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Reducing the Need to Burn: How Applying Sustainable Agricultural Mechanization in Indonesia can Improve Air Quality

Picture courtesy: Universitas Gadjah Mada, Indonesia

ESCAP
CSAM
Centre for Sustainable Agricultural Mechanization

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I. INTRODUCTION

Rapid population growth and the accompanying economic development have been significant contributing factors to increased air pollution in Southeast Asia[1] where 99.9% of the population – around 656 million people – live in regions with fine particulate matter ($PM_{2.5}$) pollution exceeding the WHO[2] guideline level[3]. Yearly average $PM_{2.5}$ pollution concentrations in Southeast Asian countries have remained high in recent years, showing relatively limited progress towards clean air (see Figure 1).

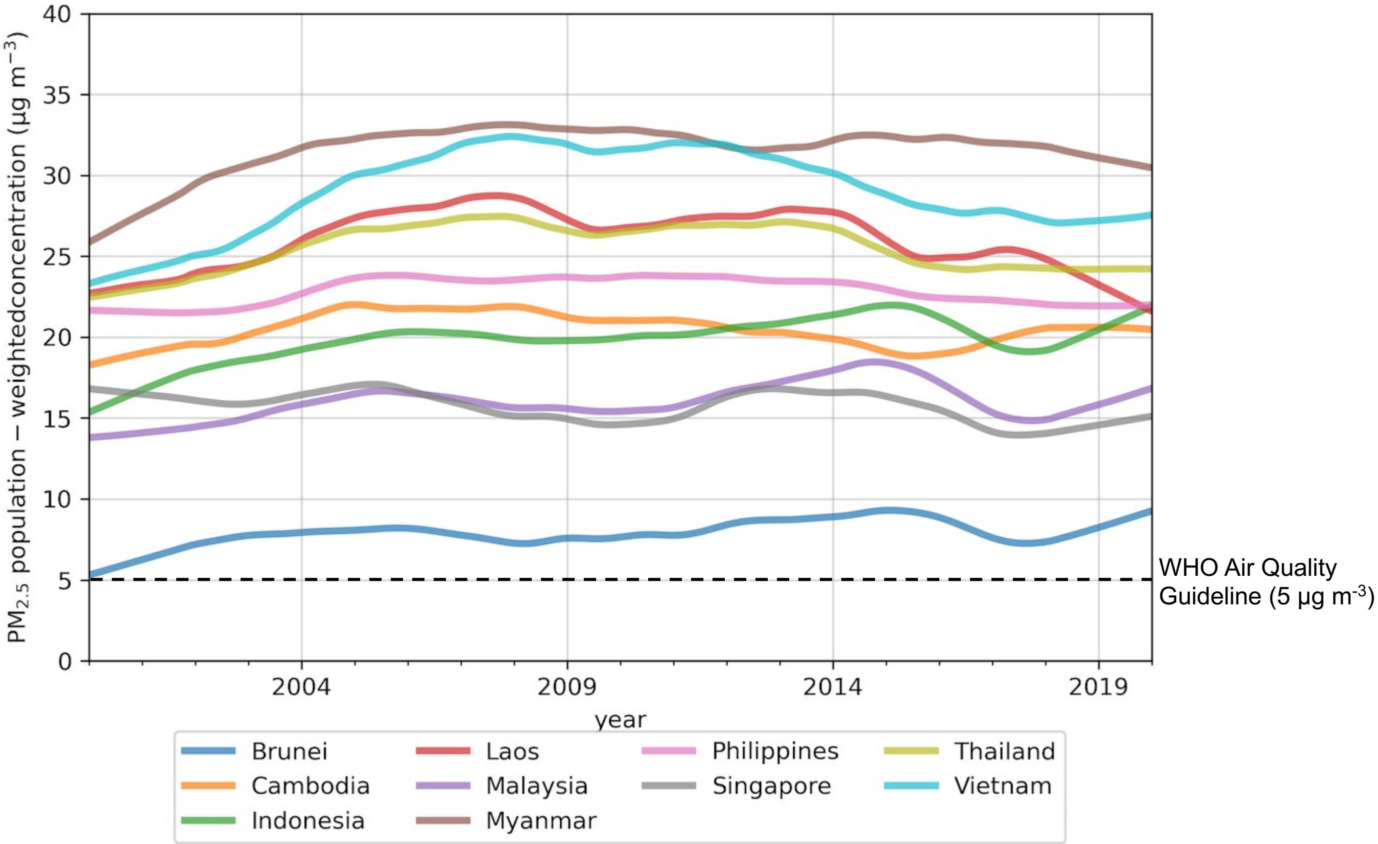

Figure 1. National population-weighted PM2.5 concentrations for Southeast Asian countries between the years 2000 to 2020. Figure was produced using PM2.5 data from van Donkelaar et al.[4] and population data from CIESIN[5].

A major source of $PM_{2.5}$ exposure in Southeast Asia is open burning of agricultural residues, forest clearance fires, and peatland fires, particularly during burning seasons[6,7,8]. Huge amounts of crop residues are burnt in Southeast Asia every year (see Figure 2). In 2020, the amount of biomass dry matter burnt per square kilometre of agricultural land in Southeast Asia was two times that in North America and mainland China, and comparable to South Asia[9,10]. Exposure to $PM_{2.5}$ pollution from agricultural and forest fires is associated with adverse health outcomes including morbidity and mortality[11-14]. Preventing these fires in Indonesia could have a substantial human health benefit; reducing regional average $PM_{2.5}$ exposure and avoiding 14,000 to 44,000 premature deaths yearly across Equatorial Asia[8].

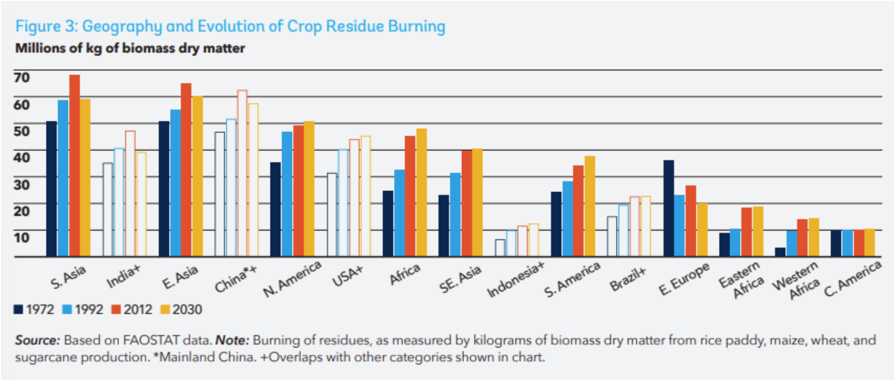

Figure 2. Geography and evolution of crop residue burning.

Open biomass burning practices in Southeast Asia are also a large source of greenhouse gas (GHG) emissions[15,16]. In some burning seasons, the amount of carbon dioxide emitted from these fires have been greater than from yearly fossil fuel emissions in countries such as Germany, Japan, and Indonesia[17].

In addition to increasing GHG emissions and causing adverse effects on air quality and public health, agricultural residue burning can negatively affect soil health, leading to a loss of soil carbon and micro-nutrients, while adversely affecting soil temperature, pH, moisture, and organic matter[18]. Farmlands that have undergone repeated burning generally have reduced soil fertility[19] and higher erosion rates[20], requiring increased use of fertilizer[21]. However, viable no-burn alternatives exist that can provide both environmental and economic benefits to the farmers[22].

Application of agricultural machinery-based solutions can promote the transition to sustainable and integrated management of agricultural residues, for example using straw cutter to utilize straw as mulch (soil cover) or straw pressing machinery to compress and transport straw as bales for use as livestock feed/bedding, bioenergy, mushroom substrate, or industry material[23]. Machinery can also be implemented to support the use of straw residues as improved animal feed and/or fertilizer (e.g., choppers, composting grinders, rotary compost sieves, and electric sprayers), which brings further benefits to the farmers.

Reducing air pollution from biomass burning in the agricultural sector in Southeast Asia can help countries uphold their commitment to the 2015 Paris Accords and other global conventions and standards to tackle climate change. In addition, agricultural emissions reductions would support the attainment of the targets laid out in the Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty) target 1.4 (poor have equal access to appropriate new technology), SDG 2 (Zero Hunger) target 2.4 (ensure sustainable food production systems, SDG 12 (Responsible Consumption and Production) target 12.2 (promote efficient use of natural resources), and SDG 13 (Climate Action) target 13.1 (strengthening adaptive capacity to climate-related hazards).

II. PROJECT BACKGROUND

A. The CSAM Regional Initiative on Integrated Straw Management

In 2018 the Centre for Sustainable Agricultural Mechanisation (CSAM) of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), with the support of ESCAP's Environment and Development Division, commenced a regional initiative to promote mechanization-based solutions for integrated management of crop straw residue to enable sustainable and climate-smart agriculture. The main objective was to identify, test and adapt innovative agricultural equipment and machinery for alternate uses and sustainable management of straw residue which could reduce farmers' inclination to openly burn this potentially valuable resource, thereby reducing air pollution and GHG emissions from the agricultural sector and preserving soil health. The approach was centred around a circular model (see Figure 3) of straw management within farming communities including use of straw for purposes such as fertilizer, fodder, substrate for mushroom growing and production of clean energy.

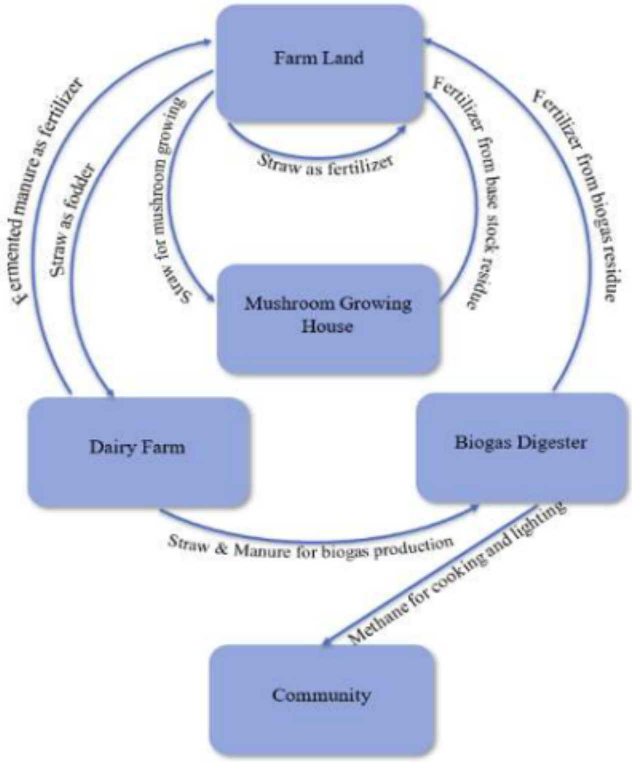

Figure 3. Circular model of straw utilisation.

Following the launch of the regional initiative, positive results were attained via pilot projects implemented in China and Viet Nam in collaboration with national partners, where agricultural machinery was applied and optimized to improve current practices and provide suitable alternatives to burning straw residue that enabled ecological and economic benefits for the farms involved. For instance, the pilot in China demonstrated utilisation of wheat and maize straw as fertilizer, fodder and production of biogas, in-place of burning, whilst increasing crop yields, soil organic matter, and the net income of the local farmers cooperative. The pilot project in Viet Nam demonstrated the yield and quality enhancement benefits from using straw to cultivate mushrooms via an indoor method. Moreover, India, which had already established a large-scale national project to combat straw burning, contributed to the initiative as a knowledge-sharing partner and hosted a study tour in 2019 to demonstrate related machinery and good practices.

In 2021 the regional initiative expanded further to build on lessons learned, with pilot sites in Cambodia, Indonesia, and Nepal. It engaged with the farming communities at pilot sites to first understand their needs through baseline assessments and workshops, then implemented technical interventions by providing training and agricultural machinery/equipment to the local community and documenting the successes and learnings in the real world.

The results of this work have shown how new measures can be applied effectively when directly engaging with local stakeholders to explore contextually suitable approaches and identify machinery that can be adapted to serve their needs.

B. Identifying key areas for interventions

Pinpointing where to apply these interventions involves identifying the areas with greatest fire activity, typically requiring a robust system to monitor and measure burning hotspots and the associated air pollution. ESCAP has been undertaking work to help governments target where interventions are critically needed which has complemented the CSAM regional initiative.

This work uses advanced data science practices to build a machine learning model that relies on simple data and the moderate-resolution imaging spectroradiometer (MODIS) satellite images to identify hotspots and make more accurate predictions about policy impacts. This model has been tested across the Asia-Pacific region, along with an in-depth case study done hand-in-hand with the local government in Chiang Mai, Thailand.

Combining this methodological approach with techniques from the CSAM regional initiative can significantly reduce the impact of air pollution by informing farmers and decision-makers of burning hotspots where the need for mechanisation should be prioritized to be most relevant.

C. Pilot on Integrated straw management in Indonesia

This Brief on integrated straw management in Indonesia analyzes the results of CSAM's pilot project in the Special Region of Yogyakarta, including findings from local surveys about farming practices and the promotion of agricultural mechanization-based solutions to incentivize sustainably using straw residue as a resource. The pilot was implemented during 2022-2023 as part of a wider project titled *'Enabling Sustainable and Climate-smart Agriculture in Cambodia, Indonesia, and Nepal Through Mechanisation Solutions for Integrated Management of Straw Residue and Air Pollution Monitoring'* with financial support from the China-ESCAP Cooperation Programme (CECP) and in partnership with the Faculty of Agricultural Technology of Universitas Gadjah Mada, Indonesia.

III. INDONESIA: AGRICULTURE AND AIR POLLUTION

The Republic of Indonesia, situated in Equatorial Asia, was chosen for CSAM's pilot project as the agricultural sector plays a vital role in the country, supporting national and local economic growth. It is a key sector not just for food security but also employment and income for many communities. Although Indonesia's rural population has declined in recent decades, in 2021 a substantial portion of the population was still living in rural areas (around 43% or 117 million people[24]), and close to 29% of the Indonesian workforce worked in the agricultural sector[25].

Agricultural straw management in Indonesia is still in the initial development stage, with around 10 to 12 million tonnes of straw residues subjected to burning yearly[9]. Agricultural residue and land clearance fires can burn out of control into surrounding forest and peatlands. Indonesia often records the highest number of yearly fire counts among countries in Southeast Asia[28]. Vegetation and peatland fires in Indonesia cause severe regional air pollution[29,30] with severe implications for public health[8]. Agricultural residue burning continues despite the introduction of the Act of Indonesian Environmental Protection and Management Number 32 – Year 2009 prohibiting this practice. Therefore, there is a demonstrable need for viable no-burn alternatives and the immediate implementation of agricultural mechanization-based solutions to reduce air pollution caused by biomass burning in Indonesia.

A. Study Area: Special Region of Yogyakarta, Indonesia

The CSAM pilot project site was established in the Special Region of Yogyakarta which was selected because of its current multi-crop-based farming system, with farmers making up around 17% of the population (616,197 people) and agricultural land contributing around 30% of the total land area. Moreover, Yogyakarta well represents Indonesia's agricultural conditions based on the diversity of topography, extensive land area, farmer characteristics, types of cultivated commodities, and diversity of cultivation methods.

In the Special Region of Yogyakarta, three locations were identified, namely Sumberharjo, Srimartani, and Sumbermulyo Villages in Prambanan, Piyungan, and Bambanglipuro Districts, respectively. All three locations had a mix of multi-crop-based farming systems and livestock farming. The cropping systems were paddy-paddy-palawija (third harvest), with the palawija crop plantation in corn, soybeans, and peanuts. The three locations differed in terms of both the agricultural management/techniques and geographical features. The multi-crop farming systems at these locations not only produced a variety of agricultural products, but also large amounts of straw residue that urgently needed improved management. The presence of multi-livestock in these areas could serve as a potential straw management supporting system, utilising the straw residue as feedstock.

IV. CASE STUDY: IMPLEMENTATION OF MACHINERY IN YOGYAKARTA

An agreement for implementation of the pilot project in Indonesia was signed in 2022 between ESCAP and Universitas Gadjah Mada. The project was implemented in the Special Region of Yogyakarta. Three pilot sites were selected: Sumberharjo, Srimartani, and Sumbermulyo Villages, located in Prambanan, Piyungan, and Bambanglipuro Districts, respectively, which feature multi-crop- and multi-livestock-based farming systems. The project aimed to deliver the following three outputs:

Output 1	Establish pilot site(s) in Cambodia for integrated management of straw residue informed by research on air pollution and GHG emissions from the agricultural sector.
Output 2	Test and adapt improved technologies and practices for integrated management of straw residue at pilot site(s).
Output 3	Enhance capacities of farming community and change agents for adopting improved technologies and practices for integrated management of straw residue.

The key project activities, summarised in the following sections, include: 1) baseline surveys to identify the current status at the pilot sites, 2) workshops and focus group discussions introducing the project and agricultural machinery, 3) equipping of related agricultural machinery and training according to location requirements, 4) field testing of agricultural machinery and its improvement, 5) adaptation and modification of the machinery, and 6) dissemination and capacity improvement of farming groups.

A. Assessing the current farming status at the pilot locations

Baseline surveys were conducted in the three locations. Several different farming groups were based at the sites, with each group operating a variety of farming activities and conducting plantation of various crop types. The groups were formed by the farmers to enhance agricultural yields, and to increase information sharing, social interaction, and opportunities for government support. Across all three locations and farming groups, a total of 87 farmers participated in the surveys.

A wide range in demographics (education, age) were found amongst the farming groups, with women farmers making up 44% of the participants (one female-only farming group was interviewed at each site). In terms of agricultural activities, many farming groups were found to have no or limited access to modern agricultural machinery and equipment. Thus, harvesting was mostly conducted manually (with the use of a sickle) or semi-manually (with use of a pedal thresher). Some farming groups rented or borrowed agricultural machinery such as tractors and threshers, with the latter the most prevalent type of machinery in use. Where livestock were kept (e.g., in Gamparan and Kwasen Hamlets), straw residue was utilised as animal feed, but mostly without appropriate pre-treatment. Livestock manure was collected and stored by some farmers to utilise as fertilizer but mostly without any treatment. Overall, the survey results demonstrated the urgent need for agricultural mechanization-based solutions for improved straw management and increasing agricultural productivity.

B. Inception workshop

A series of inception workshops and focus group discussions were conducted at the pilot locations to introduce the project objectives and activities to local government and farming communities, to highlight the importance of integrated straw management, and to develop the implementation programme. The agricultural extension workers played a vital role in discussions, apprising the current farming situation at each pilot location. With the productive inputs of all stakeholders, these discussions delivered an implementation plan on straw management that was suitable and relevant for the local farming conditions and straw production.

C. Proposed straw management Programme

The straw at the sites was derived from paddy, corn (corncob, cornstalk, corn leaves), soybeans (untreated tree, leaves, husk), peanuts (untreated tree, leaves, husk), and animal manure. The proposed straw management programme (SMP) focused on smallholder-friendly machinery and equipment for supporting operations during production, harvest, post-harvest as well as transportation, storage and utilization. The focus of the last step (utilization) was especially on 1) fermented feed production and enhancing current processes, and 2) strengthening and enhancing liquid and solid organic fertilizer (compost) production. Implementation plans and proposed technology/machinery were continually adjusted during the project to meet the farmers' needs and ensure relevance for the existing conditions and straw commodity in each location. The projected outcomes of the SMP were not only improving sustainable straw management practices which can provide an alternative to burning, but also improving the status of agricultural mechanization and productivity, and importantly increasing awareness of environmental sustainability.

D. Equipping pilot sites with required agricultural machinery

Once valuable information on the status of agricultural mechanisation in each pilot site was acquired from the surveys and discussions, a list of necessary machinery was developed, with emphasis on simple and relatively low-cost machinery and equipment that was suitable for the local context and for resource-poor smallholder farmers. The pilot locations were equipped as follows to assist with various farm operations:

- Production: Handy straw cutter, straw cutter/mower
- Harvest: Mobile rice power thresher and mobile corn power thresher
- Post-harvest: Chopper, grinder, customized straw pressing equipment to make straw blocks
- Transportation, storage and utilization as compost or fermented feed: Chopper, grinder, electric sprayer, rotating compost sieve, trailer for transportation.

Handy straw cutter

Thresher

Customized straw pressing equipment for compact storage

Trailer for straw transportation

Figure 4. Simple and low-cost machinery suited for local context. Pictures courtesy: Universitas Gadjah Mada, Indonesia.

E. Field trials of agricultural machinery

Field trials of the machinery were carried out at the pilot locations, with demonstration and training for farmers and local operators in operation and maintenance (see following section) prior to handover of the equipment. The field trials were also followed by workshops led by experts on composting treatment and feedstock-making at the three locations. The objectives of these activities were to: 1) educate farmers on agricultural machinery and mechanized practices under local conditions, 2) motivate farmers to adopt sustainable agricultural mechanization, and 3) enhance efficient and mechanized straw residue management.

Based on the results from the field trials, modifications were made to the customized straw pressing equipment, straw cutter/mower, and trailer in order to make their operation easier under local conditions (eg. on wet soil) and for better compatibility with other locally available machinery.

F. Awareness building and demonstration sessions

Awareness and demonstration sessions were conducted for relevant stakeholders to promote adoption of improved integrated straw management technologies and practices. Several sessions were run concurrently, firstly, involving dissemination of agricultural machinery and integrated straw management technologies and its practices for the farming communities, and secondly, involving focus group discussions between local governments and local farmers on the extensive straw management programme.

For example, in Japuhan Hamlet, eight different types of agricultural machinery (chopper, straw pressing equipment, straw cutter, grinder, corn power thresher, rotary compost sieve, electric sprayer, and trailer) were equipped and supplied to the three local farming groups. Selected machinery was demonstrated under local conditions and tried by the farmers. Following these activities, focus group discussions were led by experts to review the current implementation and results of straw management training, and to discuss challenges during the trial (post training), safety, and further possible laboratory analysis of compost or fermented feed products. To increase knowledge transfer to the wider farming community, a booklet on composting processes and fermented feedstock-making was also distributed to all participants.

Overall, the dissemination and focus group activities successfully increased the motivation of local farmers and local governments to support each other in implementing integrated straw management in this area. A total of 105 farmers (48% women) and 30 change agents from local government and agricultural extension workers were reached through the pilot. The awareness and demonstration sessions were also complemented with 21 rounds of training on agricultural machinery and related straw management practices at the pilot locations.

Feedback on the pilot project implementation was gathered from the farming groups at the awareness and demonstration sessions. Overall, the feedback was very positive as evidenced by the results below:

- Considered national/local contexts and conditions (combined rating of 4.65 out of maximum 5).
- Tailored to participants' needs and requirements (combined rating of 4.72 out of maximum 5).
- Participants are looking forward to taking part in more such events in future (combined rating of 5 out of maximum 5).

V. KEY RESULTS OF PILOT PROJECT IN INDONESIA

The pilot project in Indonesia achieved the following key results in relation to its objective to promote the sustainable and climate-smart management of straw residue through use of agricultural machinery-based solutions:

1. Supported the objectives of the Indonesian Environmental Protection and Management Law Number 32 enacted in Year 2009 which prohibits the burning of straw.
2. Achieved strong engagement of the local farming communities, including women groups, as well as change agents who obtained a better understanding of the need for integrated and climate smart straw residue management.
3. Better equipped the local farming communities at the pilot locations with contextually suitable, smallholder-friendly agricultural machinery and equipment for sustainable straw residue management and enhanced technical capacities in their use.
4. Increased the agricultural mechanization index at the pilot locations from 0 - 0.39 HP/ha prior to the pilot project to 1.32 - 2.46 HP/ha after implementation, with accompanying benefits for overall productivity.
5. Achieved significant increase in actual amount of straw sustainably utilized through improved mechanization-based technologies and practices at the pilot locations.
6. Firmed plans of Universitas Gadjah Mada for the three pilot locations to serve as a field laboratory / field experimental and agricultural mechanization learning centre to support relevant community services and student academic competencies in the future, thus enabling sustainability of the results.

VI. POLICY RECOMMENDATIONS

A. Further promote implementation of crop residue management

Implementation of straw residue management programmes in farming communities should be formulated with specific considerations for the local conditions, straw commodities of the farms, and needs of the farmers. Each area and farming group has particular characteristics (topography, commodity, socioeconomic status, culture, education, and other demographics) that will affect the suitability of different types of agricultural machinery and practices. Considering these characteristics prior to implementation, will improve the success and effectiveness of the straw management solutions proposed.

B. Provide targeted support for smallholder farmers

Smallholder farmers suffer from specific constraints which impede their adoption of new or improved technologies and practices. These constraints include lack of resources for investment, inadequate technical capacities or skills, and high vulnerability to climate impacts and external shocks. Therefore targeted policy and programme support should be provided to them to facilitate the transition towards more sustainable straw management practices.

C. Engage all stakeholders and change agents

To successfully achieve adoption of improved agricultural machinery-based solutions for straw residue management by the farming community at large scale, multi-stakeholder efforts are needed involving national and local governments, research institutions, extension agents, civil society, private sector, and development partners. Effective engagement and coordination among these diverse stakeholders should be ensured.

D. Strengthen farmers groups

Farmers groups should be provided with technical, financial and capacity building support to strengthen their organization and functioning. Opportunities for ongoing knowledge exchange should also be made available to them. This would better equip them to adopt and promote innovative and sustainable agricultural mechanization solutions and improved straw management practices.

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