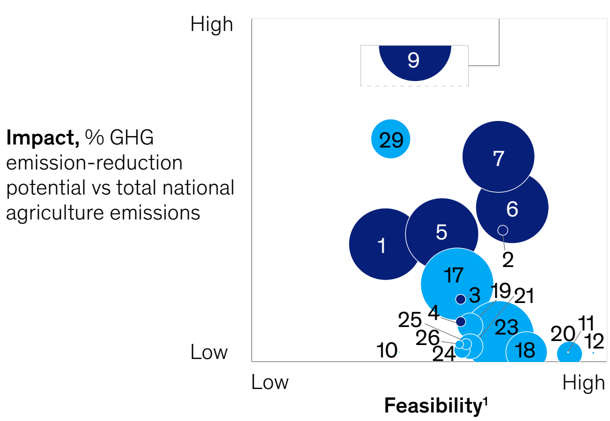
India



Ethiopia



Mexico



[1]Feasibility is based on a composite score of cost of adoption, ease of adoption, and access to markets.

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Table 3. Priority measures by country

Rank within lever type: ● Rice-based measures ● Crop- or land-based measures ● Livestock-based measures

Rank	India		Ethiopia		Mexico	
1	29	Expand agroforestry	9	Scale rotational grazing and rangeland restoration	9	Scale rotational grazing and rangeland restoration
2	13	Improve rice straw management by incorporating crop residues	7	Improve timing of livestock sales to maximize productivity and reduce emissions	29	Expand agroforestry
3	17	Intercrop to improve soil health and reduce pest and disease outbreaks	6	Improve animal health moni-toring and illness prevention to maximize productivity	7	Improve timing of livestock sales to maximize productivity and reduce emissions
4	19	Expand use of soil testing to guide fertilizer application	5	Integrate livestock and crop sys-tems to reduce nutrient losses and need for more inputs	6	Improve animal health moni-toring and illness prevention to maximize productivity
5	11	Improve water management to reduce methane emissions in rice paddies	1	Improve breeding systems for increased productivity and reduced emissions	2	Intensify fodder production to reduce extensive grazing and associated land-use change
6	10	Utilize dry direct-seeding technology and optimize rice variety selection to reduce meth-ane emissions	3	Expand use of feed processing for improved digestibility to reduce methane emissions	5	Integrate livestock and crop sys-tems to reduce nutrient losses and need for more inputs
7	16	Scale low- or no-tillage farming to minimize soil disturbance	2	Intensify fodder production to reduce extensive grazing and associate land-use change	1	Improve breeding systems for increased productivity and reduced emissions
8	20	Reduce overapplication of nitro-gen fertilizers	4	Optimize the animal feed com-position	17	Intercrop to improve soil health and reduce pest and dis-ease outbreaks
9	12	Improve placement of fertilizer (eg, urea deep fertilization)	29	Expand agroforestry	3	Expand use of feed processing for improved digestibility to reduce methane emissions
10	3	Expand use of feed processing for improved digestibility to reduce methane emissions	24	Introduce irrigation (from exclu-sively rainfed farming)	16	Scale low- or no-tillage farming to minimize soil disturbance

Implications for actors seeking to support adaptation and mitigation for smallholder farmers

Governments, financiers, development organi-zations, and private-sector players have a key role to play in supporting the global smallholder-farming community's shift to more sustainable practices. Our analysis highlights two important considerations for this support.

First, as described above, it is important to prioritize which measures to focus on at a subnational level given the heterogeneity of smallholder farmer production systems, the range of impact, and the feasibility of adoption. This prioritization exercise could enable the identification of clusters of smallholder farms in which multiple measures are feasible for adoption and piloting could begin.

On this point, concerns such as market access are critical. For example, in India, almost all farmer types are within four hours of a market by road. By comparison, in Ethiopia, as few as 10 percent of farmers have market access in some areas because of greater population dispersion and less-developed infrastructure. This low market access suggests a potentially higher cost per farmer to implement measures at scale.

Second, driving adoption of these measures will require solutions at the farm and agriculture-system levels. Not only will farmers have to consider changing on-farm practices, but national agriculture research systems will also have to reflect on how to develop and commercialize new technologies, such as drought-tolerant seeds. Additionally, stakeholders will have to consider investments such as improved infrastructure to build resilience in the face of climate volatility. Government and private-sector actors will also have to consider building market linkages for crops in different areas because farmers might switch crops due to changing land suitability, as described earlier.

We identified several cross-cutting approaches that could help scale priority measures (Table 4). These solutions start with building a climate risk–adjusted agriculture and land management plan that geospatially prioritizes adaptation and mitigation measures at a subnational level and that ties investments to that prioritization. The solutions also include developing financing and incentive mechanisms to encourage on-farm practice shifts (for example, redesigning subsidy schemes, offering tax incentives, and linking farmers to carbon markets); putting system enablers in place (investing more in R&D and scaling traceability systems); and mitigating climate-induced volatility (scaling up crop insurance and integrating climate modeling into food security planning).

Few of these cross-cutting approaches have been applied in practice, given that the discussion of adaptation and mitigation for smallholder farmers is relatively new. However, there are some pilots under way. In China, for example, the government changed its subsidy policies to discourage use of chemical fertilizer for specific crops and encourage the adoption of organic fertilizer substitutes, with a particular focus on reducing nitrogen overapplication. This policy has helped reduce the application of chemical fertilizers by 111.5 kilograms per hectare in pilot counties and increase the use of organic fertilizers by 346.36 kilograms per hectare for sampled farmers. One estimate found that such policy reforms could reduce fertilizer use by 30 percent compared with current rates.[17]

Additionally, the International Food Policy Research Institute's modeling of historic data in Punjab, India, has been used to project the effect of removing the subsidy for groundwater extraction, eliminating minimum support price policies for water-intensive crops, and reallocating subsidies to climate-smart technologies such as crop diversification, low tillage, and on-farm rainwater-harvesting ponds with solarized pumps and microirrigation. The modeling suggests there is potential to reduce water consumption by 15 billion cubic meters per year and reduce GHG emissions by 23 million metric tons by 2050. The modeling also finds that there will ultimately be no change to Punjab's budget if subsidies for groundwater extraction are reallocated as incentives for the adoption of climate-smart agriculture practices.[18]

Development partners and private actors are also implementing pilots to support adoption of climate-smart measures. One Acre Fund, a social enterprise that works with more than one million smallholder farmers in Africa, is expanding an agroforestry program, exploring the link to carbon credit markets to offer incentives for on-farm tree planting.[19]

Others are using financial innovation to support climate-smart agriculture and resilience. F3 Life and Financial Access piloted a Climate-Smart Lending

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Table 4. Cross-cutting solutions to scale adoption of the prioritized measures

		Primary actor		
Type	**Macrosolutions**	**Government**	**Development partners**	**Private sector**
Plan and prioritize at a national and subnational level	— Develop a climate risk-adjusted sustainable agriculture investment and land management plan at national and subnational levels including the following:			
	• Geospatially prioritized adaptation and mitigation measures at a subnational level, identifying clusters where multiple measures are feasible to focus efforts at the start	✓	✓	
	• Opportunities for land-use optimization tied to financing and incentive mechanisms, such as where to encourage migration of production to alternative crops or more favorable locations, planning where to give (or no longer give) agriculture land leases, and establishment of nature-based solutions (eg, mangrove forest expansion for carbon sequestration)	✓		
	• Plan for internal climate migrations (including estimation on number of people, supporting programs such as education and job training to diversify livelihoods, inclusion and participation of marginalized and displaced populations, and access to social services)	✓		
	— A revised national agriculture budget and investment plan tied to above and transparent to all	✓		
Develop financing and incentive mechanisms to encourage shifts	— Redesign subsidies to offer incentives for the adoption of adaptation and mitigation measures (eg, reduce subsidies for nitrogen fertilizers or introduce targeted subsidies to promote growing specific crops in areas according to the land management plan)	✓		
	— Develop land buyout products aligned with land-use optimization assessment	✓		
	— Introduce tax incentives to increase adoption of prioritized adaptation and mitigation measures (eg, reduced land tax for farmlands with mixed-use systems, sales tax exemptions for specific inputs such as drought-resistant seeds)	✓	✓	✓
	— Link farmers adopting mitigation measures to carbon markets through aggregators		✓	✓
	— Design agriculture lending products specifically linked to adoption of prioritized adaptation and mitigation measures		✓	✓

Table 4. Cross-cutting solutions to scale adoption of the prioritized measures (continued)

		Primary actor		
Type	**Macrosolutions**	**Government**	**Development partners**	**Private sector**
Develop financing and incentive mechanisms to encourage shifts (continued)	— Launch a results-based payments scheme tied to achievement of goals under the agriculture investment and land management plan	✓	✓	
	— Explore regulatory measures (eg, limiting legal limit of nitrogen per ha, imposing a minimum tree cover per hectare)	✓		
Put system enablers in place	— Scale investment in R&D and commercialization of technologies for mitigation and adaptation (eg, for pest-resistant seeds, livestock breeds, fertilizer coatings, and biostimulants)	✓	✓	✓
	— Redirect and reinforce extension systems for crops and livestock to focus on subnational priorities as per the investment and land management plan, leveraging digital where relevant	✓	✓	
	— Improve traceability systems and sustainability certifications for applicable crops (likely most applicable to high-value crops—eg, coffee or cocoa) to drive adoption of mitigation and adaptation measures linked to those certifications	✓		✓
	— Invest in market linkages (eg, supply chain infrastructure or offtake agreements) for new crops in different areas based on expectations on evolving land suitability for crop production			✓
	— Invest in downstream infrastructure to reduce postharvest losses (eg, storage facilities and cold chain or regulations on storage conditions)			✓
Mitigate climate-induced volatility	— Incorporate climate change intelligence and predictive analytics into food security planning (eg, leverage insights from climate risk analysis and early warning systems to proactively adjust production, storage, trade and distribution efforts; ensure policy coordination to mitigate crop price crises)	✓	✓	
	— Scale up crop insurance mechanisms (eg, weather index insurance targeting smallholder farmers)			✓
	— Invest in resilience-related infrastructure (eg, flood protection, water storage)	✓	✓	

Platform in 2017 with 10,000 farmers in Kenya and Rwanda. They worked with lenders to develop loan products that featured terms and conditions encouraging farmers’ uptake of climate-smart agricultural and land management practices and use of mobile technology to monitor the adoption of climate-smart farming in compliance with loan agreement requirements.[20] Pula, an insurance tech start-up in Africa, has provided agriculture insurance to 6.8 million farmers,[21] including products to address weather-related yield impacts.

Resilience-related infrastructure is being put in place in even the most remote and low-tech contexts. For example, “contour bunds” (low walls) combined with Zai pits[22] have been established in 200,000 to 300,000 hectares of land across the Sahel. The approach almost doubled the yield of cereals, despite frequent droughts.[23]

This is not a comprehensive list of macroscale solutions. But they illustrate some powerful initiatives stakeholders can pursue to support the scaling of adoption of adaptation and mitigation measures among smallholder farmers.

Additionally, actors can support further research to inform decision making. For example, the cost to adopt and scale these measures is largely unexplored in the currently available literature. While we use a qualitative assessment on cost, understanding the true costs is critical in making trade-offs on what measures to choose. Another research question could explore the effectiveness of various measures, particularly regarding adaptation where there is no common metric or set of metrics. Finally, extensive piloting would be helpful to test which macrosolutions are most effective in encouraging farmers to adopt priority measures and to develop and derisk sustainable business models to support adoption.

Smallholder farmers can adopt a range of measures to mitigate and adapt to the risks of climate change. Governments and other stakeholders could consider supporting them in their efforts to adopt sustainable farming practices. In doing so, stakeholders could reflect on the national context in which they are working and collaborate to identify adaptation and mitigation priorities. The prioritization would ultimately act as a North Star and would feed into an agriculture land management plan to inform a more efficient allocation of investment and effort, from innovative financing mechanisms to targeted research and development and technology innovations. Climate change is already creating huge losses for smallholder farmers globally. To achieve a 1.5° pathway, responsible actors have no time to lose in supporting the sustainable smallholder farmer community.

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[21] *Agricultural insurance for smallholder farmers: Digital innovations for scale*, GSMA, 2020.
[22] Zai pits are shallow bowls filled with compost or manure in which crops are planted, allowing more water to soak into the soil and trapping silt and organic matter that would have washed away.
[23] Paul J.H. Neate, *Climate-smart agriculture: Success stories from farming communities around the world*, CGIAR, November 2013.

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Technical Appendix. Thirty-three mitigation and adaption measures would apply in a smallholder farmer context

Animal production practices

	Measure	Mitigation	Adaptation	Case study	Country
1	Improve breeding systems (breed selection and breeding or insemination timing management) for increased productivity and reduced greenhouse-gas (GHG) emissions (with GHG-focused breed selection)	●		A community-based goat breeding program with 269 smallholder farmers in Malawi and Uganda improved livestock breed quality with higher average weight (16 kg to 19 kg) and higher survival rates (72% to 91%). It led to improved end products with a reduced impact on the climate.[1]	Malawi, Uganda
2	Intensify fodder production to reduce extensive grazing for dairy cattle and reduce emissions from land-use conversion	●		A life cycle assessment of different feeding practices in Tanzania found that feed intensification increased milk yield by up to 60.1% and reduced GHG emissions by up to 52.4% for farmers with traditional cattle and 38.0% for farmers with improved cattle due to land-use reduction. A further 11.4–34.9% GHG reduction could be realized by reducing the yield gaps of concentrate feed crops.[2]	Tanzania
3	Expand use of feed processing for improved digestibility to reduce methane emissions from enteric fermentation	●		A program in Nigeria using processed ensiled maize with minimum concentrates to improve dry-matter intake and digestibility of 20 West African dwarf sheep found improved weight gain (90.48 g per day per head).[3]	Nigeria
4	Optimize the animal feed composition and transition to diets that reduce methane production from enteric fermentation	●		A program across 5 counties in Kenya using fodder legumes and fodder trees for dairy cattle resulted in an 8–18% reduction in enteric methane emissions.[4]	Kenya
5	Integrate livestock and crop systems to reduce nutrient losses (ie, management of farm-level nutrient flows and losses from manure) to reduce further input requirements and related emissions	●		Nutrient recycling in integrated crop–livestock systems in Madagascar, using practices such as collection of liquid manure or manure composting, improved the circulating of nutrient flows by up to 76%.[5]	Madagascar
6	Improve animal health monitoring and illness prevention to control disease outbreaks (predicted to increase with warming climates), thereby increasing productivity and creating GHG emissions savings	●	●	Vaccination centers set up in Zambia to prevent animal disease outbreaks such as contagious bovine pleuropneumonia benefitted 253,000 farmers by reducing cattle mortality rates.[6]	Zambia
7	Improve timing of livestock sales (eg, by weight, age and time of year) to maximize productivity and reduce GHG emissions footprint per head	●		A combination of a lower slaughter age and improved feed quality could reduce emissions intensities by 34% for cattle and 40% for sheep and goats, with the lower age at slaughter having the major impact.[7]	Kenya

Animal production practices (continued)

	Measure	Mitigation	Adaptation	Case study	Country
8	Optimize stocking rate (livestock heads per hectare [ha]) according to land capacity to minimize land degradation and maximize grassland and livestock performance		●	Analysis of the effect of optimal stocking levels in the rangelands of Narok County in Kenya found fewer crop farming conversions, greater stabilization in herd levels, and an increase in intensification while preserving and improving ecosystem production.[8]	Kenya
9	Scale rotational grazing and rangeland restoration to improve grassland health and increase soil carbon content	●	●	Rotational grazing practices and grassland restoration among pastoralists in northern Kenya resulted in 1.4% annual increase in soil organic carbon.[9]	Kenya

Crop production practices: Rice

	Measure	Mitigation	Adaptation	Case study	Country
10	Utilize dry direct-seeding technology and optimize rice variety selection (eg, aerobic rice that grow in nonflooded fields) to increase productivity, and reduce methane emissions from rice paddies, as well as reduce reliance on water	●	●	Demonstration trials across 15 smallholder farms in an area of Thailand with erratic rainfall using mechanized dry direct-seeding reduced seeding rate by 52–61%; the technology design reduces the risk of climate variations by reducing water use while increasing productivity and reducing production costs.[10]	Thailand
11	Improve water management to reduce methane emissions in rice paddies	●		A sustainable intensification program using techniques such as alternate wetting and drying (rather than continuous flooding) was employed by more than 1 million smallholder farmers across 185,000 hectares of land. It resulted in 33% reduced water use compared with conventional farming practices. In aggregate, all interventions (including water management, but also management of input use) resulted in emissions reduction of 20–62%.[11]	Philippines
12	Improve placement of fertilizer (eg, urea deep fertilization) to mitigate emissions from rice fields	●		Microdosing fertilization near the seed and root zone at 3 sites in the central highlands of Madagascar increased yields by 55–67% while reducing the risk of climate stress by reducing the time to heading (and consequently shortening required growth durations.[12]	Madagascar

Crop production practices: Rice (continued)					
	Measure	**Mitigation**	**Adaptation**	**Case study**	**Country**
13	Improve rice straw management by incorporating crop residues into paddy soil to maintain and enhance soil fertility and carbon storage	●	●	Direct incorporation of crop residues into the soil by rice farmers in Northern Vietnam resulted in a significant increase in soil organic carbon (up to 3 metric tons of carbon per ha per cropping season) as well as the returning of key nutrients to the soil.[13]	Vietnam
14	Expand use of new pest management practices (eg, seeds, integrated pest management [IPM], pheromones) to maintain productivity in the face of projected increased pest and disease threats in a warming climate		●	Field trials conducted in Kenya found that certain drought tolerant species of forage legumes in the genus *Desmodium* effectively controlled the parasitic weed *Striga hermonthica*, which is set to become more competitive given anticipated conditions under climate change; the two species that successfully suppressed *Striga* also significantly increased cereal grain yields.[14]	Uganda
15	Expand use of drought-tolerant crop varieties and hybrids to maintain productivity in the face of projected increased rainfall variability		●	A breeding trial of 160 varieties of drought-tolerant maize conducted with 15 smallholder farmers across 13 sub-Saharan African countries found yield improvement of more than 600 kg per ha over a 7-year period in high-drought conditions.[15]	Multiple
16	Scale low- or no-tillage farming to minimize soil disturbance and retain organic soil cover	●	●	Employing zero-till and minimum-till practices in Bangladesh reduced negative externalities on wheat farms, including increasing soil carbon accumulation, preventing water loss, and mitigating GHG emissions without compromising yield.[16]	Bangladesh
17	Intercrop to improve soil health, reduce pest and disease outbreaks, and optimize fertilizer use	●	●	Coffee–banana intercropping systems at several smallholder farms in Uganda showed increased coffee quality and higher yields, increased carbon stocks (from 10.5 megagrams [Mg] per ha to 42.5 Mg per ha), and increased soil carbon stocks (1.5 times as much).[17]	Uganda

Crop production practices: Rice (continued)					
	Measure	**Mitigation**	**Adaptation**	**Case study**	**Country**
18	Expand use of crop rotations and cover cropping using legumes or a mix that includes a legume to improve soil health and reduce nitrogen application	●	●	A study of 6 combinations of tillage, residue management, and green gram legumes integration in rice–wheat systems resulted in the lowest global warming potential, ranging from –3,301 kg to –823 kg CO_2 equivalent (CO_2e) per ha per year compared to 4,113 kg to 7,917 kg CO_2e per ha per year in other treatments; the water footprint was 29% lower, with soil sequestration having significant effects on the total global warming potential.[18]	India
19	Expand use of soil testing to guide fertilizer application, increasing yields, improving soil health, and reducing overall fertilizer application	●	●	A nationwide soil-mapping effort in Ethiopia boosted wheat yields from 1 metric ton to 3 metric tons per ha by using local soil fertility analysis to inform development of tailored fertilizer blends.[19]	Ethiopia
20	Reduce overapplication of nitrogen fertilizers in India and China to reduce emissions associated with fertilizer losses	●		Use of a “nutrient expert” tool in India that optimizes fertilizer management practices reduced nitrogen application by 15–35% in rice and wheat, which increased yields by 4–8%, resulting in a reduction in global warming potential of 2.5% in rice and 12–20% in wheat.[20]	India
21	Expand use of soil amendments (eg, manure, compost, crop residue, lime, biochar, and various inoculations) to improve soil health	●	●	A trial in 75 test areas in Cameroon found that biochar made from agricultural wastes and tree thinnings improved soil productivity and increased maize production from 1.7 metric tons per ha to 2.4 metric tons per ha (40%); it also produced an overall gain of 85% in grain weight.[21]	Cameroon
22	Switch to other crops better suited to climate-related land suitability changes to ensure long-term sustainability		●	An assessment of 2,000 farmers across 7 Latin American countries found that farmers adapt to climate change by switching crops to fruits and vegetables in warmer locations and wheat and potatoes in cooler locations to maximize yields and revenues.[22]	Multiple

Land-use change and intensification					
	Measure	**Mitigation**	**Adaptation**	**Case study**	**Country**
23	Expand adoption of effective rainwater harvesting (eg, with earth or stoneworks) to prolong access to water and reduce runoff, improving soil health and reducing fertilizer losses	●	●	Stone bunds and Zai pits were used to reduce rainwater and topsoil runoff in the highly arid Sahel region while creating water storage systems, resulting in sorghum and millet yields of 1 metric ton per ha—double the yield achieved on unimproved land.[23]	Sahel region

Land-use change and intensification (continued)					
	Measure	**Mitigation**	**Adaptation**	**Case study**	**Country**
24	Introduce irrigation (from exclusively rainfed farming) to increase productivity and resilience in relation to increased rainfall variability and reduce risk of land-use change and related emissions	●	●	A drip irrigation system was introduced in a dry, high-altitude area of Ecuador, allowing crops to be watered for up to 2 weeks while doubling incomes by using stored water as fish nurseries.[24]	Ecuador
25	Transition to drip or sprinkler irrigation (from flood irrigation) to improve water efficiency and reduce soil erosion, improving soil health and reducing fertilizer losses	●	●	The use of low-cost drip irrigation systems in South Africa enabled reduction in water use by 30–50%, accompanied by yield improvements in smallholder farm trials.[25]	South Africa
26	Scale solar-powered irrigation (from petrol pump irrigation) to reduce emissions from fossil fuel–powered alternatives	●		Replacing diesel-powered irrigation with solar irrigation was implemented across 20 acres of rice fields in Bangladesh, allowing farmers to grow 3 crops as opposed to 1 over the year, increasing soil nutrition (through crop rotation) and saving 19.6 MWh of electricity per year (equivalent to 26 metric tons of CO_2 emissions per year).[26]	Bangladesh
27	Electrify on-farm machinery and equipment (except scaling solar-powered irrigation) to reduce fossil fuel–powered alternatives	●		A study on vegetable smallholder farms in China simulating a switch to using biodiesel in place of gasoline and diesel reduced total the total carbon footprint by 6.6% to 10.9%; using hydropowered electricity, instead, reduced the total carbon footprint by 10.0% to 15.9%.[27]	China
28	Develop eco-engineering (use of ecology and engineering to restore and protect ecosystems) of reefs to protect mangrove forests to provide coastal flood buffers, protecting coastal agriculture		●	After 10 years, an assessment of a 45,000-hectare mangrove restoration project in Senegal found that it had led to an increase of fish stocks of more than 4,200 metric tons per year, allowed restoration of 15% of previously abandoned rice fields, and enabled a 10% yield increase for rice fields farther offshore.[28]	Senegal

Land-use change and intensification (continued)					
	Measure	**Mitigation**	**Adaptation**	**Case study**	**Country**
29	Expand agroforestry (integrating trees into cropland for firewood, forestry-based land restoration, and diversified income) to improve ecological functions, improve soil water storage, increase soil productivity, reduce erosion, improve the microclimate, and buffer against climate variability—all while increasing carbon sequestration and reducing the need for deforestation for fuelwood.	●	●	An agroforestry program in the highly arid Sahel aiming to restore indigenous tree cover resulted in multiple benefits, including increased firewood, fewer pests and diseases, less soil erosion, and rising water tables. Yields of millet more than tripled from 150 kg per ha to 500 kg per ha in Niger. In addition, the estimated value per household of the tree products became $1,000 per ha.[29]	Niger

Postharvest and processing losses					
	Measure	**Mitigation**	**Adaptation**	**Case study**	**Country**
30	Improve loss management in meat and dairy production (eg, through solar cold-chain storage)	●		Due to the lack of on-farm refrigeration, evening milk is forcibly consumed, is sold cheaply to nearby neighbors or hawkers, or spoils. A project piloting 80 off-grid solar milk chillers capable of storing 40 liters of evening milk allowed farmers to sell five to 40 extra liters per day of evening milk, resulting in additional income of $60 to $500.[30]	Kenya
31	Introduce mechanization in rice farming to reduce food loss and associated emissions	●		Smallholder farms in Nigeria using mechanized harvesting and threshing of rice as a mitigative measure increased profit by ~$200 per ha and avoided 1.7 metric tons of CO_2e emissions per ha through reduced losses.[31]	Nigeria
32	Reduce on-farm postharvest crop loss through improved storage and packaging	●		Smallholder banana farmers in Embilipitiya, south of Sri Lanka—after being introduced to technical innovations such as harvesting at correct maturity, applying correct harvesting methods, and implementing appropriate handling—improved packaging and transportation and reduced postharvest losses from 28.80% to 19.05%.[32]	Sri Lanka
33	Utilize crop waste (eg, for animal feed, biomass energy production, biochar production, biofuel generation and composting), particularly in lieu of burning, to reduce related emissions	●		~150 smallholder farming households in Kenya were provided biochar gasifiers and training on biochar production and use; after biochar use, 96% stated that it benefited soil health, and 33% stated that it provided savings in terms of purchased fertilizer.[33]	Kenya

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