INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
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TRANSFORMING FALLOW LANDS

An Impact Evaluation of the Comprehensive Rice Fallow Management (CRFM) Program in Odisha

An evaluation report by the International Food Policy Research Institute

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Suggested citation: Roy, D., A. Padhee, M. Pradhan, S. Saroj, V. Vidhani, D. Kumar and A. Burman (2025). Transforming Fallow Lands: An Impact Evaluation of the Comprehensive Rice Fallow Management Program in Odisha. Delhi: International Food Policy Research Institute-South Asia Regional Office.

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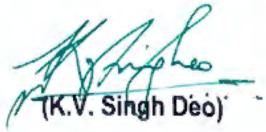
MESSAGE FROM
THE DEPUTY CHIEF MINISTER

Odisha's agricultural sector has been transforming rapidly. The state has made significant strides in modernizing the sector, enhancing productivity, and ensuring sustainable livelihoods for its farming communities. Despite significant diversification, however, rice remains a principal staple and rice fallow continues to be an important aspect of paddy cultivation. Following the paddy harvest and the end of the monsoon (Kharif) season, approximately 1.6 million hectares of land are left fallow during the subsequent Rabi season.

To address the issue of rice fallow, in 2023 the Department of Agriculture and Farmers' Empowerment (DAFE) launched the Comprehensive Rice Fallow Management (CRFM) program. This initiative aims to transform fallow lands across 30 districts into productive fields, focusing on cultivation of pulses and oilseeds. The CRFM program takes a holistic approach, integrating social and behavioral change interventions to encourage sustainability and the cultivation of scarce nutritious crops such as pulses and oilseeds. It aims to foster dietary diversity, environmental benefits, and improved livelihoods.

I commend the Directorate of Agriculture for bringing nearly 4.5 lakh hectares of fallow land under cultivation within a short period of time. I also extend my gratitude to the International Food Policy Research Institute (IFPRI) for their early comprehensive evaluation of the CRFM program and for identifying avenues for scaling up and options for course correction if needed.

I encourage all stakeholders to utilize the findings of this report to scale up the program and contribute to sustainable improvement in the incomes of small and marginal farmers. This document constitutes a valuable resource in shaping future strategies. It can help reinforce our commitment to empowering livelihoods through sustainable and resilient agricultural practices.



Shri Kanak Vardhan Singh Deo

Deputy Chief Minister,
Agriculture & Farmers' Empowerment and Energy
Government of Odisha

ACKNOWLEDGEMENTS

We express our deepest gratitude to all those whose unwavering support and motivation made possible the successful completion of this report on rice fallow management (RFM). Their invaluable guidance, encouragement, and contributions have been pivotal in shaping this comprehensive analysis. Our sincere thanks to Sri Prem Chandra Chaudhary, IAS, Director of Agriculture & Food Production, for his exceptional support and proactive approach toward addressing key challenges in agriculture. We extend our heartfelt appreciation to Sri Shubhranshu Mishra, OAS, Additional Secretary; Dr. Rajesh Das, Director-IMAGE; Sri Bishnu Pattnaik, Joint Director and Smt. Jyotika Rath, Assistant Director of the Department of Agriculture & Farmer's Empowerment, for their insightful inputs and relentless efforts in ensuring the success of the RFM program. Special thanks to Dr. Sangram Keshari Pattanaik, Deputy Director of Agriculture, and Sri Nagendra Kumar Malik, Assistant Director of Agriculture, for their technical expertise and commitment to the program's implementation.

We are deeply grateful to Smt. Sarita Sahoo and Sri Ashok Behera, Scientists at the National Informatics Centre, for providing Krushak Odisha Portal data. We also acknowledge the contributions of Mr. Mihir Kirloskar from Samagra, who provided vital inputs for the Krushak Odisha Portal and ADAPT Database. Special thanks are due to Smt. Sonali Mishra and Mr. Biranchi Narayan Nanda from CSM Technologies Pvt. Ltd., for their IT consultancy and technical support, which facilitated mapping the farmers' details with the Krushak Odisha Portal. Their assistance in facilitating and coordinating the data delivery process was indispensable to the seamless execution of the project and the assurance of a large database. We would also like to express our gratitude to Mr. Pushkar Gaur, Research Analyst from IFPRI, for his valuable guidance and support on the remote sensing component of our study.

We are immensely grateful to Dr. Shahidur Rashid, Director of IFPRI - South Asia, for his strategic insights and expert guidance throughout this project. His leadership and vision have been instrumental in steering this initiative toward impactful outcomes. We also extend our gratitude to the Gates Foundation for providing the funding for this work which has been prepared as an output of the Food & Agricultural System Transformation Research project.

Finally, we would like to express our heartfelt thanks to all stakeholders, partners, and collaborators whose dedication and collective efforts have contributed significantly to the success of this endeavor. This report stands as a testament to the shared commitment and hard work of everyone involved.

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1. EXECUTIVE SUMMARY

The Comprehensive Rice Fallow Management (CRFM) program, initiated by the Department of Agriculture & Farmers' Empowerment (DAFE), Government of Odisha, is a program to address the underutilization of rice fallow lands in Odisha, particularly during the Rabi (post-monsoon) season which occurs following the Kharif (monsoon) paddy harvest. These sizable fallow lands, accounting for as much as 1.6 million hectares, represent a significant opportunity to spur productivity, enhance food security and improve rural livelihoods, mainly by promoting the cultivation of pulses and oilseed crops. The program aligns with the objectives of increasing cropping intensity, diversifying the income sources of farmers, and ensuring food security and nutrition by enhancing resilience in a climate-affected world.

Approximately 80 percent of India's rice fallows are concentrated in the eastern states, including Odisha, West Bengal, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, and Assam (Ali, Ghosh, and Hazra 2014; Singh, Praharaj, and Sandhu 2016; Kumar et al. 2020). In eastern India, rice is predominantly grown during the Kharif season, leaving extensive areas fallow in the Rabi season. In these regions, a range of environmental and socioeconomic factors limit the adoption of a second crop after rice (Kumar et al. 2019b). These factors include limited irrigation facilities, inadequate moisture levels, low soil fertility, problems with input supply, and insufficient risk mitigation for risk-averse smallholders.

In the long run, effective Comprehensive Rice Fallow Management (CRFM) can drive economic growth, alleviate poverty, offer the rural communities with diversified income sources and employment opportunities, and support sustainable development and resilience across the region (FAO 2002; NAAS 2013). Agricultural intensification makes for a sustainable approach to meeting the growing food demand without expanding cropland; it thus mitigates environmental risks (Burney, Davis, and Lobell 2010), alleviates pressure on natural ecosystems (Garnett et al. 2013), and offers a pathway to improved farmer incomes (Wu et al. 2018).

Effective management of CRFM is even more important under conditions of climate change as it offers climate-resilient practices such as drought-tolerant crop varieties, agroforestry, and sustainable water management, all of which help sustain long-term productivity in rice fallow areas (Wangpakapattanawong et al. 2017). Incorporating legumes into crop rotation, for example, improves soil health by fixing nitrogen and thereby supporting sustainable land use.

A key factor contributing to the prevalence of fallow land is the lack of supplementary or life-saving irrigation, as the dry season often depletes residual soil moisture making it challenging to sustain a second crop (Ghosh et al. 2016; Kar and Kumar 2009). Another factor is the widespread use of long-duration rice varieties; these require 150 to 165 days to mature, which results in late harvesting and further limits the potential for then cultivating a subsequent Rabi crop (Pande, Sharma, and Ghosh 2010; Kumar, Mishra, and Hans 2018). Short duration, high yield crop varieties suitable for the Rabi season are limited in terms of availability, which may further restrict farmers' options. Efficient utilization of available soil moisture in rice fallows may be enhanced by selecting appropriate crops and seed varieties and implementing effective crop management methods (Kumar et al. 2019b). This approach may also promote efficient water use by employing low-cost irrigation techniques such as drip and sprinkler systems. Such choices could be endogenous responses of farmers if cropping in rice fallow areas were chosen, further optimizing water resources in these regions. Strengthening market linkages for crops such as pulses and oilseeds can further motivate farmers to diversify their crop choices by utilizing rice fallows. Active promotion of these crops by initiatives such as the National Food Security Mission (NFSM) presents growing opportunities for CRFM.

Yet, there remain notable knowledge gaps in areas where intensification is most needed; such gaps highlight the importance of empirical analysis of the determinants and effects of the utilization of rice fallows (Srivastava et al. 2023; Bégué et al. 2018). Evaluation of the CRFM program is relevant for planning and implementation of the program to realize its full potential. In this context, administrative and satellite remote sensing data, inter alia, are tools that reliably identify and monitor land use patterns; they offer synoptic and repeated coverage at various resolutions, making it suitable for both real-time and historical data analysis (Duveiller and Defourny 2010).

Geospatial technologies have also proven critical in mapping agricultural practices (Bégué et al. 2018), with vegetation indices being used to calculate harvest frequencies and cropping cycles, and to identify fallow land (Wardlow, Egbert, and Kastens 2007; Yan et al. 2014; Chen, Son, and Chang 2012; Paliwal et al. 2019; Bandyopadhyay et al. 2015; Gumma et al. 2018). This method can also aid crop suitability analysis by evaluating the relative importance of different factors in fallow areas (Rahman and Saha 2008).

Incorporating additional data such as agro-meteorological observations, topography, and land use information further enhances the accuracy of mapping multiple cropping areas (Yan et al. 2014; Conrad et al. 2016). Studies utilize satellite data from various sensors—including optical, thermal infrared (Zhang and Zhou 2016), and microwave (Kolassa, Reichle, and Draper 2017; Das and

Paul 2015)—to estimate residual soil moisture after the Kharif season, which is crucial for planning the Rabi crop in fallow rainfed regions.

This report presents the findings of the impact evaluation of CRFM in Odisha, with a particular focus on targeted interventions, inclusivity, resource utilization, productivity, acreage expansion, and preliminary indications of socioeconomic impact. CRFM involves an assemblage of interventions that are targeted at expanding the area under CRFM. The evaluation uses secondary data on the use of rice fallows both before and after CRFM, employing remote sensing data and economic impact evaluation methods. It then assesses the factors associated with the patterns of utilization of rice fallows such as soil moisture and other land characteristics. Upon utilization of the fallows, it evaluates the impact on production and yields in pulses and oilseeds at the state level. Impact evaluation uses within-project variation in terms of treatment-composite CRFM comprising different interventions.

Remote sensing analysis helps look at the utilization of both perennial and ephemeral rice fallows. These are mapped with the locations' time-specific credentials such as soil moisture levels that are predetermined by rainfall as residual from the Kharif season, as well as levels associated with supplementary or life-saving irrigation. The initial patterns show an inverted U-shaped relationship between utilization of rice fallows and soil moisture levels.

Apart from descriptive measures that are based on remote sensing data on the utilization of rice fallows, for the outcomes on yields the evaluation of CRFM also relies on quasi-experimental methods. These include Propensity Score Matching (PSM), Coarsened Exact Matching (CEM), and Inverse Probability Weighted Regression Adjustment (IPWRA), which create comparable groups between treated and control based on the intensity of CRFM intervention. Since CRFM covers all 30 districts in Odisha, to enable an evaluation of the program effectiveness we rely on variations in intensity of CRFM.

Implementation of CRFM—apart from the most significant engagement of the government—is implemented in collaboration with other organizations including the Consultative Group on International Agricultural Research (CGIAR), Indian Council of Agricultural Research (ICAR) institutions, and local Non-Governmental Organizations (NGOs). By supporting the cultivation of pulses and oilseeds that are scarce commodities both regionally and nationally, the program seeks to improve soil health through increased organic matter, higher biomass, and nitrogen fixation, while also addressing food security needs. The program is geared toward inclusiveness, with targeted support for marginalized groups including women, Scheduled Caste/Scheduled Tribe (SC/ST) communities, and lagging areas.

The simple evaluation shows evidence of effective and inclusive targeting across districts and socioeconomic groups. Matching required pairing of multiple data sources from the ADAPT Portal with data from the Krushak Odisha Portal,[1] each of which offers unique but complementary information. Apart from indicative evidence on greater utilization of rice fallows, evaluation of the utilized rice fallow areas showed significant yield improvements for key crops including Bengal Gram, Grass Peas, Lentils, and Mustard. The information yielded by program evaluation underscores the importance of robust data systems to monitor outcomes, with the integration of the Krushak Odisha and ADAPT portal enabling tracking, and geospatial mapping and remote sensing yielding important information regarding targeting accuracy.

[1] The Krushak Odisha Portal is a comprehensive and reliable database encompassing 80 lakh farmers. It includes small and marginal farmers, landless cultivators, and agricultural laborers. The database contains verified information on all registered farmers including their residential details, land ownership and usage, crops cultivated, livestock reared, and fisheries activities practiced. This verification process has been meticulously carried out by government extension workers to ensure accuracy and authenticity. The link to the portal is https://krushak.odisha.gov.in/website/home.

2. INTRODUCTION

The CRFM program was implemented in 20 districts of Odisha, in collaboration with the Consultative Group on International Agricultural Research (CGIAR) and the Indian Council of Agricultural Research (ICAR), Government of India empaneled agencies that have a presence in the state and prior experience in similar programs. In the remaining 10 districts of the state, the CRFM program was implemented by the state government's Chief District Agriculture Officers (CDAOs).

The impacts of CRFM interventions that are evaluated by this study comprise, among other things, crop demonstrations that were organized in clusters of at least 20 hectares, with crops like black gram, green gram, chickpeas, lentils, grass peas, sesamum, and mustard. The choices of crop were based on agroclimatic conditions and were identified on the basis of sowing window and available irrigation sources. Coordination with district officials from other departments such as the Department of Water Resources and the Department of Co-operation was ensured for credit, and inputs' provision.

For crop demonstrations conducted by department officials, seeds were supplied by the Odisha State Seeds Corporation Limited (OSSC), and inputs such as biofertilizers, biopesticides, and micronutrients were purchased by farmers through registered dealers via the e-Demonstration Portal. Funds for demonstrations and for inputs were transferred directly to farmers' accounts through direct benefit transfer (DBT), based on the approved limit. Soil ameliorants for acid soil management were supplied through the Odisha State Co-Operative Marketing Federation (Odisha-MARKFED) and the Odisha Agro Industries Corporation Limited (OAIC), with prices determined through a transparent tender process. Light traps and Integrated Pest Management (IPM) materials such as pheromone traps and lures were supplied by the National Rice Research Institute (NRRI) and the Indian Institute of Chemical Technology (IICT) Hyderabad, based on indents from implementing agencies and CDAOs.

Other expenses under the demonstration component were also covered, including awareness campaigns, documentation, display boards, and mobility support for officials and scientists. Funds for documentation and publicity were split between the state headquarters and the districts, with Rs. 150 per hectare being allocated to the CDAOs and Rs. 100 per hectare to the Joint Director of Agriculture (Information) for promotional activities.

Odisha's strides in transforming fallow rice lands into productive agricultural areas stand out as a significant achievement. CRFM programs have also been carried out in a number of other states. In the state of Chhattisgarh, approximately 0.5 million hectares of rice fallow were converted into productive fields for crops like chickpeas and lentils. The introduction of improved seed varieties and the provision of irrigation infrastructure resulted in a 40 percent increase in cropping intensity. Similarly, in Jharkhand, the focus was on integrating short-duration pigeon peas and mustard into fallow lands; a 30 percent reduction in fallow areas was achieved and programs targeting 2 lakh farmers enhanced agricultural productivity and rural incomes, particularly in tribal regions. In West Bengal, where mustard and lentils were cultivated on rice fallows with residual soil moisture, significant increases occurred in productivity and income diversification for farmers. In Madhya Pradesh, CRFM leveraged mechanization and creation of robust market linkages. In Odisha, CRFM employed a comprehensive approach that involved several of these interventions in unison (Appendix A). Odisha's strides in transforming fallow rice lands into productive agricultural areas stand out as a significant achievement. There, this evaluation of CRFM looks at outcomes in terms of acreage and yields of cultivated crops that have followed from conversion of fallow lands, comprising the following research questions:

(1) What is the effect of CRFM on the utilization of fallow lands considering soil moisture and rainfall in the region?
(2) Upon utilization of fallow lands, considering different interventions under the program, what are the effects on yields of pulses and oilseeds grown on the converted fallow lands?

The report is organized as follows: Section 2 discusses the data and methodology for the analysis, Section 3 presents results and findings, Section 4 highlights key takeaways, and Section 5 offers conclusions and policy recommendations.

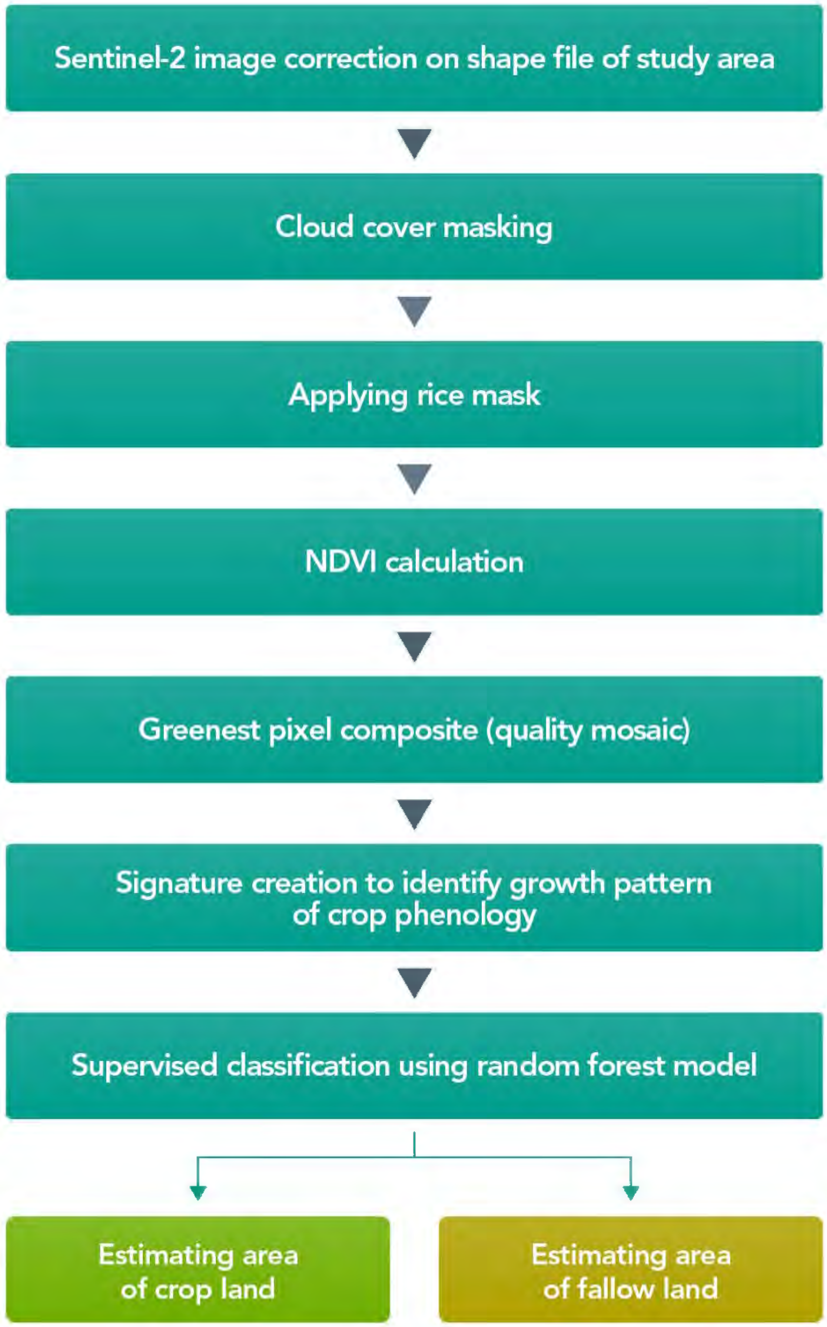
3. DATA AND METHODOLOGY

To evaluate the utilization of rice fallows, at a primary level we employ remote sensing data that uses a supervised machine learning classification algorithm. Table 1 and Figure 1 depict the execution of the algorithm in terms of data employed and the steps in the algorithm. The remote sensing data per se cannot delineate which crops are used in the rice fallows, but it is useful in answering the question of whether fallows are being put to use and to what extent. Using remote sensing, we identify the area under rice fallow and the area under rice cropping, and we identify areas where intervention seems most likely to be beneficial based on soil quality, climate, and agricultural potential.

Table 1. Data used in remote sensing

	Data	Year	Frequency	Source
1	Rice crop mask (10m*10m)	2018–2023 (Kharif season)	NA	Mahalanobis National Crop Forecast Centre
2	Sentinel–2 satellite imagery (10m*10m)	Nov 1 to April 30 (Rabi season) from 2018 to 2023	10 days	European Space Agency
3	Soil Moisture Active Passive (SMAP) (spatial resolution – 9 km)	2018–2023	Daily	NASA (Reichle et al. 2022)
4	Rainfall dataset (spatial resolution ~ 5.6km)	2018–2023	Daily	Climate Hazards InfraRed Precipitation with Station data (CHIRPS) (Funk et al. 2015)

Figure 1. Steps in estimating acreage using remote sensing



Source: Adapted from Sonia et al. (2022).

As the study is specific to understanding the impact of interventions on fallow land post rice cultivation, we use a rice mask on the state district boundary to identify the rice crop area for the Kharif season for six years (2018–2023). To identify a shift in the acreage of the fallow land, it is imperative to distinguish between crop and non-crop land; we use a Normalized Difference Vegetation Index (NDVI) for that purpose. NDVI is a proxy for vegetation health and can distinguish between vegetated and non-vegetated land. It is useful for identifying an association between the red (RED) band and the near-infrared (NIR) band, which helps distinguish between different growth phases of the crop (Sonia et al. 2022). The NDVI computation is given below in Equation 1:

$$NDVI = \frac{\rho NIR - \rho RED}{\rho NIR + \rho RED} \quad (1)$$

Prior to the NDVI calculation, pre-processing was performed on Sentinel-2 imagery to minimize the impact of atmospheric effects. To further ensure robustness, cloud masking was performed to remove cloud-covered pixels, ensuring accurate NDVI calculations for the period November 1 to April 30 (covering the Rabi season) for each year of the 2018 to 2023 period. We used a supervised machine learning algorithm to classify the NDVI time series data into two primary categories:

- **Crop land:** Areas demonstrating a growth pattern of crop phenology
- **Fallow land:** Areas without the growth pattern of crop phenology

Finally, to assess the change in acreage post-CRFM, the areas classified as crop land and fallow land were estimated for each year's Rabi season.

3.1. Assessing the suitability of rice fallows by measuring soil moisture and rainfall

To assess soil moisture availability across Odisha during the Rabi season, we utilized the NASA Soil Moisture Active Passive (SMAP) dataset. The analysis focused on aggregating district-wise mean soil moisture values from 2018 to 2023; this provided critical insights into regional soil moisture trends and patterns for effective rice fallow management. The dataset, with a spatial resolution of approximately 9 km, was processed using advanced geospatial techniques to calculate district-wise mean soil moisture values.

These values were further used to generate soil moisture suitability maps, particularly for short-duration and water-efficient pulses. To analyze rainfall patterns across Odisha during the Rabi season, we utilized the CHIRPS Daily dataset, which provides daily precipitation data at a spatial resolution of ~ 5.6 km. The analysis focused on aggregating district-wise total rainfall values from 2018 to 2023 for the Rabi season. This data captures rainfall distribution patterns that bear on strategies for rice fallows.

3.2. Production and productivity impact upon utilization

Recognizing that pre-intervention conditions often vary significantly for potential CRFM beneficiaries, effective targeting becomes an essential component of gauging the intervention's impact. The evaluation framework consists of two tiers. The first tier leverages secondary data sources, providing a foundational understanding of pre-existing conditions and general trends that may influence intervention outcomes. Studies show that initial conditions bear on post-intervention outcomes and must be considered as conditioning factors (Jin et al. 2017; Duflo and Saez 2002).

We implemented a novel approach for matching observations from the CRFM database (20 districts of Odisha) with data from the Krushak Odisha Portal. Though merging the two sets of data offers advantages, it also poses unique challenges as the combination of data is contingent on the presence of a common identifier, which is missing. The ADAPT portal contains data primarily on the area under CRFM for each crop, along with productivity metrics at the cluster level. Each cluster, identified by a unique ID provided by the implementing partners, comprises a set of farmers who received CRFM pivotal agricultural inputs. The number of farmers within these clusters ranges from 25 to 40. The CRFM database, however, only provides limited data comprising the location of the farmer, the farmer's name, the area under CRFM, and the productivity levels of different crops.

To address this limitation, discussions were held with departmental representatives, where it was noted that the Krushak Odisha Portal (Farm Registry) maintained additional details on CRFM beneficiaries. The Farm Registry database includes key farmer demographic information on gender, age, social category, and occupation, as well as information on farm equipment, farm practices, land size, cropping patterns, land type, and irrigated and unirrigated areas.

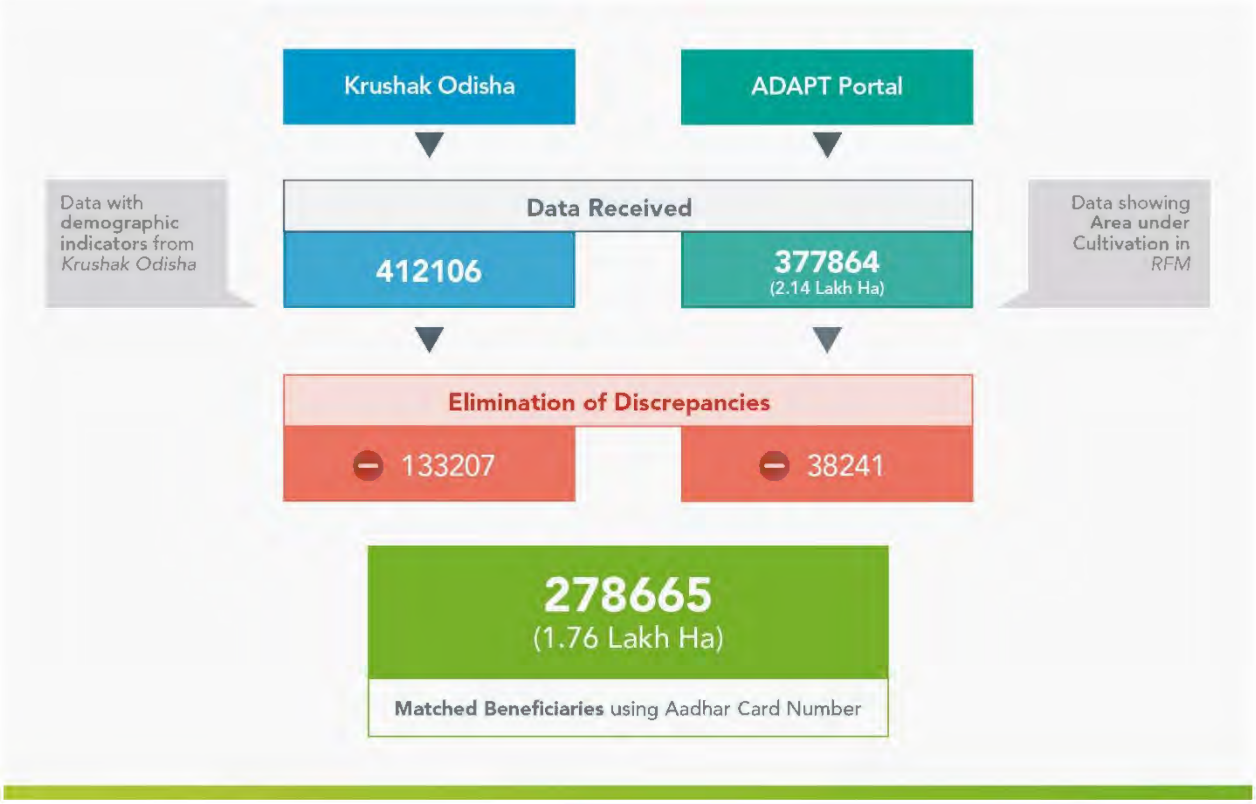
To match the datasets, we used anonymized Aadhar card numbers to combine the data from the two portals. Using these unique identifiers, CRFM beneficiaries were mapped to the corresponding farm records from the Krushak Odisha Portal. This mapping allowed for individualized data analysis by linking area and productivity information from the CRFM Portal with the demographic and farm-specific data from Krushak Odisha Portal.

Figure 2 illustrates the steps involved in matching the households of the CRFM and Krushak Odisha Portal, which enabled generation of the database for evaluation of CRFM Odisha. To validate the matching process, a simulation approach was conducted which used various scenarios to determine the potential accuracy of the observations. The results indicated that the estimates were statistically significant and closely aligned with the matched data. The application of this integrative approach is unique as it is employed in this study.

In the case of the 10 districts, data was sourced from the National Informatics Centre (NIC) and subsequently mapped to the Krushak Odisha Portal. In this mapping process, the NIC team applied a similar approach, utilizing key beneficiary identifiers to ensure accurate linkage with the Krushak Odisha data. Like the previous matching process, this approach necessitated the exclusion of certain observations to maintain data consistency and reliability in the analysis.

The availability of key indicator information varies by level; for example, demographic data and information on the area under CRFM cultivation are available at the beneficiary level, while inputs, IPM, and farm practices data are accessible at the block level. Yield information, on the other hand, is captured at the cluster level. In the 10 districts managed by the department, input subsidy data is specifically available at the beneficiary level. The data thus faced the twin challenges of aggregation and matching.

Figure 2. Flowchart of matching data from the Krushak Odisha and the CRFM Portals



Source: Authors' work.

In principle, evaluation of CRFM has several options for exploiting treatment variations. If CRFM interventions were implemented over time, then the same location could constitute both the treated and the untreated (control) group, based on when data was gathered at that location. Unfortunately, that information is unavailable. As all 30 districts of Odisha are sites for CRFM, and without data on timing of interventions or the incidence of treatment and control contexts across locations (districts), we rely on differences in treatment intensity in CRFM to evaluate the impact. These differences thus lend the distinction between treatment and control.[2]

Following the methodology outlined earlier, we employed the Duflo and Saez (2002) approach which emphasizes the "treatment within control" paradigm. This was achieved by using the median value of the proportion of land under CRFM as a threshold to divide the sample into two groups: a high intensity CRFM (treatment) group, that is, locations with an above-median proportion of land under CRFM, and a control group made up of locations where a below-median proportion of land is under CRFM.

[2] A detailed district-wise analysis is provided in Appendix B.

The possible heterogenous effects of CRFM were evaluated by looking at outcomes by sub-groups that were based on key characteristics such as gender, socioeconomic status, age, and caste. The evaluation is thus done at different scales, that is, at the district, cluster, and beneficiary levels. Each district may experience different levels of intervention intensity, making it important to distinguish between district-based degrees of intensity in IPM implementation, adoption of new farm practices, and utilization of funds and services provided through state programs. We thus implemented evaluation for specific treatments such as IPM for the 10 districts.

4. RESULTS AND FINDINGS

4.1. Effect on utilization of rice fallows

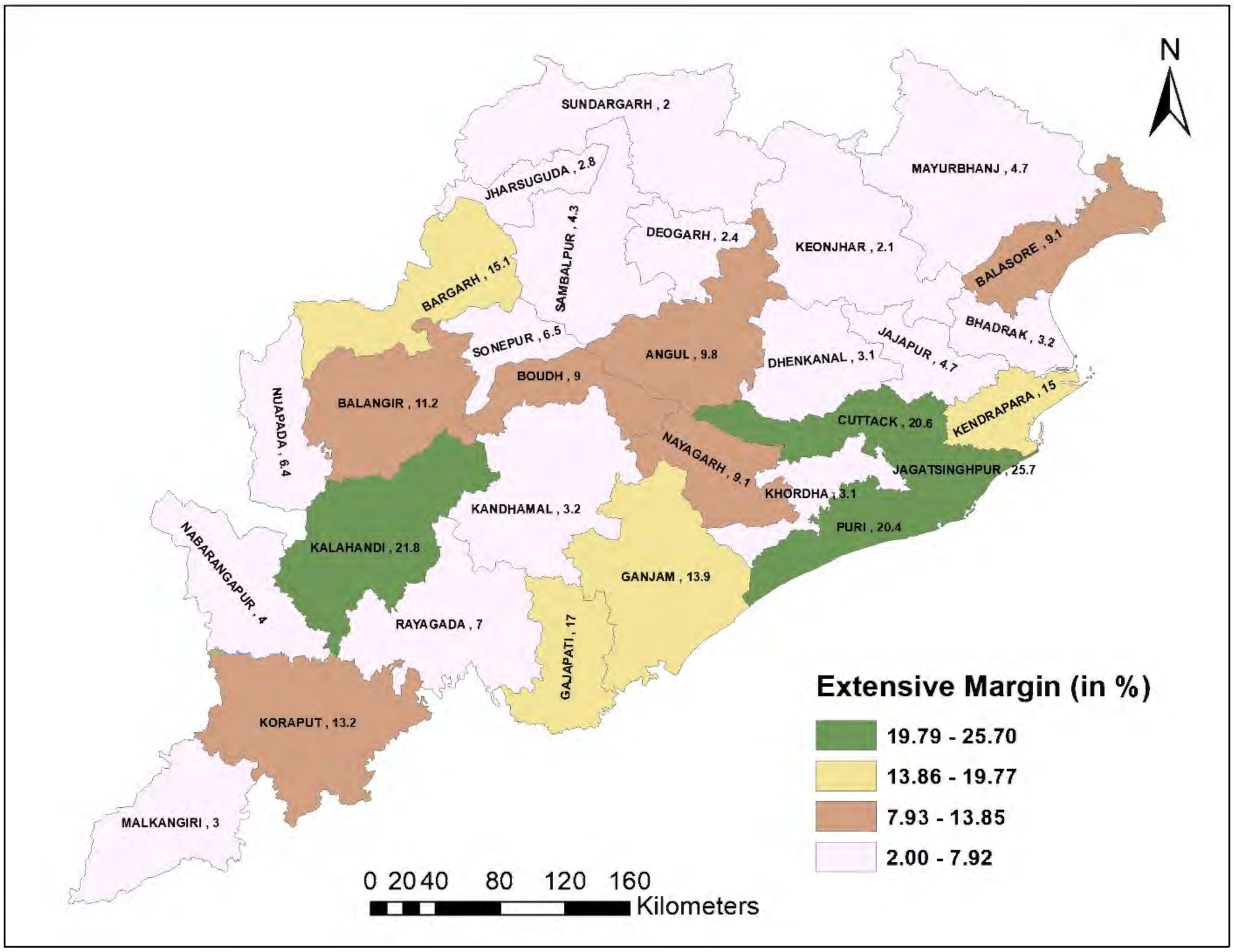
As discussed above, using remote sensing data we calculated the area of newly cultivated regions, that is, the utilization of rice fallows. By employing a rice mask, we analyzed data from 2020 and 2021 to identify pre-existing rice fallow areas, particularly perennial fallows (patches left fallow during the entire period). We then overlaid the fallow layers with data from 2022 and 2023 to identify patches of land that had newly transitioned from fallow to non-fallow areas, that is, ephemeral fallows.

4.1.1. Extensive margin expansion with CRFM

Using the remote sensing data, we used the extensive and intensive margin approach to understand the change in fallow land in different scenarios. In the extensive margin approach, we looked at the percentage change in the areas of land that were consistently left fallow prior to CRFM and have been converted to crop land post CRFM. As shown in Figure 3, Jagatsinghpur, at 25.7 percent, is among the districts with the highest new utilization of fallow land; this corresponds to 18.9 thousand hectares. As per the report of the implementation partners, this substantial increase was facilitated by efficient resource utilization, improved input access, and favorable agroclimatic conditions. Kalahandi, a tribal district, follows closely with 21.8 percent, amounting to the utilization of 36.3 thousand hectares. The corresponding figures from remote sensing for Cuttack (20.6 percent) and Puri (20.4 percent) are 22 thousand and 18 thousand hectares, respectively, which indicates that coastal area challenges such as salinity and waterlogging were addressed. The figures for Gajapati and Bargarh are 17.0 percent and 15.1 percent, respectively. While these margins are lower than the top-performing districts, they still reflect significant progress in the reduction of fallow lands.

Kendrapara (15 percent) and Ganjam (13.9 percent) experienced area expansions of 17.5 and 28.5 thousand hectares, respectively; however, Sundargarh, (2 percent) showed only a modest area increase of 3.1 thousand hectares, which may indicate barriers to the adoption of CRFM. At the state level, Odisha achieved an overall extensive margin of 9.1 percent, representing a total of 257.3 thousand hectares of newly cultivated land under the CRFM program.

Figure 3. Distribution of extensive margin (new land) using remote sensing data



Source: Remote sensing and authors' analysis.

We cross-validated our findings using the IRRI report on crop suitability areas to assess whether districts with a higher percentage of suitable land area were more likely to have a larger fraction of new area engaged under CFRM (the extensive margin).[3] Figure 4 illustrates the correlation between the extensive margin and the percentage of suitable land across districts. The results indicate a strong positive relationship between land suitability and transformation of perennial fallows in Odisha. For instance, Jagatsinghpur (26%), Puri (20%), and Kendrapara (15%) which have a high percentage of suitable land (above 84%) also exhibit a higher case of perennial fallow transformation under CRFM.

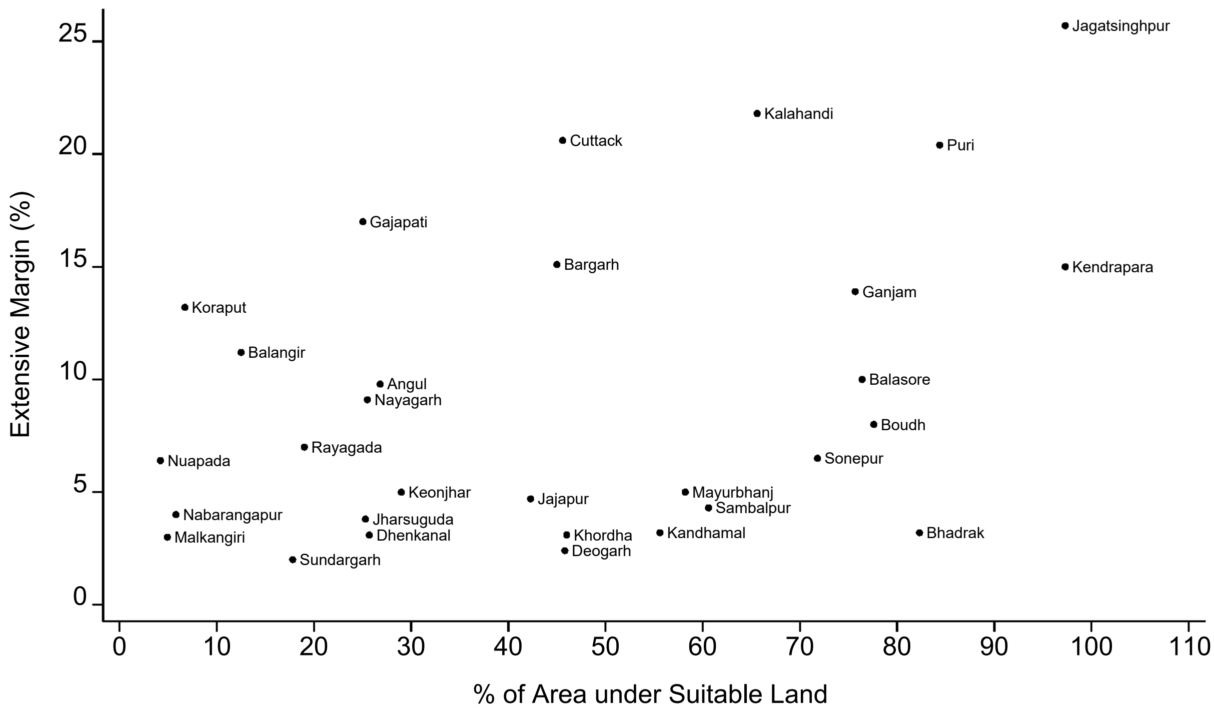
On the other hand, districts with poor land suitability such as Koraput (13%), Malkangiri (3%), and Nuapada (6%) where the suitable land area is below 10 percent indicate comparatively limited

[3] IRRI Report on Targeting Rice Fallows: A Cropping System-Based Extrapolation Domain Approach. Sub Project 2 (2016-2022).

scope for expansion under CRFM. There indeed exist exceptions like Balasore (76%) and Boudh (78%), where the percentage of suitable land is relatively high, but not positively and significantly associated with incorporation of new fallows into cultivation.

These findings underscore the importance of district-tailored strategies that focus on enhancing land productivity in high-suitability areas while simultaneously working on infrastructure and input support in low-suitability regions to improve their agricultural potential.

Figure 4. Association between area under cultivation and extensive margin (new land) using remote sensing data



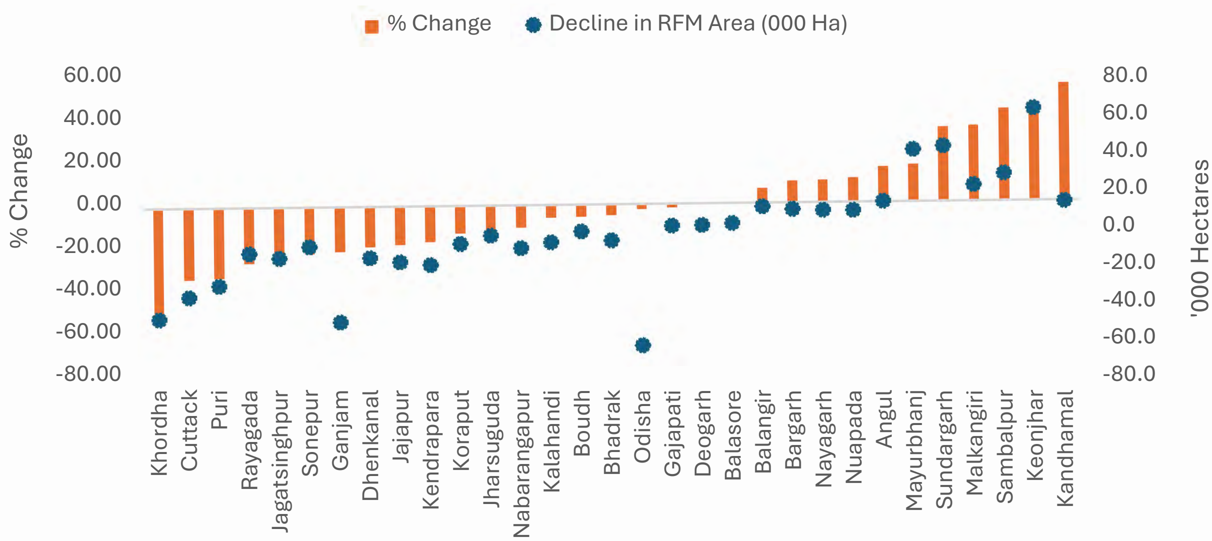
Source: IRRI Project Report (2016-22) on "Targeting rice fallows: a cropping system-based extrapolation domain approach" and Authors' analysis

4.1.2. Intensive margin expansion with CRFM

The earlier approach looked at changes in fallow lands that had persisted prior to CRFM. Here, in the intensive margin approach, we look at the percentage change in the area of fallow land for those areas that were cultivated at least once or occasionally prior to CRFM, and we categorized them as "ephemeral fallows". Figure 5 presents district-wise data on the percentage decrease in both perennial and ephemeral rice fallow areas, highlighting patches that were either cultivated (growth) or remained fallow (shrinkage) during the pre-CRFM period but were subsequently utilized post-CRFM.

Figure 5 represents the change in ephemeral fallows across Odisha's districts from the pre-CRFM period (TE 2021) to the post-CRFM period (2022 and 2023). The negative values in Figure 5 represent declines in fallow areas. At the state level, Odisha recorded an overall decline of 64.5 thousand hectares in ephemeral fallows. Among the districts, Khordha showed the steepest decline in ephemeral fallow area, with a reduction of 48 thousand hectares, translating to a decline of 54.8 percent. Note that the CRFM package comprises improved access to seeds, better irrigation infrastructure, farmer training programs, and IPM simultaneously, which underscores the complementarity among the interventions. Similarly, Cuttack (36.4 thousand hectares; 33.6 percent) and Puri (30.5 thousand hectares; 32.9 percent) exhibited substantial reductions in ephemeral fallows in coastal areas.

Figure 5. Change in rice fallow area across districts

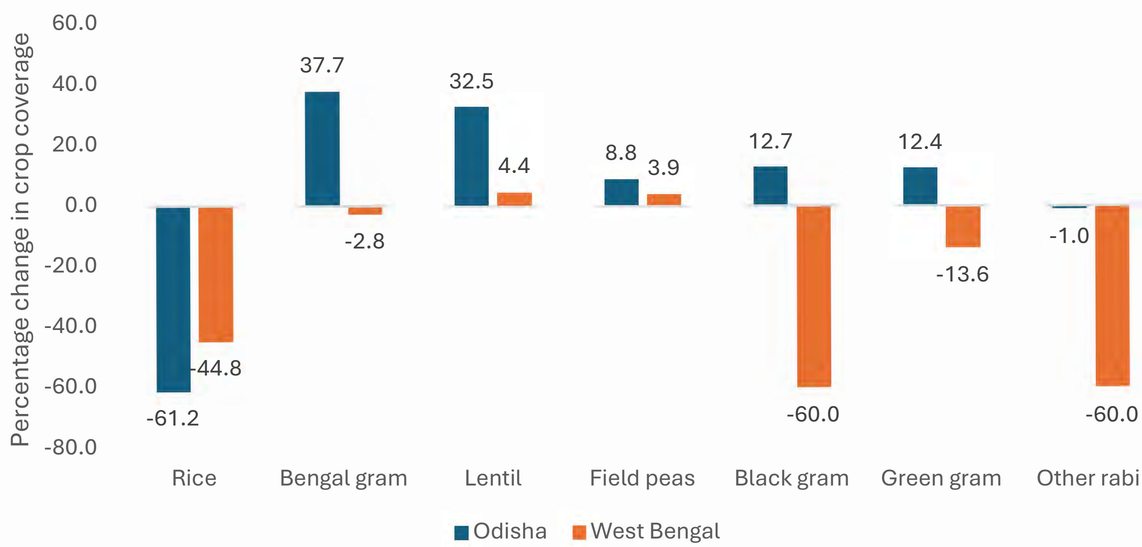


Source: Remote sensing data and authors' analysis.

Rayagada (13.3 thousand hectares; 26 percent) and Jagatsinghpur (11.7 thousand hectares; 22.3 percent) represent smaller declines in ephemeral fallows. Despite the average and modal reduction in fallow areas, remote sensing data revealed that some districts sporadically experienced an increase in ephemeral fallows. These districts include Keonjhar, Sundargarh, and Malkangiri. Significant increases in cultivated fallow areas occurred in Sambalpur (26 thousand, hectares; 42.8 percent) and Mayurbhanj districts (39.2 thousand hectares; 17.1 percent). Comparatively moderate increases in ephemeral fallow areas were observed in Nuapada, Nayagarh, and Bargarh. In terms of the overall trend in the state, Odisha has observed a decline in ephemeral fallow lands in 18 out of 30 districts.

The detailed description of extensive and intensive margins primarily focused on district-wise overall growth or reduction in acreage. Figure 6 highlights the percentage change in crop coverage area between the pre-CRFM period (2020/2021 and 2021/2022) and the post-CRFM period (2022/2023 and 2023/2024) for Odisha and West Bengal. The figure depicts Odisha's significant post-CRFM success in crop diversification from Rabi rice to pulses. In Odisha, during the Rabi season, rice cultivation saw a 61.2 percent decrease and rice fallows were effectively utilized for pulses; West Bengal, on the other hand, showed a 45 percent decline in Rabi rice. Odisha experienced an impressive 37.7 percent increase in coverage by Bengal gram, while West Bengal showed a 2.8 percent decline. The area under lentil cultivation in Odisha also rose by 32.5 percent, far outpacing West Bengal's modest 4.4 percent growth. Cultivation of other crops such as black and green gram showed increases in the area of 12.7 percent and 12.4 percent, respectively, while West Bengal experienced short term declines in cultivation of these crops.

Figure 6. Percentage change in crop area during Rabi season (CRFM states comparison)



Source: India, Department of Agriculture and Farmers' Welfare (2023).

4.1.3. Comparison between perennial and ephemeral fallows in relation to CRFM

Table 2 presents the matrix categorizing Odisha's districts based on CRFM area trends. It distinguishes patterns from the pre-CRFM period (2018–2021) to the post-CRFM period (2022–2023). The matrix categorizes districts based on whether their fallow area increased or decreased in the post-CRFM period. It also identifies districts with a consistent decline in perennial fallow land from 2018 to 2021, a consistent rise in perennial fallow land from 2018 to 2021, and a fluctuation or mix (increase or decrease) during the pre-CRFM period. These classifications help capture three distinct scenarios, outlined as follows:

A. Ephemeral fallows in the pre-CRFM period

- **Increase in fallow area:** Districts such as Kandhamal, Malkangiri, Nayagarh, and Rayagada showed fluctuations in fallow area during the pre-CRFM period but experienced an increase in fallow lands in the post-CRFM period. Such districts comprise a small share of the total (4 out of 30).
- **Decrease in fallow area:** Districts such as Bhadrak, Boudh, Cuttack, Ganjam, Jagatsinghpur, Jharsuguda, Kendrapara, Koraput, Mayurbhanj, Nabarangpur, Nuapada, Puri, and Sonepur demonstrated fluctuating patterns during the pre-CRFM period but successfully reduced their fallow lands after implementation of the CRFM program.

B. Perennial decrease of fallow areas in the pre-CRFM period

- **Increase in fallow area:** Districts such as Angul, Balasore, Bargarh, and Gajapati showed consistent decreases in fallow area during the pre-CRFM period but exhibited an increase in fallow lands during the post-CRFM period. This reversal may suggest systemic issues or implementation gaps in sustaining the program's benefits. Structural challenges such as fragmented landholdings or declining farmer participation may have contributed to this negative outcome.
- **Decrease in fallow areas:** Districts such as Dhenkanal, Jajapur, and Keonjhar exhibited decreases in perennial fallow land during the pre-CRFM period and experienced further decline in fallow land post-CRFM. These changes may reflect the efficacy of the program implementation or external factors such as favorable rainfall patterns and input availability.

C. Perennial increase in fallow areas in the pre-CRFM period

- **Increase in fallow areas:** Districts such as Balangir and Sundargarh showed consistent increase in perennially fallow land during the pre-CRFM period and continued to see increases in the post-CRFM period. However, Balangir district is recognized as one of the most water-stressed regions in Odisha, frequently experiencing severe water scarcity due to low and erratic rainfall.
- **Decrease in fallow area:** Districts such as Deogarh, Kalahandi, Khordha, and Sambalpur demonstrated consistent increase in perennially fallow land during the pre-CRFM period but reversed the trend post-CRFM, showing reductions in fallow lands.

Table 2. Matrix of districts showing increased or decreased ephemeral and perennial fallows pre- and post-CRFM

Pre-CRFM (2018 to 2021)	Post-CRFM (2022 to 2023)	
	Increase in fallow area	Decrease in fallow area
Ephemeral fallow area	Kandhamal, Malkangiri, Nayagarh, Rayagada	Bhadrak, Boudh, Cuttack, Ganjam, Jagatsinghpur, Jharsuguda, Kendrapara, Koraput, Mayurbhanj, Nabarangapur, Nuapada, Puri, and Sonepur
Decrease in perennial fallows	Angul, Balasore, Bargarh, Gajapati	Dhenkanal, Jajapur, Keonjhar
Increase in perennial fallows	Balangir, Sundargarh	Deogarh, Kalahandi, Khordha, Sambalpur

Source: Remote sensing and authors' analysis.

4.1.4. Factors associated with utilization of fallow land: Soil moisture and rainfall

In remote sensing analysis, soil moisture and rainfall data play a critical role in evaluating the potential for utilization of fallow land in terms of land suitability, crop viability, and land use dynamics. Figure 7 depicts district-wise data on soil moisture and rainfall in Odisha; however, other factors such as soil type, vegetation cover, and irrigation practices can influence land suitability.[4]

Malkangiri, with the highest rainfall (57.7 mm), shows a relatively moderate soil moisture level of 0.26 cubic meter of water per cubic meter of soil (m^3/m^3), indicating the direct influence of precipitation on soil moisture. Ganjam (54.7 mm of rainfall) and Jagatsinghpur (52.3 mm) also maintain soil moisture levels of 0.25 m^3/m^3 and 0.29 m^3/m^3, respectively. Puri and Khordha exhibit the highest soil moisture levels (0.32 m^3/m^3 and 0.31 m^3/m^3), with moderate rainfall of 49.5 mm and 50.4 mm, respectively. There are a few aberrations in some districts where, even with comparatively high rainfall, soil moisture levels are low or moderate; these include Gajapati and Bhadrak, which experience rainfall levels of 48.8 mm and 48.2 mm, respectively, but where soil moisture values are 0.25 and 0.26 m^3/m^3. This deviation may suggest potential issues such as poor water retention, high evaporation rates, or high runoff.

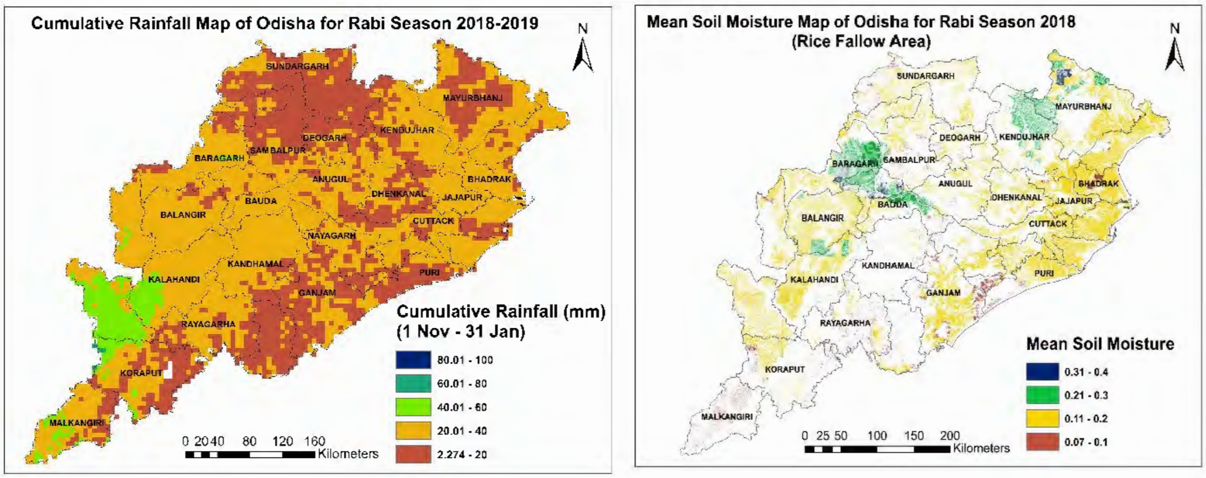
In areas where there is a weak link between rainfall and soil moisture levels, interventions such as rainwater harvesting and improved irrigation systems may be required with the provision that

[4] While analyzing, we considered five-year averages of soil moisture and rainfall data.

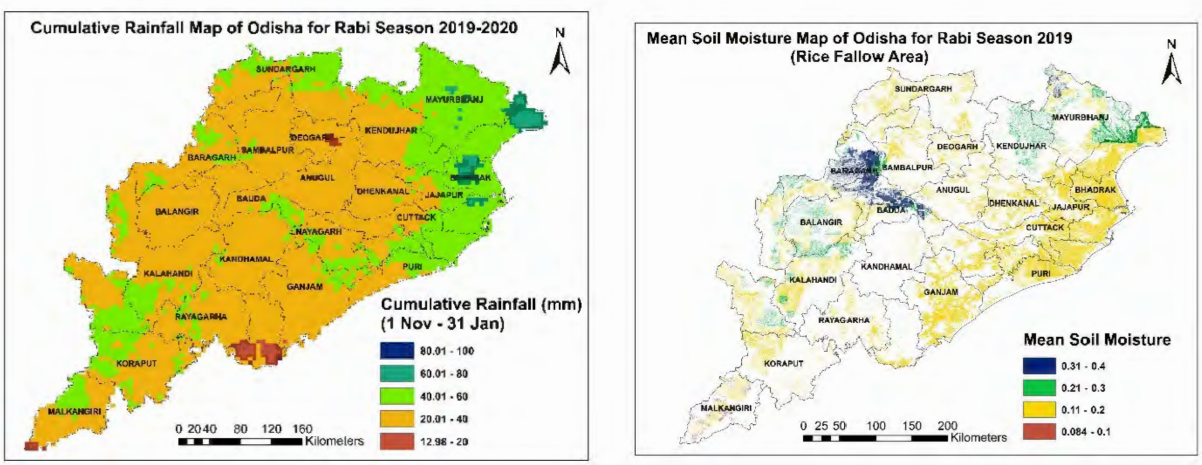
the CRFM is predicated on utilizing residual soil moisture for transforming fallow lands. Excessive soil moisture is also unfavorable as it adversely affects pulses and oilseeds by causing root rot, reduced yields, and increased susceptibility to diseases. With excessive soil moisture, pulses also suffer from disrupted nitrogen fixation, while oilseeds face compromised soil quality. Proper drainage, balanced irrigation, and effective residual moisture management are critical for maintaining the health, productivity, and quality of these crops.

Figure 7. Association of rainfall and soil moisture

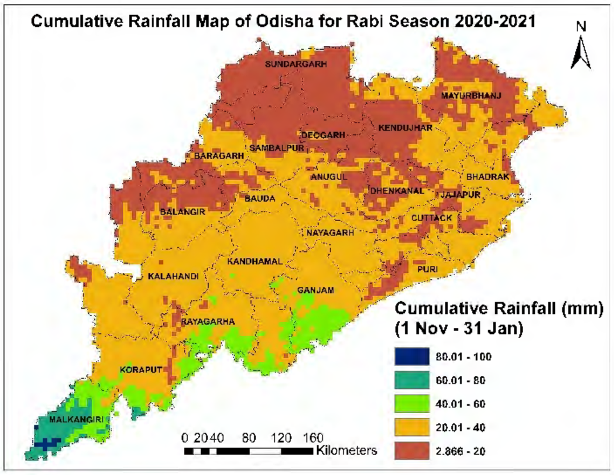
2018 (Correlation coefficient = 47%)

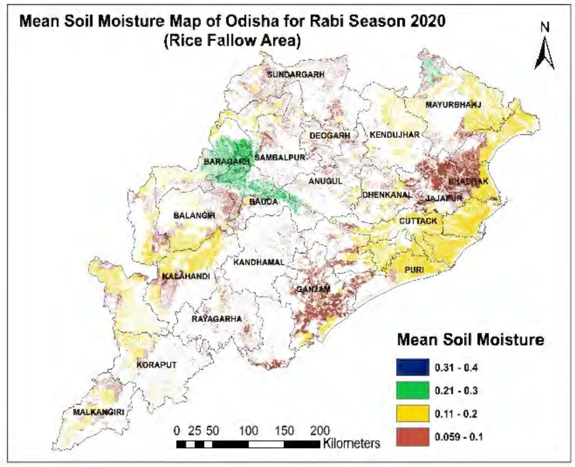


2019 (Correlation coefficient = 47%)

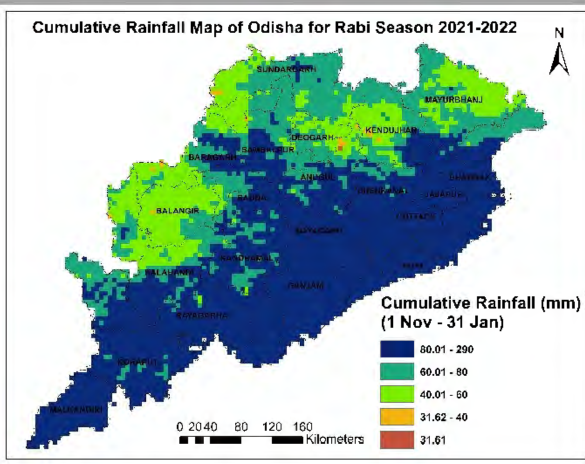


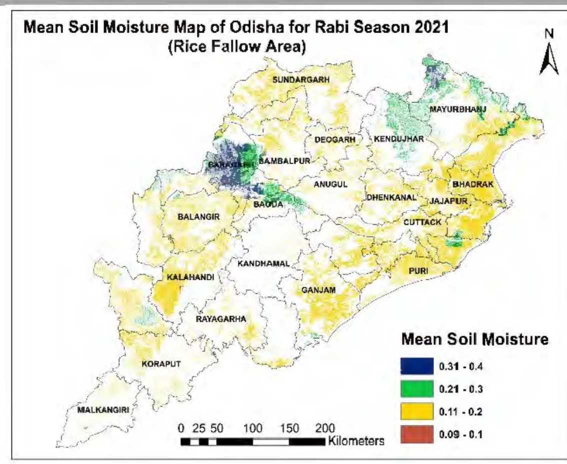
2020 (Correlation coefficient = 20%)



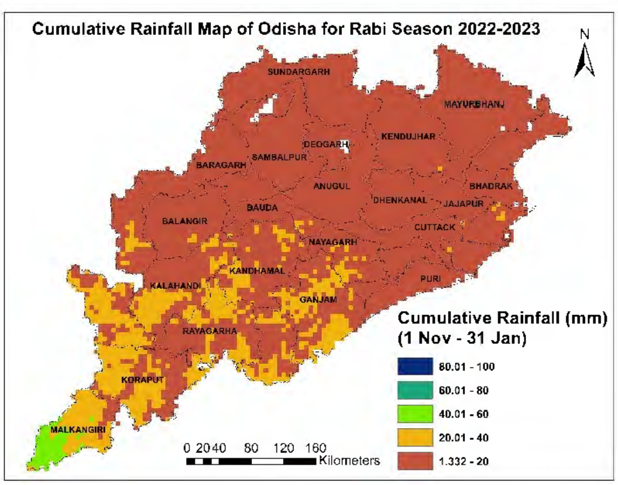


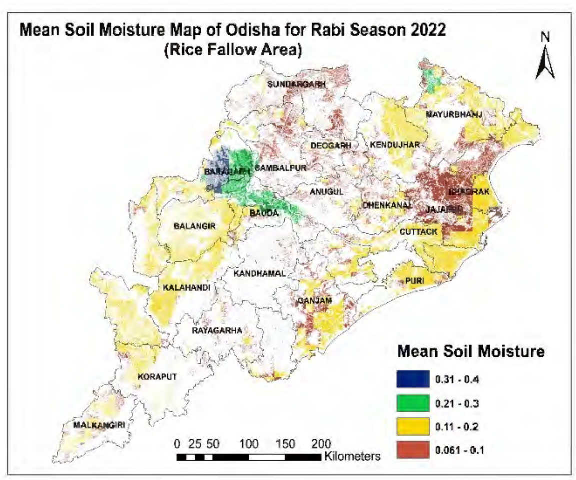
2021 (Correlation coefficient = 54%)



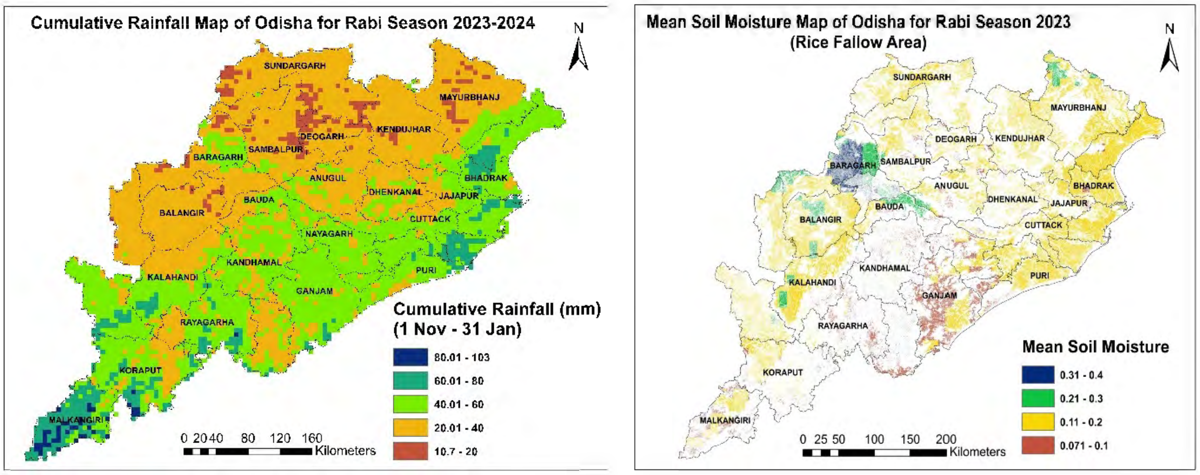


2022 (Correlation coefficient = 6%)





2023 (Correlation coefficient = 19%)



Source: Funk et al. (2015) for rainfall data and Reichle et al. (2022) for soil moisture data.

4.2. Outcomes upon utilization of rice fallows

Above, we looked at the question of whether rice fallows are being utilized/cultivated after CRFM interventions and to what extent this is utilization as measured by acreage of crops. Upon cultivation of fallow lands, the question emerges regarding production and productivity of the cultivated crops and the effect of these changes on average state-level outcomes. Supported by interventions in seed, fertilizers, and pest management on incremental land, if the additional cultivation of these lands is carried out more productively, the average state-level production or productivity would increase.

In the absence of experimental data, we employed quasi-experimental methods, cognizant of the fact that results will reflect only the short-run effects of CRFM. As all districts were subject to CRFM interventions, we implemented matching estimation, with treatment and control samples varying by the intensity of their respective CRFM treatments. We used propensity score matching (PSM), coarsened exact matching (CEM), and inverse probability weighted regression adjustment (IPWRA) as evaluation strategies to address potential biases in treatment assignment.[5]

In observational studies, matching methods are primarily used to estimate causal effects. They create comparable groups (treated and control) that are similar on observable covariates. By matching treated and control units exactly on coarsened covariates, CEM reduces imbalance

[5] In the PSM method, once the common support assumption is met, it is essential to test the balancing property of the propensity score. In our analysis, both the common support assumption and the balancing property were satisfied. For the CEM method, the primary objective was to minimize the L1 values (which measure the statistics of imbalance), which we achieved within the range of 0.3 to 0.4 across all specifications.

between groups—the sine qua non of evaluation—thus enhancing the validity of causal inferences.

The steps in the estimation involve: (1) estimating the propensity score, that is, the conditional probability of being in a treatment group for each unit, whether treated or not; estimating the probability of receiving treatment, that is, of adopting CRFM on an above-median area of land, based on observed characteristics; this score summarizes the likelihood of treatment assignment and is crucial for matching treated and control units; (2) once the propensity scores are estimated, we compute the average treatment effect for treated units by comparing their outcomes with those of control units that have similar propensity scores.

This comparison enables us to assess the impact of high intensity CRFM intervention on outcomes (increases in, for example, acreage, production, and productivity) between treated and control units with similar propensity scores, while controlling observable differences. Taking the average treatment effects calculated for all matched pairs gives us the average treatment effect on the treated (ATT), which provides an estimate of the impact of CRFM interventions on those who adopted the program. The estimated ATT is calculated upon satisfying the conditions of common support in propensity score distribution and satisfaction of balancing property.

There are several possible matching estimators. We chose the nearest neighbor matching (NNM) to estimate the ATT, which makes it possible to obtain analytical standard errors for the estimated treatment effect. Apart from propensity score matching, the evaluation also implemented coarsened exact matching (CEM) and inverse probability weighted regression adjustment (IPWRA) for robustness. The IPWRA method is an econometric tool that is used to estimate causal effects in observational studies. It combines two key approaches—inverse probability weighting (IPW) and regression adjustment (RA)—to address potential biases arising from confounding variables and selection into treatment groups.

4.2.1. Effect on yield and acreage: Short-run outcome as a gateway to long-term effects

Given the short time that has elapsed for CRFM, the short-term outcomes such as immediate gains in productivity and acreage may serve as gateways to achieving long-term goals such as sustainable agricultural development, improved market integration, and higher or stable farmer incomes over time. In this section, we present the results derived from the Krushak Odisha (KO) Portal and ADAPT database and employ matching estimators.

Table 3 presents the estimated impact of the CRFM program on crop yield using the PSM and IPWRA methods. The ATT values are calculated using the NNM approach with three variations: matching with 1, 3, and 5 nearest neighbors and using IPWRA to calculate the average treatment effect on the treated (ATT). The values demonstrated positive and significant effects of the CRFM program on crop yields, indicating that farmers participating in CRFM achieve higher yields relative to the control group.

Field pea cultivation experiences one of the most substantial impacts of CRFM on yield, with ATT values ranging from 486.6 to 490.8 kg/ha, that is, an approximately 38 percent change between the treatment and control units. This suggests that CRFM interventions such as improved seed varieties, pest control, and optimized nutrient management have had a significant positive effect on field pea productivity (Table 3).

In some other cases, though yields increased in a statistically significant way the economic magnitude may be small. For Bengal gram, the yield increase due to CRFM participation was clear, with an increase of 19.5 kg/ha (1.6 percent) when matched with one neighbor, 35.1 kg/ha (3.0 percent) when matched with three neighbors, and 30.0 kg/ha (2.6 percent) when matched with five neighbors. This suggests a positive but comparatively small impact of CRFM on productivity. There could also be a positive outcome over time in terms of stability of yields. Combined with impacts on acreage this may still translate into significant increases in production.

Grass pea yields have also increased substantially under CRFM, with ATT values of 86.6 kg/ha (10.7 percent), 82.8 kg/ha (13.4 percent), and 82.0 kg/ha (10.1 percent). This is particularly valuable for regions where grass pea is among the primary pulses cultivated. Lentils show consistent yield improvements under CRFM, with ATT values of 75.9 kg/ha (10.2 percent), 83.4 kg/ha (11.3 percent), and 82.6 kg/ha (11.2 percent). For green gram, the yield increases are positive but relatively modest, with less than a 10 kg/ha (1.2 percent) increase in yield.

In the case of oilseeds, sesamum yields have benefited from CRFM, showing ATT values of 28.4 kg/ha (5.1 percent), 33.9 kg/ha (6.2 percent), and 33.8 kg/ha (6.1 percent) across matching methods, and, finally, mustard yields show improvements ranging from 18.4 kg/ha (4.5 percent) to 21.8 kg/ha (5.6 percent) across different matching specifications. Table 3 also presents the impact of CRFM on yield using CEM. The values in this table show positive and significant impacts across all crops, reinforcing the results obtained by PSM and IPWRA.

Table 3. Effect of CRFM program on yield (kg/ha): Estimates from PSM, IPWRA, and CEM

Methods →	PSM			IPWRA	CEM
Crops	**NNM (1)**	**NNM (3)**	**NNM (5)**	**ATET**	
Bengal gram	19.5*** [1.6%]	35.1*** [3.00%]	30.0*** [2.6%]	27.9***	20.930*** (5.313)
Black gram	5.3*** [0.7%]	5.5*** [0.8%]	5.5*** [0.8%]	0.47*	0.374^{ns} (1.754)
Field pea	486.6*** [38.3%]	486.7*** [38.3%]	490.8*** [38.7%]	127.0***	44.173^{ns} (48.771)
Grass pea	86.6*** [10.7%]	82.8*** [10.2%]	82.0*** [10.1%]	35.5***	50.317*** (7.949)
Lentils	75.9*** [10.2%]	83.4*** [11.3%]	82.6*** [11.2%]	63.0***	44.379*** (9.678)
Green gram	8.9^{ns} [1.2%]	9.4^{ns} [1.3%]	9.2^{ns} [1.2%]	5.5^{ns}	0.271^{ns} (0.844)
Sesamum	28.4*** [5.1%]	33.9*** [6.2%]	33.8*** [6.1%]	36.2***	34.863*** (14.712)
Mustard	20.5*** [2.7%]	18.4*** [2.4%]	21.8*** [2.9%]	16.7**	20.912*** (4.702)

Source: Authors' calculation using psmatch2 command in Stata 18 Version.
Note: *, **, and *** indicate statistical significance at the $p < 0.1$, $p < 0.05$, and $p < 0.01$ levels, respectively; ns = not significant; the percentage change between the treatment and control units is indicated by square brackets; parentheses denote standard error; for CEM, the authors used the "imb" and "cem" command in Stata 18 Version.

Figures 8 to 13 illustrate the yields of Bengal gram, black gram, green gram, lentils, sesamum, and mustard (Rabi) across states at the aggregate level, comparing data from before and after Odisha's CRFM intervention. The most striking observation in the line graph is the overall yield increase in Bengal gram, black gram, green gram, lentils, sesamum, and mustard for Odisha following CRFM.

For specific crops such as pulses or oilseeds, the extent of the average yield transformation effect depends both on pre-CRFM yield levels as well as on the productivity of incremental or transitioned land area. Odisha's post-CRFM changes in yield align closely with those of high-performing states where the structural shift in yield is driven by the transformation of low- or zero-yield land into cultivated and productive land; for crops where pre-CRFM yield trends were positive, the shift in yields could be comparatively small. Pre-CRFM relative yield trends also would help determine if yield will converge toward those of other states post-CRFM (for example, green gram). Also, if CRFM-type interventions are taking place in other states, this effect will be embedded in the yields of the comparator states.

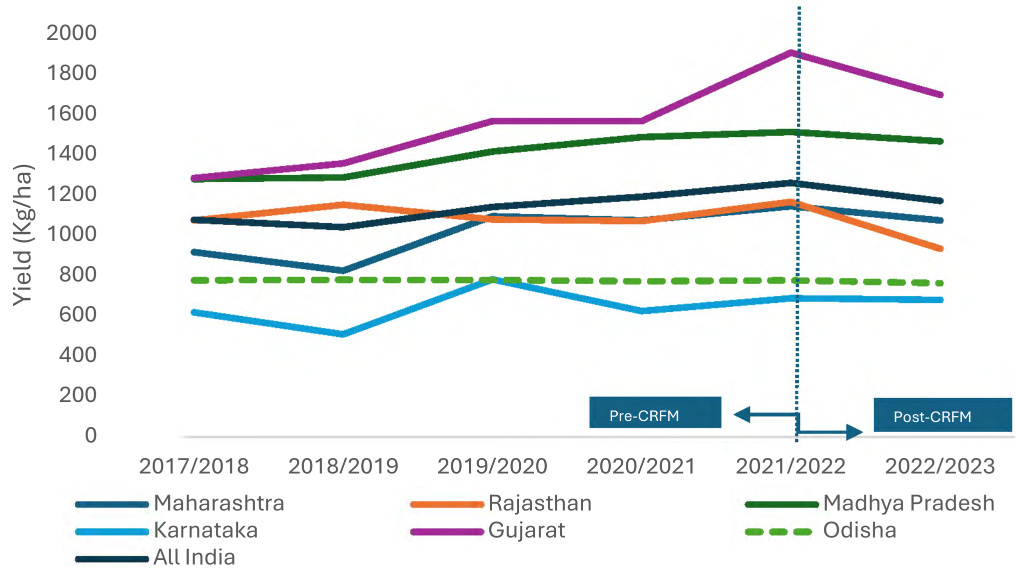
The following formula presents the evolution of yields with CRFM of commodity j in $location$ $k. y_{ieldpre\ RFSA}(jk)$ is $given$ as .

$$y_{ieldpre\ RFSA}(jk) = \frac{Total\ production\ of\ commodity\ j\ in\ location\ k\ (production\ in\ cultivated\ land + (0 - fallow\ land\ contribution)}{Cultivated\ land\ with\ the\ specific\ crop} \quad (2)$$

The yields post-CRFM are given as:

$$y_{ieldpost\ RFSA}(jk) = \frac{Total\ production\ of\ commodity\ j\ in\ location\ k\ (production\ in\ cultivated\ land + (converted\ fallow\ land\ contribution) + 0\ production\ from\ fallow\ land}{Cultivated\ land} \quad (3)$$

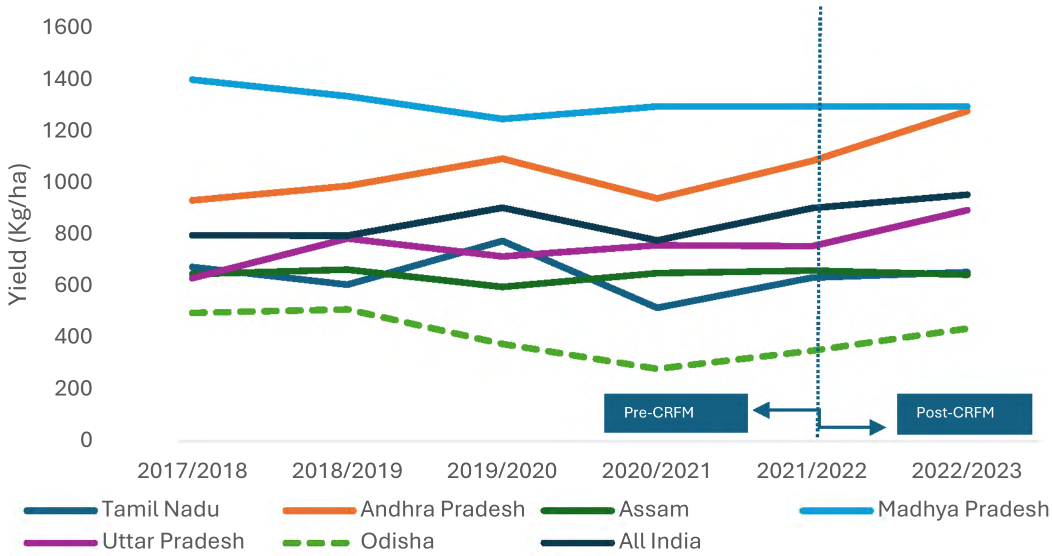
Figure 8. Bengal gram (Rabi) yields pre- and post-CRFM



Source: India, Ministry of Agriculture & Farmers' Welfare (n.d.).

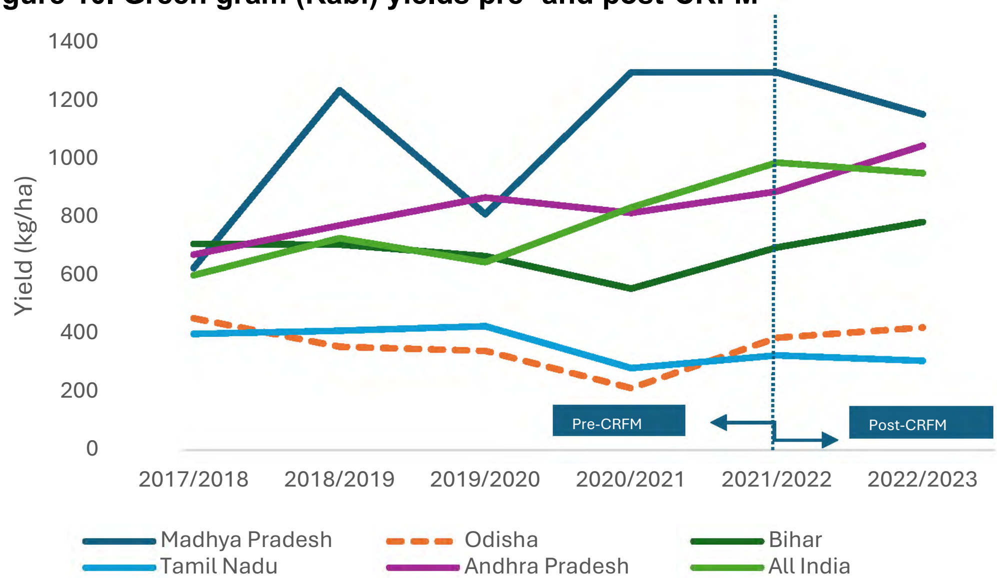
For Bengal gram, Odisha displayed significantly lower yields during the pre-CRFM period, possibly because a large share of private farmland was left fallow. In the pre-CRFM period, black gram yields dropped from 498 kg/ha in 2017/2018 to 281 kg/ha in 2020/2021. The CRFM intervention in 2022/2023, however, resulted in a significant increase to 437 kg/ha, due at least partially to relatively high yields on newly cultivated fallow land. Figure 9 presents the case for black gram.

Figure 9. Black gram (Rabi) yields pre- and post-CRFM



Source: India, Ministry of Agriculture & Farmers' Welfare (n.d.).

Figure 10. Green gram (Rabi) yields pre- and post-CRFM

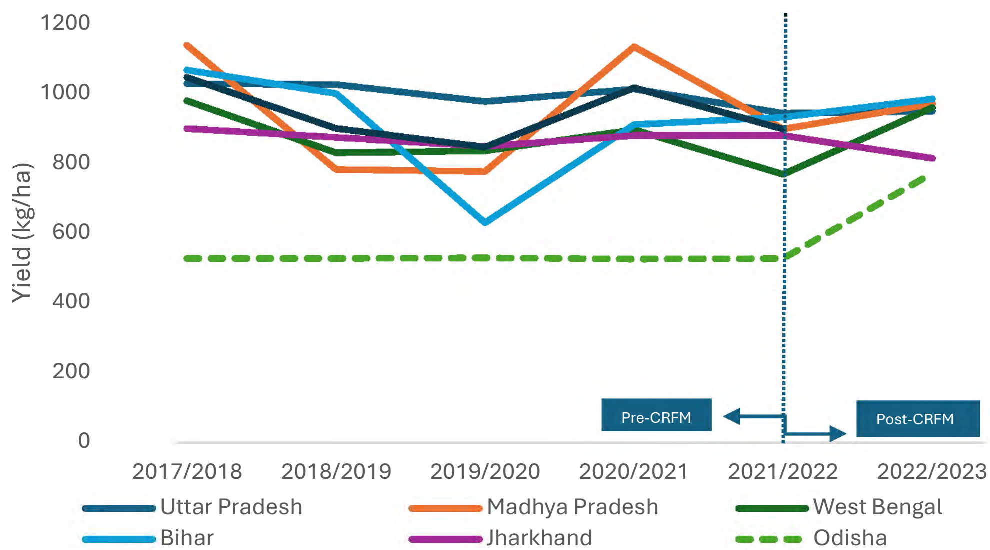


Source: India, Ministry of Agriculture & Farmers' Welfare (n.d.).

Uttar Pradesh, throughout the pre-CRFM period, demonstrates consistently high lentil yields, beginning at 1,029 kg/ha in 2017/2018, fluctuating slightly, and then reaching 944 kg/ha in 2021/2022 (Figure 11). Madhya Pradesh, a major contributor to lentil production, exhibits fluctuating trends. It achieved a peak yield of 1,139 kg/ha in 2017/2018 but then saw a sharp decline to 783 kg/ha in 2018/2019, and a further decline to 777 kg/ha in 2019/2020. West Bengal exhibits a similar pattern, starting with a yield of 980 kg/ha in 2017/2018 and declining to 769 kg/ha by 2021/2022. Bihar demonstrates significant volatility, with lentil yields ranging from a high of 1,068 kg/ha in 2017/2018 to a low of 630 kg/ha in 2019/2020, before recovering to 933 kg/ha in 2021/2022. Jharkhand maintains relatively stable yields across the years, ranging from 849 /ha to 900 kg/ha.

Constrained to zero or very low production in the pre-CRFM period, Odisha lagged behind other states, with yields stagnating around 528 kg/ha from 2017/2018 to 2021/2022. A significant turnaround occurred, however, in 2022/2023, with lentil yields increasing to 772 kg/ha, the 46 percent improvement underscoring the transformative impact of CRFM. Comparing Odisha's post-CRFM performance to that of other states highlights its progress. Although Odisha's yield of 772 kg/ha in 2022/2023 still falls short of the yields of leading states Uttar Pradesh and Madhya Pradesh, it surpasses West Bengal's recent performance. This improvement indicates that CRFM interventions have enabled Odisha to begin closing the productivity gap and enhancing its agricultural competitiveness.

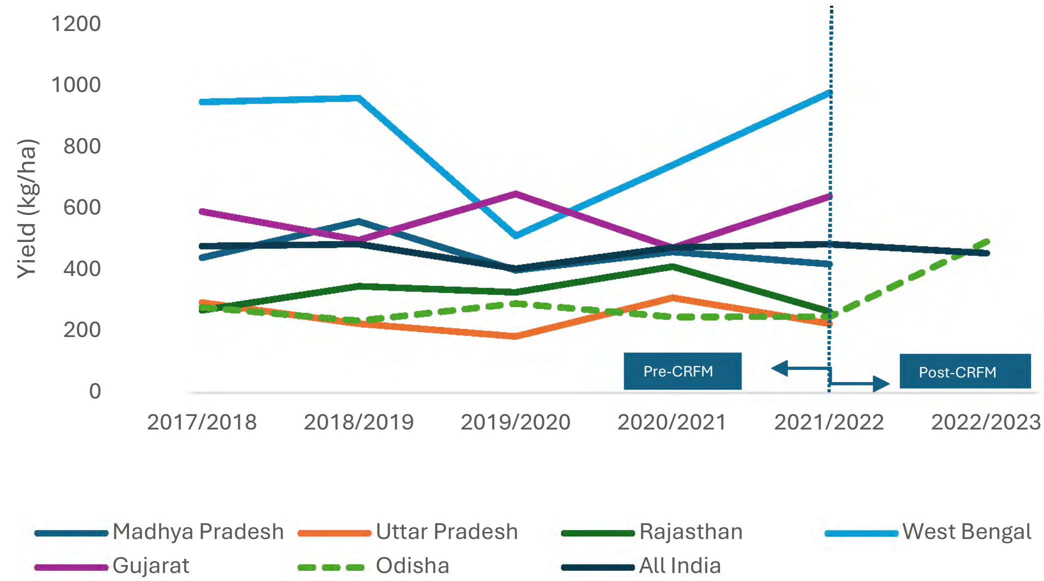
Figure 4. Lentil (Rabi) yields pre- and post-CRFM



Source: India, Ministry of Agriculture & Farmers' Welfare (n.d.); Department of Agriculture & Farmers' Welfare (2023); ADAPT and Krushak Odisha Portals.

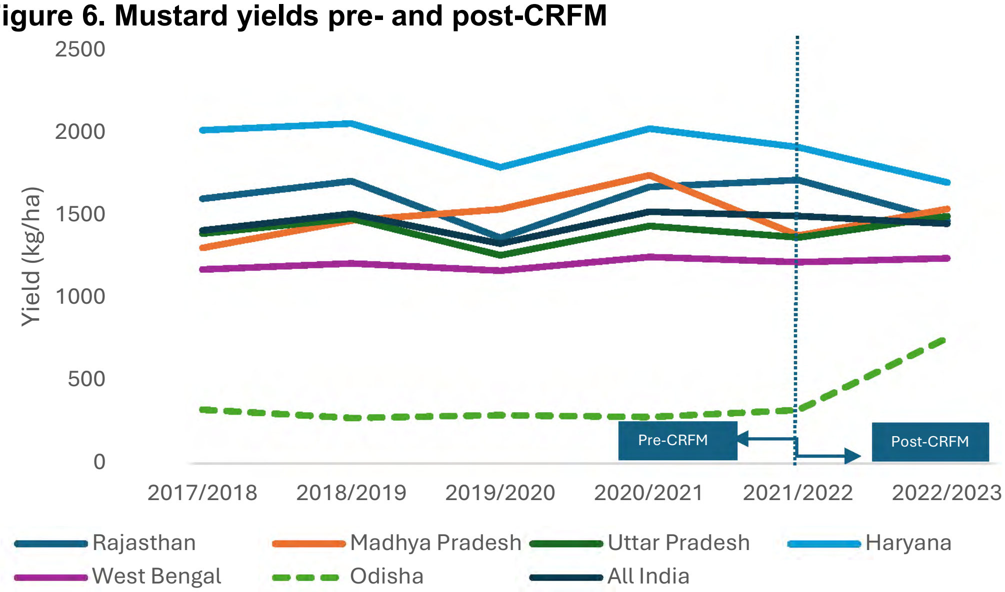
In oilseeds, Madhya Pradesh, with 20.6 percent of India's sesamum cultivation area, shows moderate yields throughout the period (Figure 12). Uttar Pradesh, contributing 19.9 percent of the total sesamum area, exhibits consistently low yields across the years. In Odisha, where sesamum accounts for only 1.5 percent of the total cultivation area, the pre-CRFM period reveals persistently low yields, ranging from 235 kg/ha in 2018/2019 to 291 kg/ha in 2019/2020; post-CRFM, however, it showed a significant improvement in yields, rising to 614 kg/ha, approaching the levels of Gujarat. Similar patterns emerge in relation to mustard (Figure 13).

Figure 5. Sesamum yields pre- and post-CRFM



Source: India, Ministry of Agriculture & Farmers' Welfare (n.d.); Department of Agriculture & Farmers' Welfare(2023); ADAPT and Krushak Odisha Portals.

Figure 6. Mustard yields pre- and post-CRFM



Source: India, Ministry of Agriculture & Farmers' Welfare (n.d.); Department of Agriculture & Farmers' Welfare, (2023); ADAPT and Krushak Odisha Portals.

As these figures show, Odisha stands out with pronounced post-CRFM increases in yields of black gram, green gram, lentils, sesamum, and mustard relative to other states and an overall convergence toward the all-India average.

The above system estimates the impact of the package of several interventions on the yield. Table 4 looks at the impacts of an individual component of the package, that is, the effect of input subsidies on the increase in acreage (hectares) under cultivation, using PSM, IPWRA, and CEM for the 10 districts governed by the CDAOs. We estimated the propensity score, which represents the conditional probability of being in the treatment group based on observed characteristics. The first step involves calculating the above-median probability of receiving a treatment such as, in this case, input subsidies. This score is essential for matching treated and control units with similar likelihoods of treatment assignment. After estimating the propensity scores, we calculated the average treatment effect for treated units by comparing their outcomes with those of matched control units.

This approach allows us to assess the impact of high intensity intervention packages on outcomes such as increased acreage, while controlling for observable differences between treated and control groups. The estimates show that various CRFM program inputs have contributed positively and significantly to increased acreage under Rabi cultivation among participating farmers. Subsidies of light traps, for example, show an ATT value of approximately 0.50 hectares (increase in acreage) across all matching specifications, highlighting their effectiveness as an environmentally friendly pest management technique that reduces pest risks and creates favorable conditions for crop expansion in a way that is pertinent under conditions of climate change.

Availability of subsidized micronutrients exhibits a substantial impact, with an ATT value of 0.68 hectares; this reflects their essential role in addressing soil deficiencies, enhancing crop health, and boosting productivity, all of which motivate farmers to expand their cultivated area. Availability of subsidized need-based pesticides have one of the highest impacts, with an ATT value of around 0.70 hectares. Need-based spraying provides pest control only when necessary, making conditions more favorable for crop expansion while avoiding unnecessary chemical exposure; it has an ATT value 0.49 hectares.

Phosphate-solubilizing bacteria (PSB) culture, the use of which yields ATT values of 0.66 hectares, enhances phosphorus availability. This is crucial for root development and plant resilience and thus encourages farmers to increase their cultivated land. Use of rhizobium culture also shows a consistent positive impact, with ATT values 0.62 hectares; it contributes to nitrogen fixation, which improves soil fertility, particularly for legumes, making it suitable for expanded cropping.

The use of Trichoderma, a beneficial fungus that controls soil-borne diseases, has ATT values 0.61 hectares; it improves crop protection, and farmers are thus encouraged to expand their cultivated area with this assurance of disease resistance. Weedicide use, with ATT values 0.68 hectares, significantly aids in reducing competition for resources; this, in turn, enhances crop growth and encourages acreage expansion by promoting better crop establishment and yield potential. Table 4 also presents the impact of input subsidies on acreage (hectares) using CEM. The values in this table show positive and significant impacts across all inputs, reinforcing the results obtained by PSM and IPWRA. With a coefficient of 0.59 hectares, Trichoderma demonstrates a substantial impact. By controlling soil-borne diseases, it helps create a disease-resistant environment that enables farmers to expand their cultivated land with reduced risk of crop loss. Weedicides, with a coefficient of 0.66 hectares, also show a positive and statistically significant impact.

Table 4. Effect of input subsidy on acreage (ha): Estimates from PSM, IPWRA, and CEM

Methods	PSM			IPWRA	CEM
Inputs	NNM (1)	NNM (3)	NNM (5)	ATT	
Light traps	0.50***	0.50***	0.50***	0.50***	0.489*** (0.043)
Micronutrients	0.68***	0.68***	0.67***	0.66***	0.661*** (0.007)
Need-based pesticides	0.70***	0.68***	0.67***	0.66***	0.665*** (0.007)
Need-based spraying	0.49***	0.49***	0.50***	0.50***	0.495*** (0.025)
PSB culture	0.66***	0.65***	0.65***	0.64***	0.642*** (0.007)
Rhizobium culture	0.62***	0.62***	0.62***	0.60***	0.609*** (0.007)
Trichoderma	0.61***	0.60***	0.60***	0.59***	0.592*** (0.007)
Weedicide	0.68***	0.67***	0.67***	0.66***	0.664*** (0.007)
Yellow sticky traps	0.60***	0.59***	0.58***	0.58***	0.630*** (0.025)
IPM	1.33***	1.31***	1.31***	1.30***	1.308*** (0.013)
INM	2.34***	2.33***	2.32***	2.27***	2.275*** (0.023)

Source: Authors' calculations.

Note for Table 4: **, **, and *** indicate statistical significance at the p < 0.1, p < 0.05, and p < 0.01 levels; ns = not significant; parentheses denote standard error; PSM = propensity score matching; NNM = nearest neighbor matching; IPWRA = inverse probability weighted regression adjustment; Integrated Pest Management (IPM) includes light traps, need-based pesticides, need-based spraying, weedicides, and yellow sticky traps; Integrated Nutrient Management (INM) includes micronutrients, phosphate-solubilizing bacteria (PSB) culture, rhizobium culture, and Trichoderma; for coarsened exact matching (CEM), the authors used the "imb" and "cem" command in Stata 18 Version.*

5. KEY TAKEAWAYS

The key takeaways based on the roadmap for CRFM intervention are outlined as follows:

A. Enhancing allocative and distributive efficiency

- *Recalibrating CRFM interventions*: To optimize the impact of CRFM interventions, there may be a need to further adjust or repurpose resource allocation across different locations and crops. This involves analyzing regional needs and identifying specific crops that require more targeted interventions. Oilseeds such as mustard and sesame, for example, appear to be comparatively under-supported.
- *Land scoping for diversification*: A strategic analysis of remaining rice fallow lands can reveal opportunities for diversification including vegetables. By identifying areas where other crops may offer a comparative advantage, the program can enhance productivity and potentially increase income for farmers. This approach is particularly useful in regions where rice fallow lands are underutilized.

B. Crop portfolio and yield analysis

- *Focused assessment of key crops*: The CRFM program's portfolio includes significant acreage devoted to crops such as green gram (57 percent), black gram (15 percent), and Bengal gram (14 percent). The relatively low yield of green gram, however, indicates the presence of factors that limit productivity. Conducting a detailed investigation into possible reasons for low productivity, such as the crop's growth duration or environmental factors, can provide insights that support yield improvement. Similarly, assessing factors that affect yield across other crops can guide more efficient resource allocation and more effective targeted interventions.

C. Market engagement and value optimization

- *Exploring market opportunities*: Identifying high value markets is essential for maximizing the profitability of CRFM-supported crops. A detailed market analysis can help locate areas with strong demand for specific crops, which would allow farmers to capitalize on value-added opportunities. Establishing connections with these markets can increase farmers' income and strengthen the sustainability of CRFM interventions.
- *Establishing a comprehensive system of outcome surveys:* Implementing regular outcome surveys is essential for monitoring the effects of the CRFM program across multiple dimensions. These surveys should assess the program's impact on climate resilience, adaptation, and mitigation. By evaluating how the program helps farmers adapt to climate variability, enhance resilience, and mitigate adverse effects, the surveys will provide data-driven insights to improve program strategies.
- *Specific water footprints and diversification*: The surveys should include an assessment of water usage and water footprints specific to different crops, especially considering the diversification of crops within rice fallow lands. By understanding water demands, the program can encourage sustainable crop choices that align with local water availability, minimizing resource strain.
- *Integrated environmental, livelihood, and economic assessment*: Outcome surveys should adopt a holistic approach that integrates environmental impact, livelihood improvement, and economic gains. This integrated perspective allows for a comprehensive understanding of how CRFM interventions benefit both the ecological health of the land and the economic stability of participating farmers, ultimately supporting a balanced approach to sustainability.

D. Focusing on long-term outcome monitoring

- *Income stability through annual outcome surveys*: To assess the CRFM program's long-term impact on income stability, annual outcome surveys should measure not just income levels but also their consistency over time. Stable income is critical for enhancing farmers' financial resilience, enabling them to reinvest in their farms and supporting overall economic well-being in rural areas.
- *Aggregated comparisons for broader insight*: Periodic ordinal comparisons at higher levels of aggregation, such as by state, can provide valuable insights into how different regions are progressing under the CRFM program. This approach enables the identification of regional disparities or successes, which can inform adjustments in resource allocation and program strategies at a state level.

E. Strengthening data integrity with a multimodal approach

- *Georeferencing and beneficiary tracking*: Incorporating georeferencing allows for precise location tracking of CRFM beneficiaries, improving the trackability of program impacts. Georeferenced data ensures that each beneficiary's data is spatially accurate, allowing for more effective resource targeting and program adjustments based on geographic factors.
- *Remote sensing for real-time monitoring*: Remote sensing technology can offer real-time insights into crop health, land use changes, and environmental impacts. This technology supports efficient monitoring of CRFM activities across large areas, providing essential data on program effectiveness, particularly for water footprint management and crop performance.
- *Triangulation of data sources*: By triangulating data from multiple sources such as on-the-ground surveys, remote sensing, and administrative records, the program can improve data accuracy and reliability. Triangulation helps verify findings and ensures that outcome measurements are consistent across different methods, thereby strengthening overall data validity.
- *Ground truthing for accuracy at granular levels*: Ground truthing involves on-the-ground verification of remotely collected data, ensuring accuracy down to the smallest geographic units. This practice helps to maintain data quality, particularly in rural and hard-to-reach areas, ensuring that program performance metrics are reflective of actual conditions.
- *Dynamic targeting for responsive interventions*: Dynamic targeting allows the program to adjust its support based on changing needs and conditions. With data continuously monitored and validated, the program can implement timely interventions, addressing emerging issues such as drought or pest infestations to ensure that resources are effectively allocated.

By implementing these strategic actions, the CRFM program can enhance its effectiveness, foster sustainable agricultural practices, and promote economic stability across the region. This approach will address current challenges and create a resilient agricultural framework that benefits farmers, supports inclusivity, and strengthens Odisha’s agricultural productivity.

6. CONCLUSION AND POLICY RECOMMENDATIONS

In the short period that has elapsed since the inception of CRFM, it has demonstrated promising outcomes regarding utilizing fallow lands, enhancing agricultural productivity, and supporting sustainable land use in Odisha. By focusing on converting underutilized rice fallow lands during the Rabi season, the program has enabled increased cropping intensity, which contributes directly to both food security and sustainability for smallholder farmers; it also provides promising evidence on sustainability. Key interventions such as the provision of quality seeds, pest management support, and the promotion of pulses and oilseeds have collectively boosted or stabilized yield outcomes for target crops such as Bengal gram, grass peas, lentils, mustard, and sesamum. These yield increases underscore the program's effectiveness in addressing factors that previously limited the productivity of fallow lands.

Some challenges may remain, however, in achieving more equitable impacts across all districts and beneficiary groups. The analysis revealed variations among districts in terms of program reach, crop adoption, and yield improvements. These were often influenced by local agroclimatic conditions, resource availability, and socioeconomic barriers; for example, while some crops and regions benefitted significantly from CRFM interventions, others such as black gram and green gram exhibited limited gains.

To maximize CRFM's potential and address these gaps, a strategic focus on targeted resource allocation, enhanced market linkages, and inclusive measures is essential. Strengthening data systems and integrating remote sensing technology for real-time monitoring can further optimize resource distribution, ensuring that interventions are more precisely tailored to regional needs. Additionally, implementing outcome surveys that assess climate resilience, water usage, and economic impacts will provide valuable data to guide adaptive management and long-term planning.

The CRFM program holds significant potential for transforming fallow lands into productive assets, thus fostering sustainable agricultural growth in Odisha. By building on current achievements and addressing identified challenges, the CRFM program can establish a resilient agricultural framework that not only increases crop productivity but also supports social and economic inclusivity, ensuring lasting benefits for rural communities across the state.

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8. FIELD PHOTOS

Source: DAFE

Source: DAFE

Source: DAFE

Source: DAFE

Source: DAFE

Source: DAFE

Source: DAFE

9. APPENDIX A: TARGETING IN CRFM

The evaluation utilized a series of targeting interventions' accuracy and efficiency as a framework for analyzing the impact of CRFM. Targeting accuracy refers to how closely the beneficiary group aligns with the established targeting criteria. In contrast, targeting efficiency relates to the extent to which the beneficiary group effectively utilized the interventions or input packages provided to make productive use of fallow land during the Rabi season. In essence, targeting is deemed efficient when the CRFM intervention is directed toward the farmers who are most likely to use fallow land in the Rabi season.

Research on agricultural input subsidy programs that are a constituent of CRFM often tend to be plagued with targeting errors (for example fertilizer coupons in Malawi). Chirwa, Matita, and Dorward (2010) find that vulnerable households, such as those headed by the elderly or those living in poverty, were less likely to receive fertilizer subsidies. This has been observed to be the case in terms of the utilization of CRFM provisions. Another line of research suggests that targeting based on observable characteristics is inherently flawed and that community- or self-selection may lead to more efficient resource allocation since local selectors often possess private information that significantly predicts program outcomes.

Recent research on land use subsidies in Malawi also reveals that resources were allocated more effectively when targeting was based on self-selection rather than a lottery system (Jack 2013). These studies underscore the challenge of creating a targeting methodology that is both well-defined and observable (and thereby verifiable and replicable) while also relying on local actors to identify less-visible factors that may be more pertinent to achieving the project's objectives (Gine et al. 2015).

Both perspectives on targeting are pertinent to the CRFM program, which aims for both accuracy and efficiency. In targeting, CRFM may engage farmers who are more likely to utilize rice fallows while addressing equity and inclusiveness concerns.

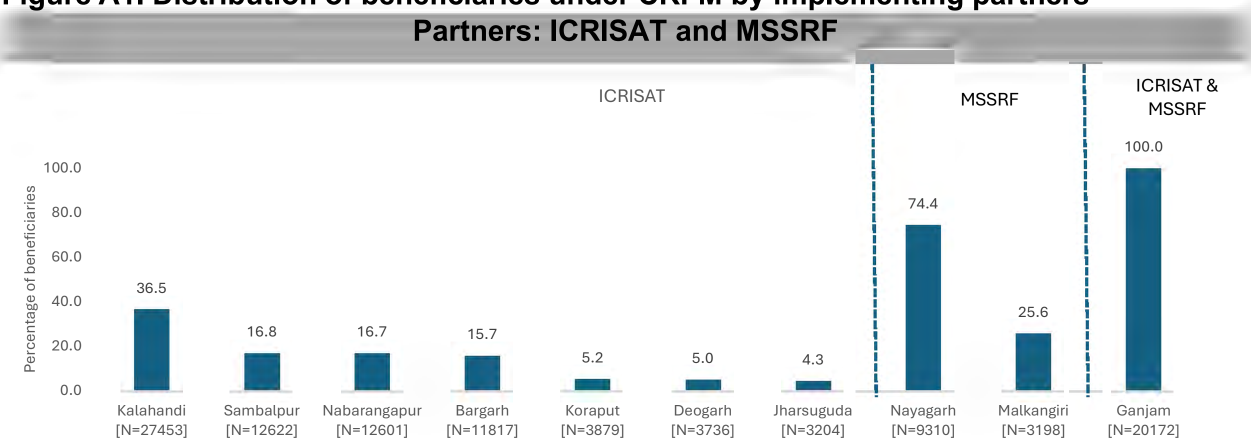
10. APPENDIX B: DISTRICT-WISE IMPLEMENTATION STRUCTURE

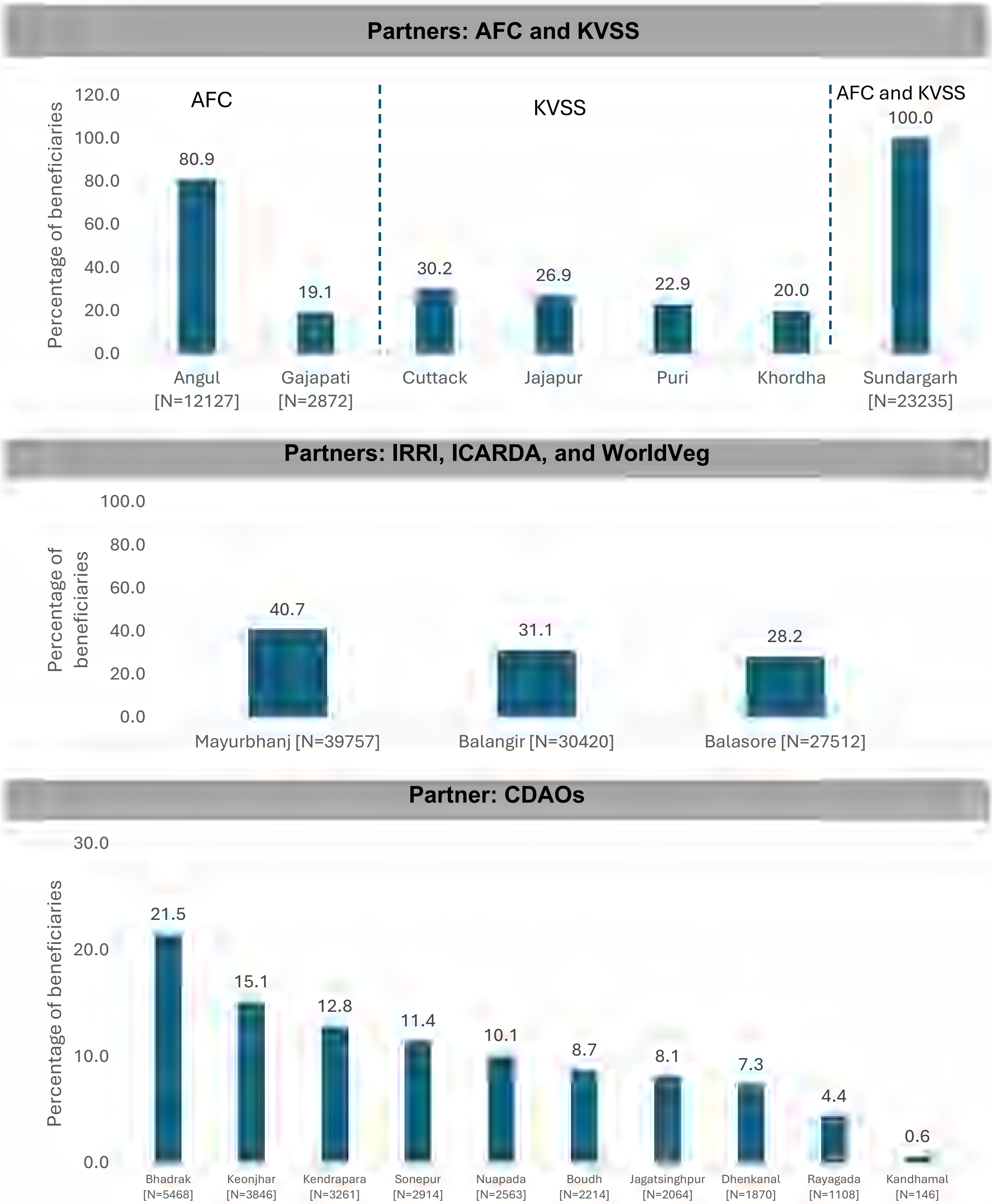
ICRISAT has managed CRFM activities in several districts, with their records showing the highest number of beneficiaries to be in Kalahandi, while Sambalpur and Nabarangapur together comprised nearly 18 percent of the beneficiaries. These three districts are almost fully dependent on rainfed paddy cultivation. The M S Swaminathan Research Foundation (MSSRF), another key implementing partner, has concentrated its efforts in Nayagarh and Malkangiri.

Agricultural Finance Corporation Ltd. (AFC) and Krishi Vikas Sahakari Samiti Ltd. (KVSS) have been implemented in Angul and Gajapati, where the implementation agencies reported coverage of over 80 percent of farmers. KVSS has been operational in Cuttack, Jajapur, Puri, and Khordha, with the lowest engagement is in Gajapati. These districts, situated in the coastal belt of Odisha, face specific challenges related to salinity and erratic weather patterns. AFC and KVSS have also collaborated in Sundargarh, a tribal district with large tracts of fallow land. The International Rice Research Institute (IRRI), the International Center for Agricultural Research in the Dry Areas (ICARDA), and WorldVeg have implemented CRFM in Mayurbhanj, Balangir, and Balasore districts.

CDAOs implemented CRFM in 10 districts, namely Bhadrak, Keonjhar, Kendrapara, Sonepur, Nuapada, Boudh, Jagatsinghpur, Dhenkanal, Rayagada, and Kandhamal. Bhadrak has the highest engagement, with over 21 percent of farmers benefitting. In other districts such as Keonjhar and Kendrapara, CDAOs have provided subsidies and promoted secondary cropping. In Kandhamal, the engagement has been comparatively low (Figure A1).

Figure A1. Distribution of beneficiaries under CRFM by implementing partners





Source: ADAPT and Krushak Odisha Portals.

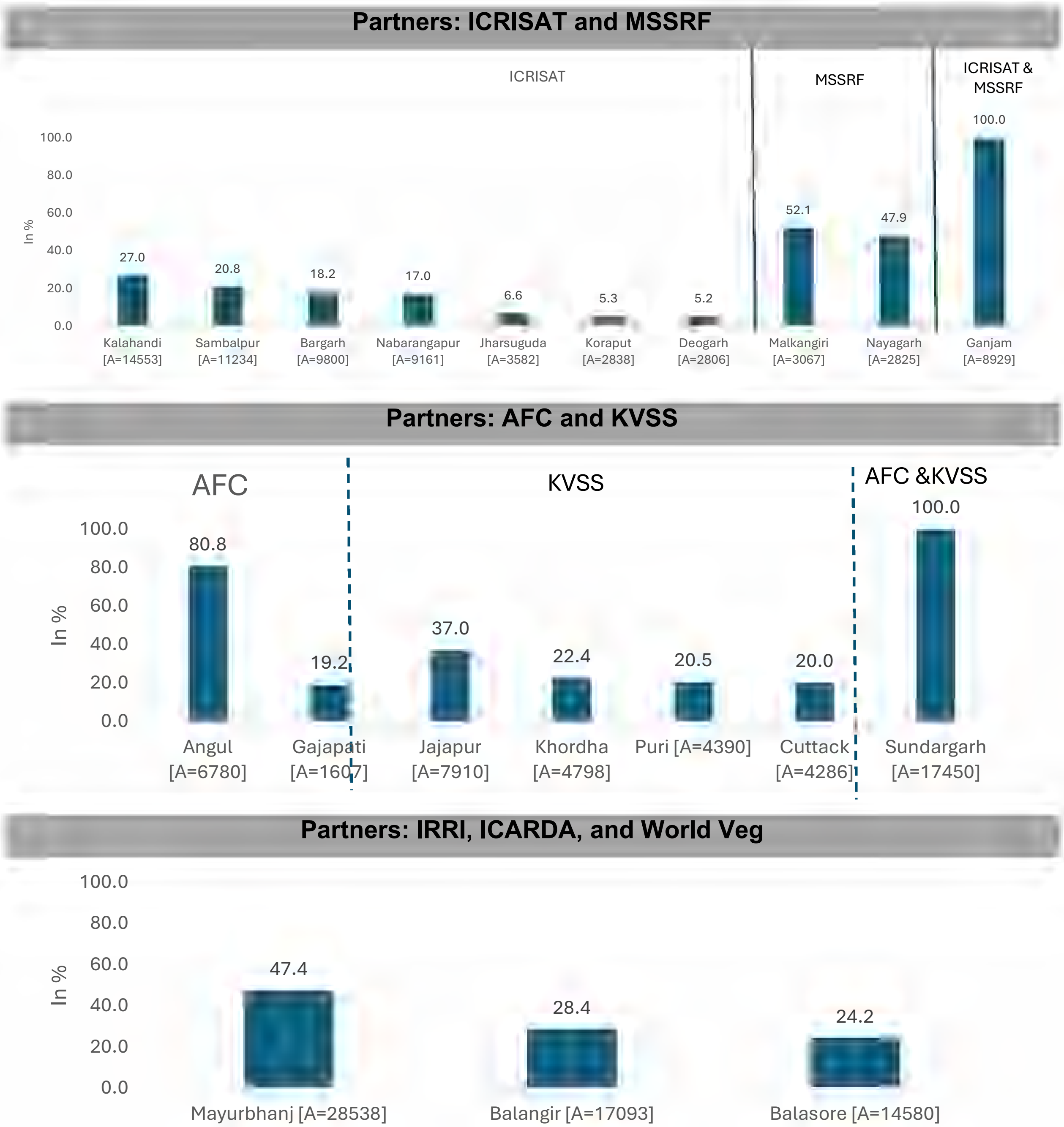
ICRISAT has intervened in districts with comparatively large areas of fallow land. Kalahandi stands out here, with 14.5 thousand hectares under CRFM. The emphasis in Sambalpur has been on the adoption of drought-tolerant crops and legumes and on optimizing water use and promoting high value secondary crops. In Bargarh, which is dominated by traditional rice cultivation, intervention was aimed at maximizing the utilization of land that had formerly been left fallow. The inclusion of Jharsuguda, Koraput, and Deogarh underscores efforts to target diverse agroecological zones. There, interventions were largely focused on improving soil fertility and introducing short-duration crops that utilize residual moisture.

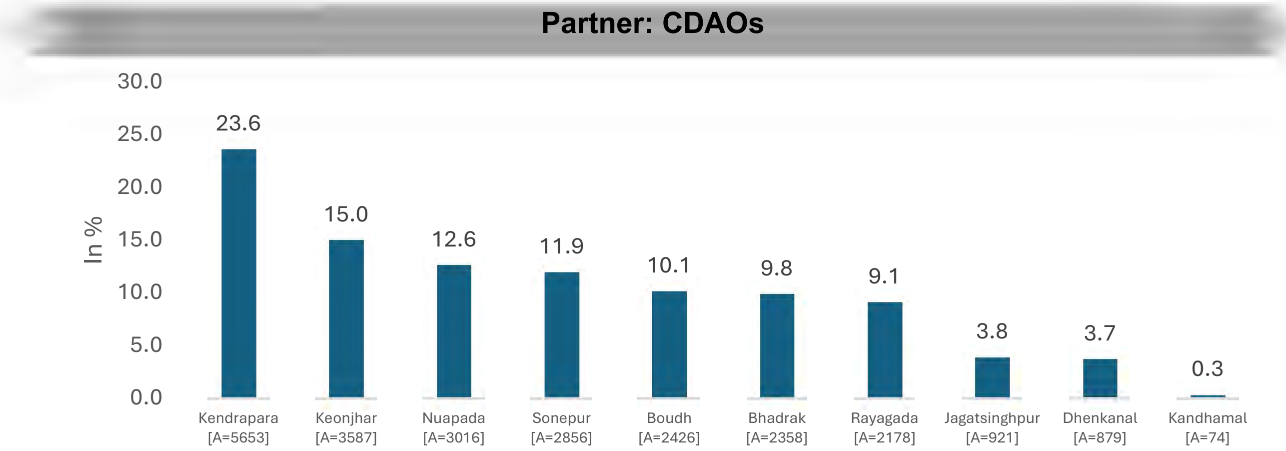
MSSRF has concentrated its efforts in Malkangiri and Nayagarh, two districts with distinct agricultural challenges and opportunities and where tribal people make up a large share of the population. In Nayagarh, substantial effort has been directed toward addressing the district's dependence on single-season rice cropping; this has taken the form of promoting pulses and oilseeds as secondary crops. KVSS has been actively engaged in several coastal districts including Jajapur, Khordha, Puri, and Cuttack. Of these, Jajapur shows the maximum coverage by CRFM interventions, though Khordha and Puri also show significant engagement

IRRI, ICARDA, and WorldVeg have collaborated on implementing CRFM in Mayurbhanj, Balangir, and Balasore. Of these three districts, Mayurbhanj has the highest penetration with over 28 thousand hectares receiving CRFM interventions, led by the introduction of high value vegetable and legume crops. In Balangir, the focus has been on promoting resilient cropping systems in rainfed agriculture.

Finally, CDAOs have overseen CRFM implementation in smaller districts such as Kendrapara, followed by Keonjhar and Nuapada. Other districts reflect moderate engagement, including Sonepur (2,856 hectares, 11.9 percent), Boudh (2,426 hectares, 10.1 percent), and Bhadrak (2,358 hectares, 9.8 percent). The lowest level of engagement is in Rayagada, Jagatsinghpur, Dhenkanal, and Kandhamal (Figure A2).

Figure A2. Distribution of total area under CRFM across districts across districts by implementing partners

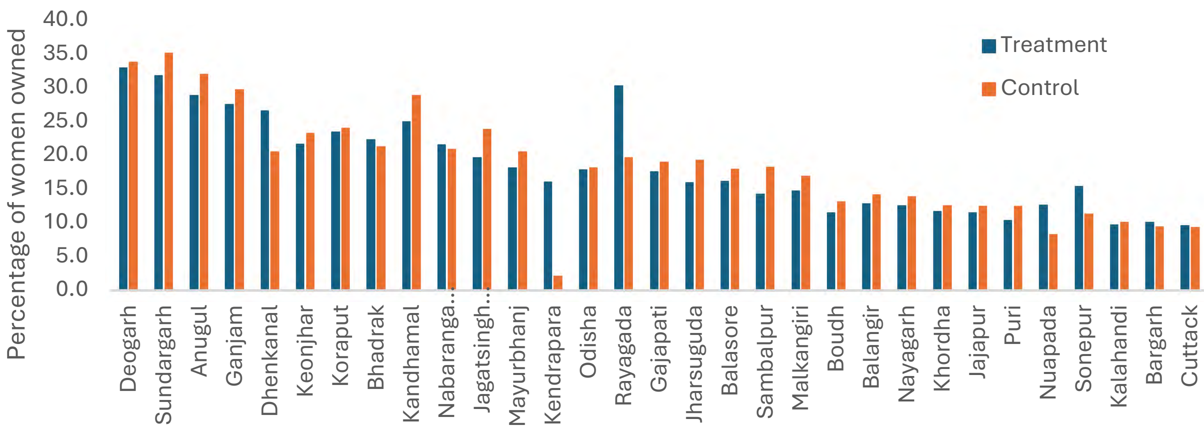




Source: ADAPT and Krushak Odisha Portals.
Note: These samples are matched with the Krushak Odisha Portal; "AFC & KVSS" means AFC and KVSS are both implementing partners, and this applies also to IRRI, ICARDA , WorldVeg, MSSRF, and ICRISAT; A = area under CRFM in hectares.

Figure A3 illustrates the distribution of land under CRFM that is owned by female beneficiaries across Odisha's districts. Deogarh emerges as the leading district here as per data provided by implementation partners, with 33.3 percent of the CRFM area owned by women.

Figure A3. District-wise distribution of area under CRFM that is owned by females across treatment and control groups



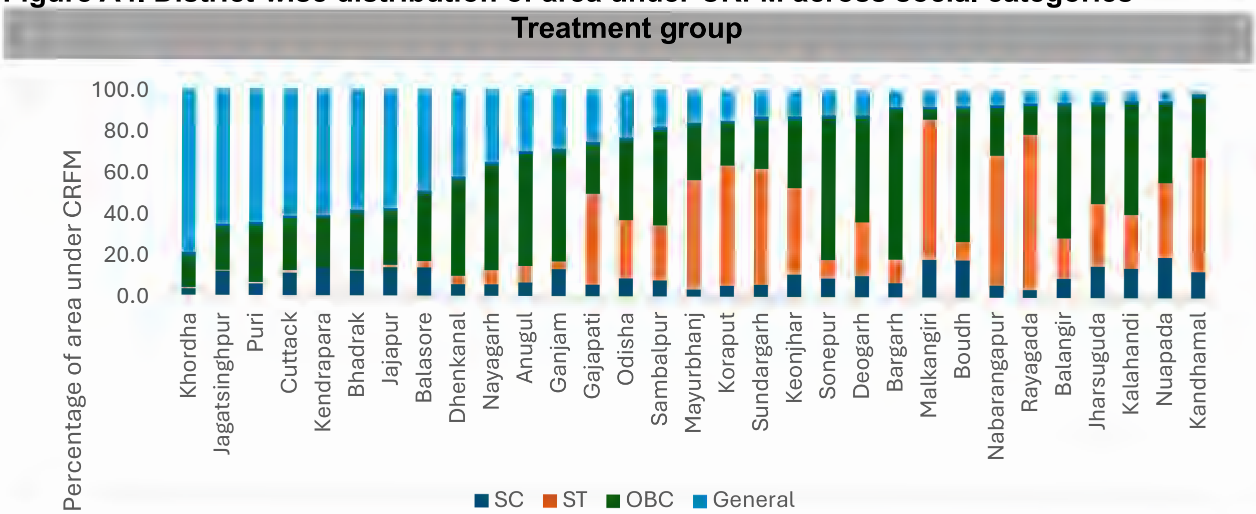
Source: ADAPT and Krushak Odisha Portals.

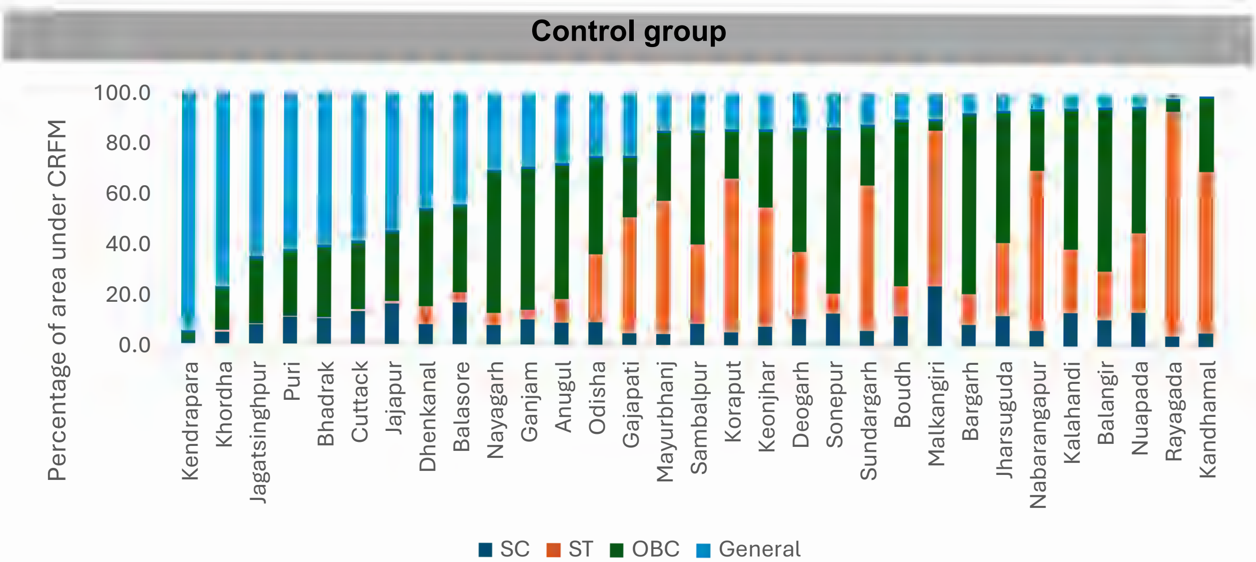
Moving to tribal-dominated districts such as Mayurbhanj, Sundargarh, and Koraput, the distribution shifts significantly. In Mayurbhanj, STs own 52.8 percent of the CRFM area in the treatment group and 53 percent in the control group, showcasing substantial inclusivity. Similarly, Sundargarh records 56.1 percent (treatment) and 57.7 percent (control) of the CRFM area under

ST ownership, emphasizing the program's reach among tribal communities. Koraput exhibits even higher ST representation, with 58 percent and 60.8 percent in treatment and control groups, respectively (Figure A4).

Overall, the state-level averages for Odisha reveal that STs own 27.9 percent (treatment) and 26.9 percent (control) of the CRFM area, reflecting significant tribal engagement. Scheduled Castes (SCs) contribute 9.3 percent and 9.6 percent while Other Backward Classes (OBCs) hold the majority with 38.6 percent (treatment) and 37.5 percent (control).

Figure A4. District-wise distribution of area under CRFM across social categories





Source: ADAPT and Krushak Odisha Portals.

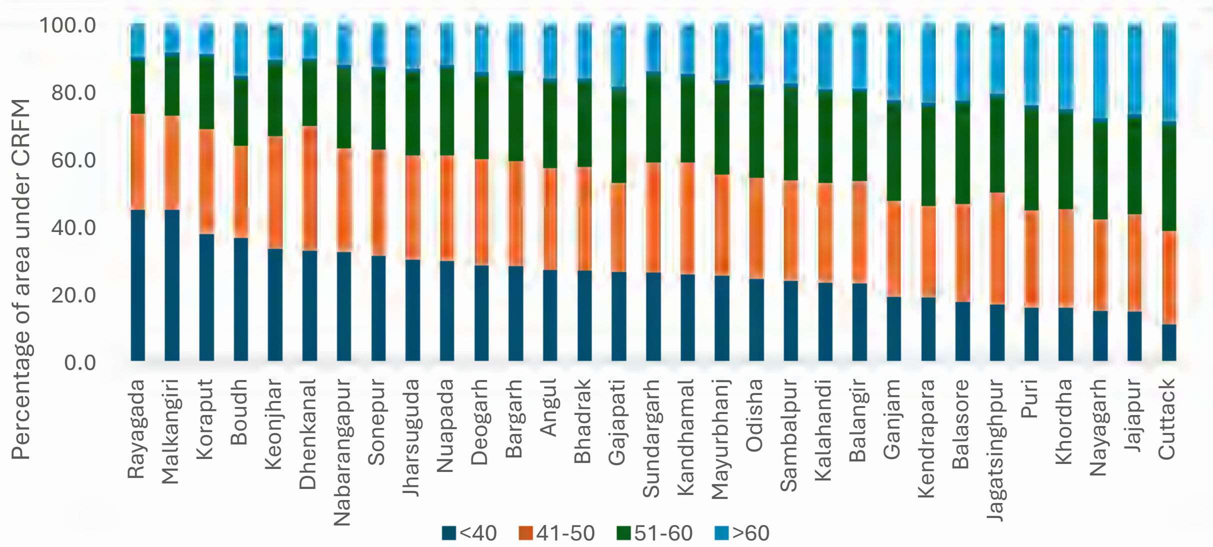
Figure A5 presents a detailed distribution of land under the CRFM program across various age groups, highlighting the role of youth in agricultural land management. The younger age group (under 40 years) emerges as a significant contributor to CRFM adoption, particularly in tribal-dominated districts such as Koraput, Malkangiri, and Rayagada. In Koraput, the participation of youth accounts for 38 percent in the treatment group and 39.3 percent in the control group. This engagement is critical, as younger farmers are often comparatively open to adopting modern techniques such as improved irrigation practices and high-yielding crop varieties, which are essential for enhancing productivity in rainfed regions. In Malkangiri, youth participation is even higher, with 45.2 percent and 46.1 percent of treatment and control groups, respectively. In Rayagada, youth account for 45.2 percent of the CRFM area in the treatment group and 34.9 percent in the control group.

Middle-aged farmers (41 to 50 years) represent the majority of CRFM participants across many districts. In Sundargarh, for example, this age group accounts for 32.6 percent of the treatment group and 30.9 percent of the control group. In Deogarh, the participation of middle-aged farmers is nearly identical in the treatment (31.5 percent) and control (31.3 percent) groups. In districts such as Angul, the middle-aged group contributes significantly, with 30.1 percent of the treatment group and 31.6 percent of the control group. In Khordha, their participation is equally significant, with 28.6 percent and 29.3 percent in the treatment and control groups, respectively.

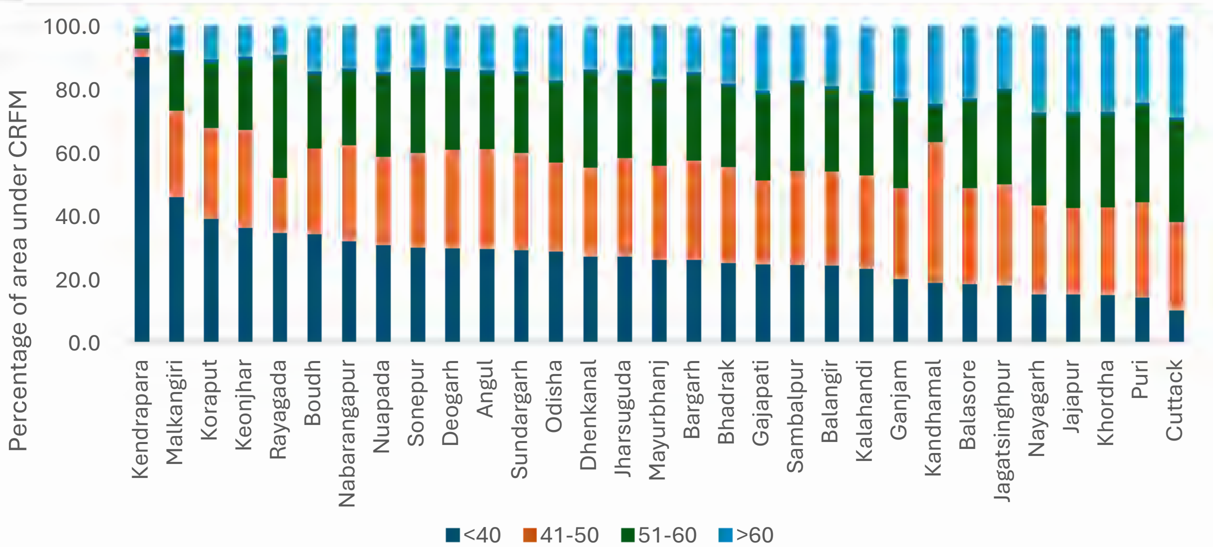
At the state level, the younger age group (under 40 years) holds 24.7 percent of the CRFM area in the treatment group and 29.0 percent in the control group. This participation reflects a growing recognition of the importance of youth engagement in agriculture. Younger farmers bring adaptability and innovation, which are critical for addressing challenges such as water scarcity, soil degradation, and market volatility. Younger farmers are also key drivers of innovation and sustainability in tribal regions, where their engagement can address generational poverty and migration trends.

Figure A5. District-wise distribution of area under CRFM across age categories

Treatment group



Control group



Source: ADAPT and Krushak Odisha Portals.

Figure A6 offers a view of the district-wise dominance of crops. The dominance of specific crops across districts is shaped by the interplay of agroclimatic conditions, socioeconomic factors, market accessibility, cultural preferences, and targeted interventions under CRFM.

In tribal-dominated districts such as Koraput, Rayagada, and Malkangiri, pulses such as black gram and Bengal gram dominate. This may be due to their adaptability to rainfed conditions and undulating terrain. In Koraput, Bengal gram accounts for 40.5 percent of the CRFM area; this is followed by black gram at 27.1 percent. These crops thrive in low-moisture environments and are a big part of the diets of tribal communities. Rayagada demonstrates the dominance of black gram (53.7 percent) alongside mustard (23.9 percent) and chickpeas (5.4 percent); this reflects a strategic alignment of crop choices with the district's agroclimatic realities. Malkangiri exhibits a similar preference for black gram and green gram. These districts showcase how tribal regions, with largely rainfed farming, are leveraging traditional crops to ensure food security and economic resilience through CRFM interventions.

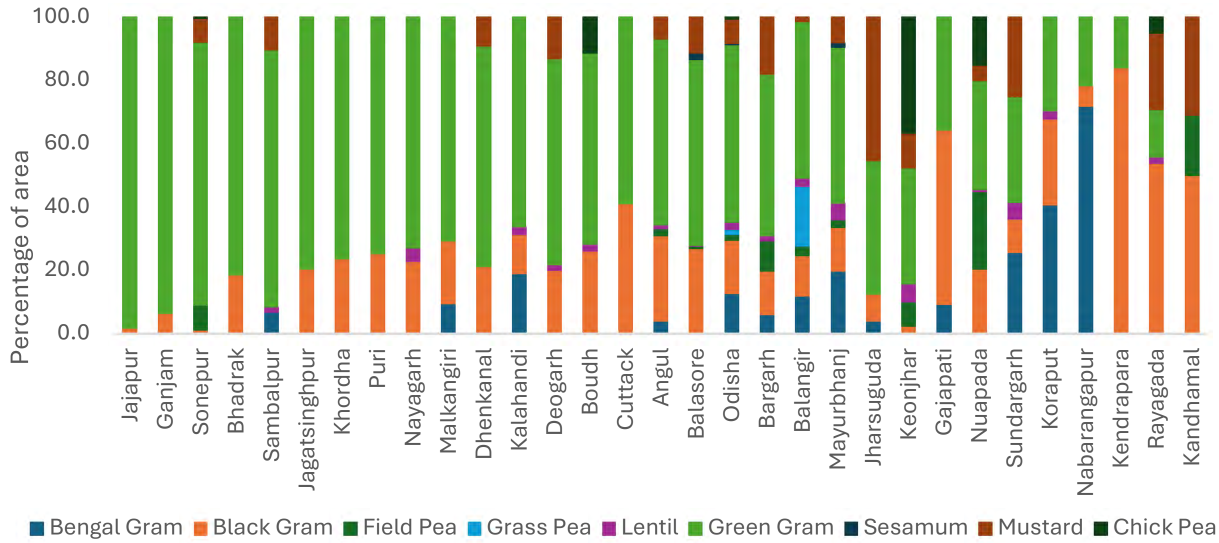
In coastal districts such as Kendrapara, Puri, and Jagatsinghpur, saline-tolerant pulses such as black gram and green gram dominate. Kendrapara dedicates 83.7 percent of its CRFM area to black gram, while Puri and Jagatsinghpur show substantial shares of 25.1 percent and 20.2 percent, respectively. These crops are preferred for their high market value and their ability to thrive in saline soil, making them economically viable choices for farmers.

Rainfed districts such as Kalahandi, Balangir, and Nuapada provide yet another perspective. Kalahandi's CRFM area is heavily dominated by green gram (66.5 percent), a drought-resistant crop that aligns with the district's limited irrigation facilities. Balangir exhibits a similar pattern, with green gram (49.4 percent) and grass peas (18.9 percent) as the leading crops, while Nuapada diversifies with field peas (24.5 percent), green gram (34.2 percent), and black gram (20.2 percent).

Urban-adjacent districts such as Sambalpur show green gram dominating in 81.1 percent of the CRFM area, while in Angul CRFM focuses on green gram (58.7 percent) and black gram (26.8 percent), with mustard also making a notable contribution. These districts have relatively better infrastructure and access to markets.

In Mayurbhanj, Bengal gram (40.5 percent) and black gram (27.1 percent) dominate, supported by the CRFM program's emphasis on reviving traditional crops with improved yields. Cuttack exhibits a dominance of black gram (64.3 percent) and green gram (20.4 percent), driven by the district's irrigation infrastructure and market connectivity. Tribal regions may also be prioritizing pulses and oilseeds as part of CRFM in order to align with cultural practices and rainfed conditions, while coastal and urbanized districts optimize for market access and economic returns and may be focusing increasingly on vegetables.

Figure A6. District-wise distribution of area under different crops



Source: ADAPT and Krushak Odisha Portals.

Districts such as Bargarh and Cuttack, in contrast, show a higher percentage of households engaged solely in crop cultivation (53.9 percent and 61.4 percent, respectively). Bargarh, known as the "rice bowl of Odisha", reflects the dominance of crop cultivation, supported by the availability of irrigation from canal systems. The predominance of rice cultivation among Cuttack's farming households, on the other hand, has likely been driven by its focus on proximity to urban markets.

Overall state-level data shows that 51.9 percent of households are engaged exclusively in crop cultivation, while 46.8 percent are involved in both labor and cultivation and only 1.9 percent are exclusively engaged in agricultural labor. Comparative analysis across districts reveals that regions with better irrigation and market access, such as Bargarh and Cuttack, tend to have higher specialization in crop cultivation. In contrast, rainfed and tribal-dominated regions such as Rayagada and Malkangiri exhibit higher levels of dual engagement in CRFM.

Figure A7 presents the distribution of land types (low land, middle land, and high land) across mechanized and non-mechanized farming contexts in relation to CRFM. These land typologies determine land use, mechanization potential, and crop suitability within the CRFM program.

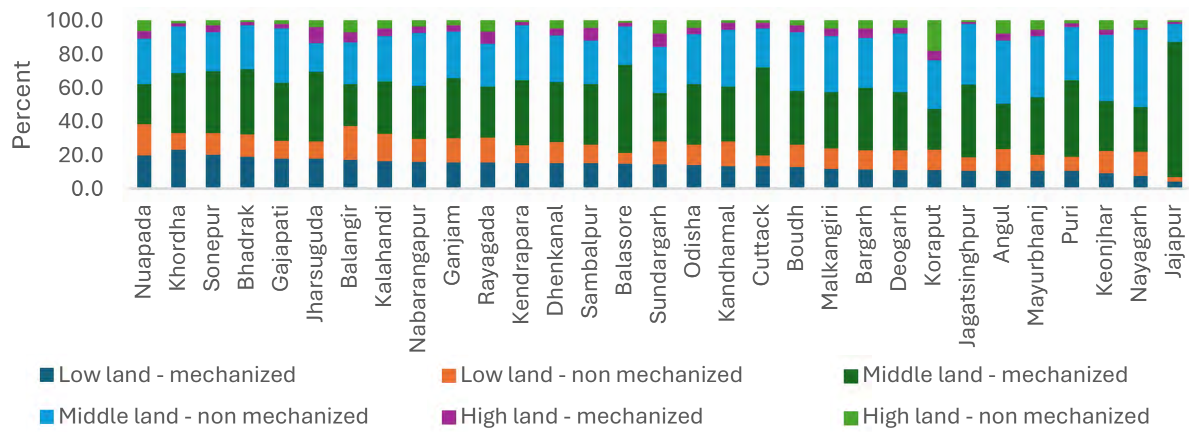
Most of the mechanized farming takes place on the middle elevation land within CRFM, which constitutes 36.4 percent of mechanized farms. Middle land, often having moderate fertility and soil stability, is ideal for machinery operations (Binswanger 1986). Districts like Jajapur (80.8 percent) and Cuttack (52.4 percent) have a large proportion of middle land under mechanized farming.

Low land under mechanized farming comprises 14.1 percent of total mechanized land, with higher percentages in districts such as Sonepur (20.2 percent) and Nuapada (19.7 percent). Mechanization on low land may involve additional soil preparation efforts as low-lying areas are prone to waterlogging, which can affect machinery efficiency. In such regions, mechanization efforts may be focused on growing crops that tolerate higher moisture or on improving drainage (Pingali 2007).

Mechanized farming on high land is limited, accounting for only 4.0 percent of total mechanized land, with a few districts such as Jharsuguda (9.5 percent) and Sundargarh (7.9 percent) showing larger areas of high land under mechanized farming. High land typically has a lower capacity for water retention, making it less ideal for certain types of machinery and crop choices. In high land areas, mechanized farming might focus on drought-resistant crops or dryland farming techniques (Swaminathan 2006).

Variation in the use of high land by non-mechanized systems highlights certain regional dependencies on high land for cultivation without machinery. Koraput (18.2 percent) and Keonjhar (5.1 percent) show a higher proportion of high land under non-mechanized use. In these regions, labor-intensive practices may be more adaptable to high lands, although mechanization could help optimize resource use on middle and low land for better efficiency.

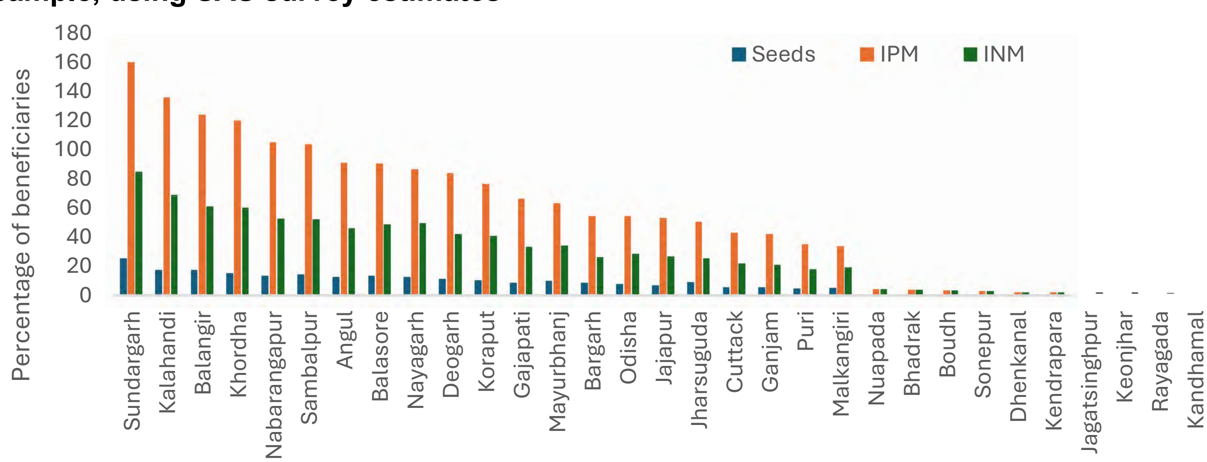
Figure A7. Distribution of area under different typologies of land across mechanized and non-mechanized farmers



Source: ADAPT and Krushak Odisha Portals.

Figure A8 shows the distribution of beneficiaries who receive the different inputs under the CRFM program, normalized against data from the nationally representative Situation Assessment Survey, 77th Round (SAS) (India, Ministry of Statistics and Programme Implementation 2019). By comparing the CRFM data to national benchmarks, this figure helps assess targeting efficiency and accuracy across districts. Values of over 100 percent in the normalized columns indicate potential anomalies or misreporting. Certain districts display values over 100 percent, particularly in the Integrated Pest Management (IPM) and Integrated Nutrient Management (INM) columns, highlighting anomalies. Sundargarh, for instance, has 159.4 percent for IPM and 84.2 percent for INM, suggesting an overallocation of resources compared to the expected beneficiary numbers.

Figure A8. Distribution of input beneficiaries across districts, normalized by district-level sample, using SAS survey estimates

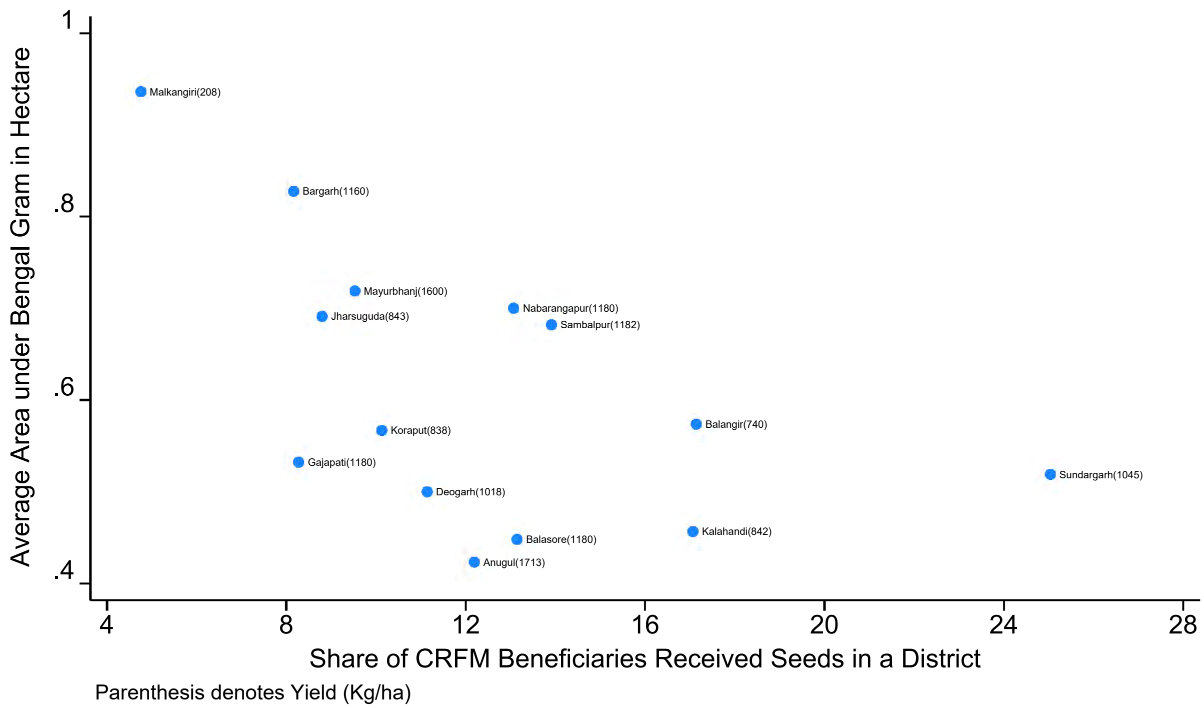


Source: ADAPT and Krushak Odisha Portals; India, Ministry of Statistics and Programme Implementation (2019).

Figure A9, illustrates the relationship between the share of CRFM beneficiaries receiving seeds in each district and the average area under Bengal gram cultivation (in hectares).[6] The purpose of the figure is to examine if there is any observable trend or association between the distribution of inputs to beneficiaries and the expansion of land dedicated to Bengal gram cultivation, as well as how yield levels vary across districts. The association between area, seed share, and yield for Bengal gram varies across districts, reflecting differences in resource utilization and productivity.

For black gram, Bargarh achieves the highest yield, at 2,107 kg/ha, far exceeding the average yield across districts of 705 kg/ha. Bargarh's high yield could result from effective pest and nutrient management, reflecting targeted agricultural practices that optimize black gram production. Yields are considerably lower in districts such as Malkangiri (600 kg/ha) and Jharsuguda (600 kg/ha).

Figure A9. District-wise association between provision of Bengal gram seeds, area under cultivation, and yield



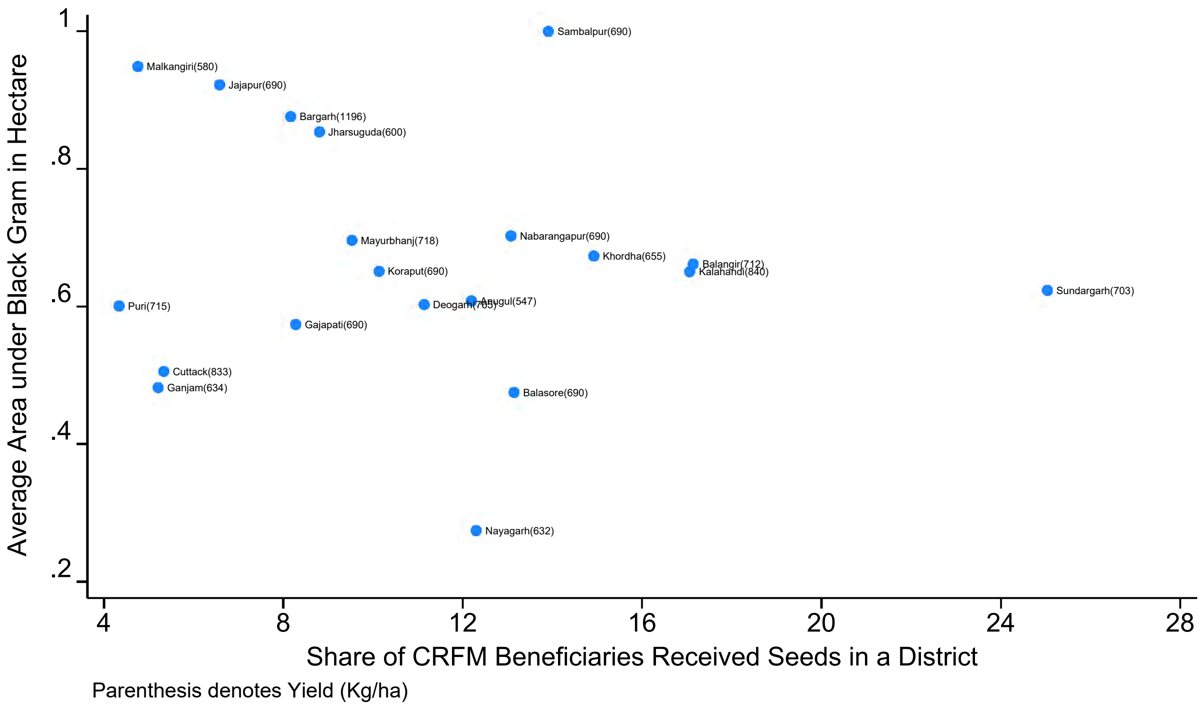
Source: ADAPT and Krushak Odisha Portals.

[6] The figures on the shares of CRFM beneficiaries receiving IPM and INM in each district are also available upon request. We have not included that data here due to brevity.

Note: Parentheses denote yield in kg/ha.

Figure A10 illustrates the relationship between the share of CRFM beneficiaries receiving seeds in each district and the average area under black gram cultivation (in hectares). Bargarh, with the highest area allocation (0.88 hectares) and a moderate seed share (8.2 percent), achieves the highest yield (1,196 kg/ha). In contrast, Malkangiri, with the highest area (0.95 hectares) and the lowest seed share (4.8 percent), records a yield of only 580 kg/ha, indicating significant inefficiencies. Sambalpur has a moderate yield of 690 kg/ha in black gram.

Figure A10. District-wise association between provision of black gram seeds, area under cultivation, and yield

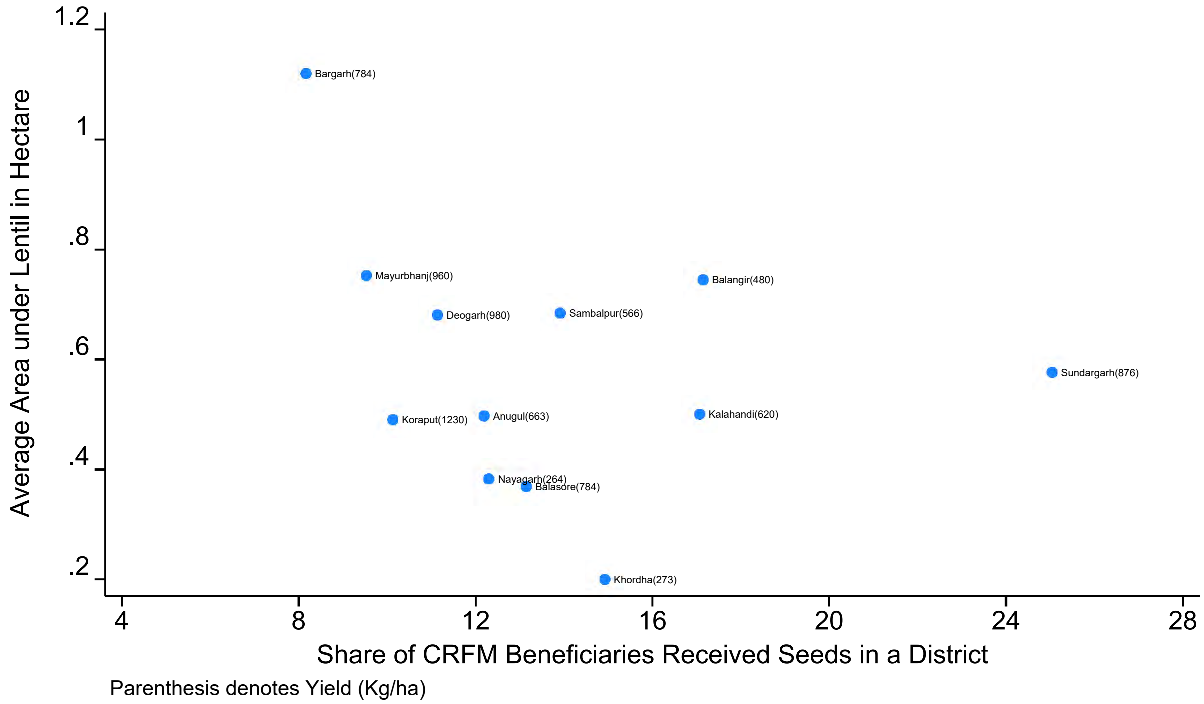


Source: ADAPT and Krushak Odisha Portals.

Note: Parentheses denote yield in kg/ha.

In Odisha, Lentils have an average yield of 772.3 kg/ha. Among the districts, Mayurbhanj has the highest recorded yield at 936.5 kg/ha. Sundargarh also has a high yield of 851.1 kg/ha, well above the state average, whereas Kalahandi records a below-average yield of 658.7 kg/ha. In CRFM, Sambalpur has one of the lowest lentil yields at 594.4 kg/ha. Figure A11 illustrates the relationship between the share of CRFM beneficiaries receiving lentil seeds in each district and the average area under lentil cultivation (in hectares). The figure reveals wide variations in the relationship between productivity and resource inputs.

Figure A11. District-wise association between provision of lentil seeds, area under cultivation, and yield

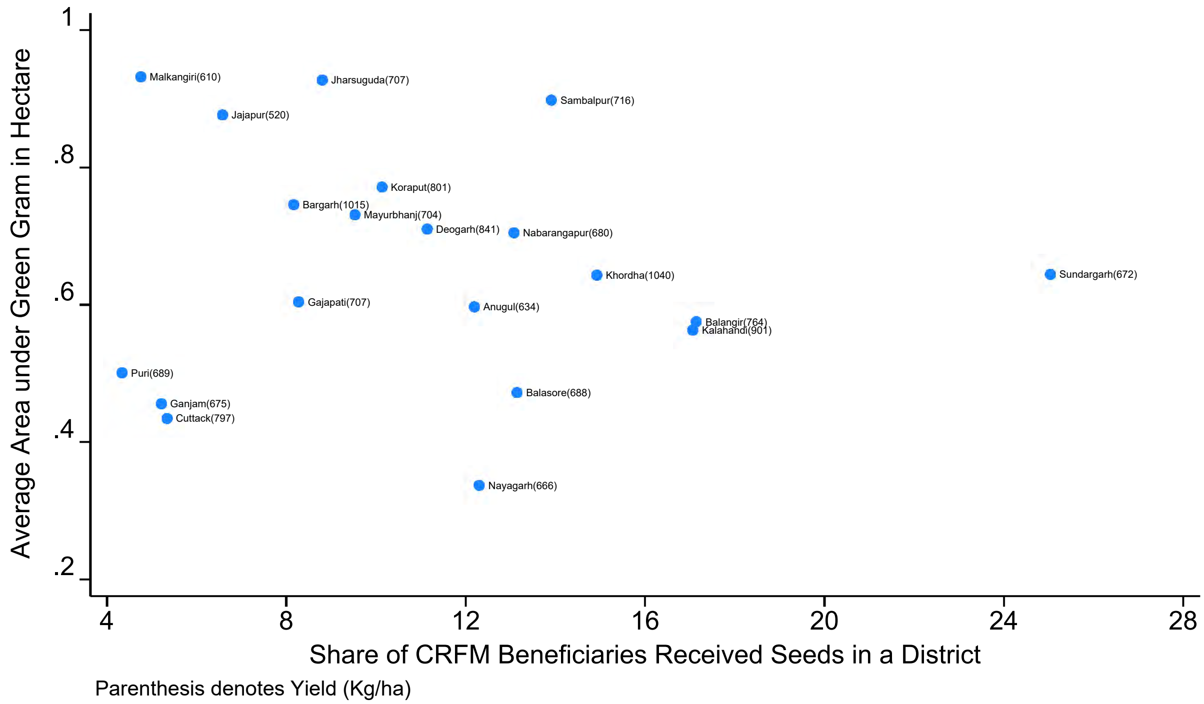


Source: ADAPT and Krushak Odisha Portals.

Note: Parentheses denote yield in kg/ha.

In CRFM areas, green gram yields are highest in Bargarh at 1,326.7 kg/ha; this is followed by Kalahandi at 908.5 kg/ha. Green gram cultivation benefits soil health through its ability to fix nitrogen, thus the promotion of higher green gram yields across more districts may align with sustainable agricultural practices. Figure A12 illustrates the relationship between the share of CRFM beneficiaries in each district who receive green gram seeds, the percentage of farmers who practice INM and IPM, and the average area under green gram cultivation (in hectares).

Figure A12. District-wise association between provision of green gram seeds, area under cultivation, and yield



Source: ADAPT and Krushak Odisha Portals.
Note: Parentheses denote yield in kg/ha.

NOTES

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