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**Dr. Raghwendra Singh**  
Director, ICAR-Agricultural  
Technology Application Research  
Institute (ATARI), Zone-III,  
Kanpur, Uttar Pradesh, India

**Dr. Ajay Kumar Singh**  
ICAR-Agricultural Technology  
Application Research Institute  
(ATARI), Zone-III, Kanpur, Uttar  
Pradesh, India

**Dr. Seema Yadav**  
ICAR-Agricultural Technology  
Application Research Institute  
(ATARI), Zone-III, Kanpur, Uttar  
Pradesh, India

**Dr. Preeti Yadav**  
ICAR-Agricultural Technology  
Application Research Institute  
(ATARI), Zone-III, Kanpur, Uttar  
Pradesh, India

**Saurabh Raj Pandey**  
ICAR-Agricultural Technology  
Application Research Institute  
(ATARI), Zone-III, Kanpur, Uttar  
Pradesh, India

**Dr. Abhishek Singh**  
ICAR-Agricultural Technology  
Application Research Institute  
(ATARI), Zone-III, Kanpur, Uttar  
Pradesh, India

**Dr. Somdutt Tripathi**  
ICAR-Agricultural Technology  
Application Research Institute  
(ATARI), Zone-III, Kanpur, Uttar  
Pradesh, India

**Corresponding Author:**  
**Dr. Ajay Kumar Singh**  
ICAR-Agricultural Technology  
Application Research Institute  
(ATARI), Zone-III, Kanpur, Uttar  
Pradesh, India

## Adaptive strategies for flood risk management in the Tarai plains of Uttar Pradesh

**Raghwendra Singh, Ajay Kumar Singh, Seema Yadav, Preeti Yadav,  
Saurabh Raj Pandey, Abhishek Singh and Somdutt Tripathi**

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### Abstract

Flooding is a major constraint to agricultural production in the Tarai plains of Uttar Pradesh, where excessive rainfall, river flooding, waterlogging and delayed crop establishment frequently affect farm productivity and income. The present study documented and synthesized agricultural adaptation strategies implemented under the National Innovations in Climate Resilient Agriculture (NICRA) programme in six flood-prone districts of Uttar Pradesh, namely Bahraich, Basti, Gonda, Gorakhpur, Kushinagar and Maharajganj. Secondary data from NICRA project records were compiled to assess reported changes in crop productivity and farmers' net returns associated with machinery interventions, climate-resilient crop varieties, agronomic practices and agriculture-allied activities. The documented interventions included laser-guided land levelling, drum seeder, zero tillage, super seeder, flood-tolerant and short-duration crop varieties, compensatory cropping, intercropping, green manuring, mulching, vermicomposting and kitchen gardening. The reported results indicated improvements in productivity and/or net returns for several interventions. Among machinery-based interventions, drum seeder technology in direct-seeded rice was associated with a 17.55% increase in productivity and a 64.11% increase in net return, while laser-guided land levelling in Gonda was associated with a 20.00% increase in paddy yield and 45.00% increase in net return. Flood-tolerant varieties such as Samba-Sub1 and Swarna-Sub1 showed reported production/yield improvements under flood-prone conditions. Agronomic and livelihood diversification practices also contributed to additional production and economic opportunities. However, the analysis was descriptive because the available project records lacked complete replicated observations, sample sizes, control data and variance estimates. The findings highlight the relevance of location-specific adaptation strategies for reducing production risk, supporting timely crop establishment, conserving resources and diversifying farm livelihoods in the flood-prone Tarai region. Further validation using complete district-wise and replicated field data is required to establish the comparative effectiveness and economic performance of individual interventions.

**Keywords:** Flood risk management, climate-resilient agriculture, Tarai plains and agricultural adaptation.

### 1. Introduction

Floods are among the most important natural hazards affecting agricultural production. The Tarai regions of Uttar Pradesh are particularly susceptible to flood-related agricultural damage because of their location near the Himalayan foothills, river systems and recurrent waterlogging. The vulnerability of agricultural production to climatic variability and extreme weather events, including floods, has been recognized in India's climate-resilient agriculture initiatives (Chaudhari, 2023) <sup>[1]</sup>. The present study focuses on six flood-prone districts of the Tarai plains of Uttar Pradesh: Bahraich, Basti, Gonda, Gorakhpur, Kushinagar and Maharajganj.

Floods affect agricultural production through crop submergence, soil erosion, sediment deposition, delayed sowing and disruption of farm operations. Prolonged waterlogging can also interfere with the establishment of subsequent crops, particularly in rice-based cropping systems. These impacts may reduce farm income and increase the vulnerability of small and marginal farmers. Recent research on district-level flood severity in India has emphasized the importance of spatially targeted flood-risk assessment and management (Saharia *et al.*, 2024) <sup>[15]</sup>.

The National Innovations in Climate Resilient Agriculture (NICRA), implemented by the Indian Council of Agricultural Research (ICAR), was launched in February 2011 to enhance the resilience of Indian agriculture to climate variability and change. The project combines strategic research, technology demonstration and capacity building to address climate-related risks in agriculture. In Uttar Pradesh, NICRA activities have included the demonstration of improved crop varieties, resource-conserving technologies, farm machinery and location-specific adaptation measures through Krishi Vigyan Kendras (ICAR, 2023) [5]. Although climate-resilient interventions have been promoted in vulnerable agricultural regions, their performance under farmers' field conditions requires systematic documentation. A comparison of agricultural machinery, crop-based adaptation and allied-sector interventions can provide evidence on their contribution to agricultural productivity and farm income. Therefore, the present study examines the reported performance of adaptive agricultural interventions in six flood-prone districts of the Tarai plains of Uttar Pradesh.

### Objectives

- To find the major agricultural adaptation strategies demonstrated in flood-prone districts of the Tarai plains.
- To compare crop productivity and farmers' net returns under conventional and adaptive agricultural practices.
- To find out the agricultural interventions that contribute to strengthening agricultural resilience and improving the economic sustainability of farming systems in the study region.

## 2. Materials and Methods

### 2.1 Study area

The study was conducted in six flood-prone districts of Uttar Pradesh: Bahraich, Basti, Gonda, Gorakhpur, Kushinagar and Maharajganj. These districts fall within the Tarai plains, where agriculture is frequently affected by excessive rainfall, river flooding, waterlogging and delayed crop establishment. The districts were selected based on their inclusion in the project material and their reported vulnerability to flood-related agricultural losses.

### 2.2 Data sources and study design

The present study is based on secondary data extracted from NICRA project records. The source records report crop productivity, percentage changes in production, percentage changes in net returns and selected economic indicators associated with different adaptation interventions. The interventions were grouped into machinery interventions, climate-resilient agriculture, agronomic adaptation, and agriculture and allied sectors.

### 2.3 Variables and economic indicators

The main outcome variables were crop productivity and net return. Productivity and net return were reported using the units available in the project records, including  $q\ ha^{-1}$ ,  $g\ ha^{-1}$  and  $kg\ unit^{-1}$  where applicable. Percentage increases in production and net return were retained as reported.

The relative increase was calculated as:

$$\text{Increase (\%)} = [(Y_i - Y_c) / Y_c] \times 100$$

### Where

- $Y_i$  = Yield/productivity or net return under the

intervention/adaptive practice.

- $Y_c$  = Yield/productivity or net return under the comparison/conventional practice.

Increase (%) = Percentage increase in yield/productivity or net return over the comparison practice.

### 2.4 Data analysis

The analysis was descriptive. It involved compilation of reported productivity, percentage change in production and percentage change in net returns. The data were presented through comparative tables and narrative synthesis. No inferential statistical tests were performed because the available project records do not contain complete replicated observations, sample sizes or variance estimates.

## 3. Results and Discussion

### 3.1 Overview of adaptive interventions

The six districts implemented a diverse range of agricultural adaptation strategies addressing different dimensions of flood risk. Machinery interventions focused on timely sowing, soil management and reduced soil disturbance. Crop-based interventions aimed to reduce the duration of exposure to adverse weather, while intercropping, green manuring and mulching improved the efficiency and resilience of production systems. Allied agricultural activities provided additional opportunities for income generation and food security. The district-wise distribution of cropped area across flood hazard zones showed considerable variation. The very low hazard zone accounted for the largest cropped area in all six districts, with the highest values in Maharajganj (84073 ha), Gorakhpur (72700 ha) and Bahraich (55616 ha). Gorakhpur recorded the highest cropped area in the moderate, high and very high hazard zones, at 16092, 3902 and 492 ha, respectively (figure 1.). In contrast, Kushinagar recorded the lowest cropped area in the very low, low and moderate zones, with no reported area in the high and very high zones.

### 3.2 Machinery interventions

**Laser-guided land levelling:** Laser-guided land levelling was demonstrated in Gonda district on 50 ha of sandy loam soil. The project records reported a 10-15% reduction in soil erosion, a 20% increase in paddy yield (NDR-359), and a 45% increase in farmers' net return (Table 1).

- The reduction in erosion may be attributed to improved field uniformity, which minimizes concentrated surface runoff and soil movement during heavy rainfall. Precision levelling also promotes more uniform water distribution and reduces localized water accumulation, making it particularly relevant to flood-prone Tarai conditions (Tohidyan Far and Rezaei-Moghaddam, 2020; Devkota *et al.*, 2021) [3]. Thus, laser-guided levelling can contribute simultaneously to soil conservation, improved crop productivity and farm profitability [19].
- **Drum seeder technology:** Drum seeder technology was demonstrated in Kushinagar district for direct-seeded rice (S-52). Project records reported a 17.55% increase in productivity and a 64.11% increase in net return. The reported gains may be associated with timely crop establishment, reduced labour requirements and lower establishment costs. Field studies have reported higher yield and net returns with drum seeding compared with conventional establishment, largely because of reduced labour and cultivation costs (Table 1).

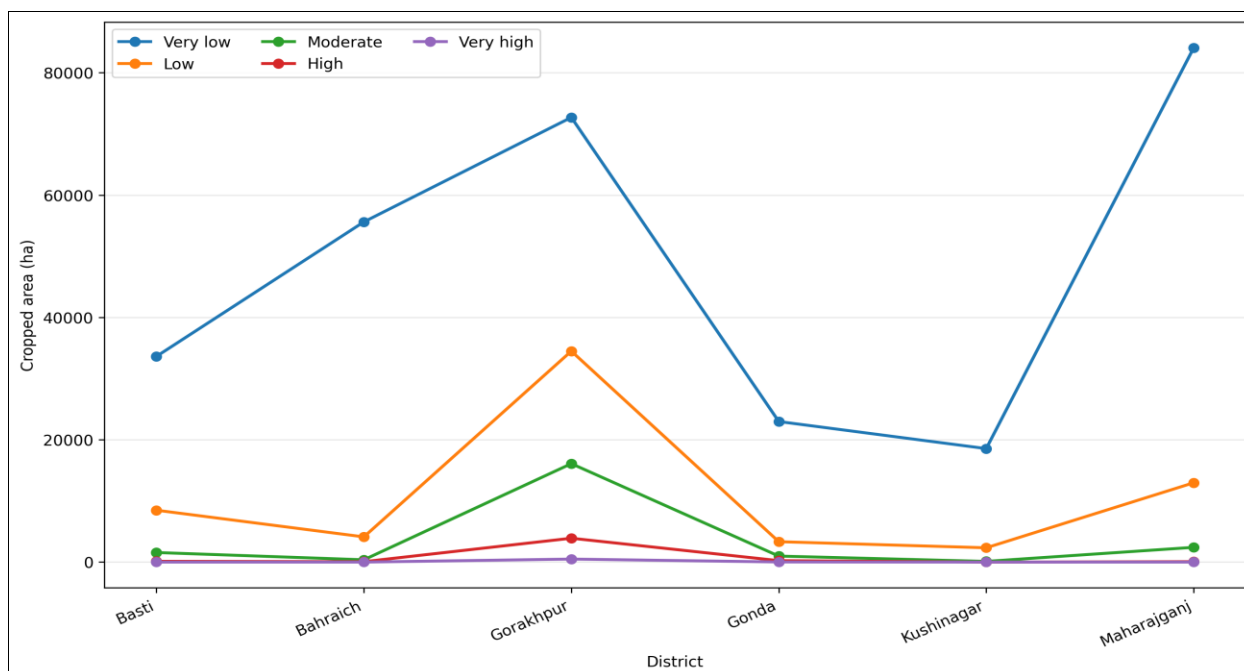


**Fig 1:** District-wise cropped area under different flood-hazard zones

Timely establishment is particularly important in flood-prone areas because a shorter crop duration provides greater flexibility where excess rainfall or flooding may disrupt subsequent crop operations. More recent evidence from India also shows that direct-seeded rice can reduce production costs while maintaining or improving productivity (Mishra *et al.*, 2017), and DSR has been associated with lower labour and production costs in Eastern India (Kumar *et al.*, 2020). Thus, drum seeder technology can contribute to timely establishment, labour saving and improved economic returns as an adaptation option in the Tarai region <sup>[11, 12]</sup>.

### Zero tillage in wheat

Zero tillage was demonstrated in Kushinagar and Gonda districts. In Kushinagar, wheat variety DBW-252 recorded a 19.24% increase in production and 47.99% increase in net return, while in Gonda, production and net return increased by 14.70% and 28.27%, respectively (Table 1). The reported gains may be associated with timely sowing, reduced tillage operations and lower machinery and fuel requirements. Similar farmer-field research in the Eastern Indo-Gangetic Plains has reported higher wheat productivity and economic benefits under zero tillage.

Zero tillage can also reduce the time required for crop establishment, allowing wheat to be sown earlier and reducing the risk of terminal heat stress. It may additionally improve

water and energy-use efficiency by reducing intensive soil disturbance (Keil *et al.*, 2015; Kumar *et al.*, 2019a). Thus, zero tillage can support timely wheat establishment, lower production costs and improved profitability in the Tarai region <sup>[6, 8, 10]</sup>.

### Super seeder in wheat

The use of a super seeder was demonstrated in Basti and Gorakhpur districts for wheat variety DBW-187. Basti recorded 23.20% higher production and 46.54% higher net return, while Gorakhpur recorded increases of 13.23% and 56.54%, respectively (Table 1). The reported improvement may be associated with timely wheat establishment and simultaneous incorporation of rice residues, reducing the need for separate residue-management and land-preparation operations. Previous studies have reported that residue-management machinery can support timely wheat establishment and improve resource-use efficiency.

Super seeder technology is particularly relevant in rice-wheat systems where short turnaround time after rice harvest and heavy crop-residue loads can delay wheat sowing. By enabling sowing with residue management in a single operation, it can reduce field-preparation time and support timely wheat establishment (Sidhu *et al.*, 2007) <sup>[17]</sup>. Thus, the technology can contribute to timely sowing, residue management and improved economic returns in the Tarai region.

**Table 1:** Reported performance of machinery interventions

| District   | Intervention                | Crop and variety | Production increase (%) | Net-return increase (%) |
|------------|-----------------------------|------------------|-------------------------|-------------------------|
| Gonda      | Laser-guided land levelling | Paddy NDR-359    | 20.00                   | 45.00                   |
| Kushinagar | Drum seeder                 | Paddy S-52       | 17.55                   | 64.11                   |
| Kushinagar | Zero tillage                | Wheat DBW-252    | 19.24                   | 47.99                   |
| Gonda      | Zero tillage                | Wheat (DBW-187)  | 14.70                   | 28.27                   |
| Basti      | Super seeder                | Wheat DBW-187    | 23.20                   | 46.54                   |
| Gorakhpur  | Super seeder                | Wheat DBW-187    | 13.23                   | 56.54                   |

### 3.3 Climate-resilient crop varieties

#### Flood-tolerant rice varieties

The use of flood-tolerant rice varieties was reported in Gonda and Bahraich districts. In Gonda, Samba-Sub1 recorded a

27.85% increase in production and 52.85% increase in net return, while in Bahraich, Swarna-Sub1 grown on 10 ha showed a 43.78% increase in yield under 15 days of stagnant water at 60-105 cm depth (Table 2). These reported results are consistent

with the documented role of SUB1 varieties in improving rice performance under temporary submergence.

The improved performance is associated with the SUB1 gene, which enhances tolerance to complete submergence by restricting excessive elongation and conserving plant energy during flooding. Studies in eastern India have reported higher yield and economic returns from Swarna-Sub1 and Samba-Sub1 under submergence-prone conditions (Ravindra *et al.*, 2020; Dar *et al.*, 2013). Field studies have also confirmed the improved performance of SUB1 varieties under flood conditions (Sarangi *et al.*, 2020)<sup>[2, 14, 16]</sup>.

#### Short-duration or medium-duration varieties

In Kushinagar, green gram variety Virat recorded a 51.24% increase in production and 42.50% increase in net return, while in Bahraich, rice variety NDR-2065 showed 23.48% higher production and 17.64% higher net return (Table 2). The reported performance of suitable varieties may improve productivity and profitability under variable weather conditions. Virat has also been evaluated under rainfed conditions, demonstrating its suitability as a green gram cultivar under such environments.

Selection of appropriate crop duration is particularly important in flood-prone areas because shorter-duration crops can provide greater flexibility for completing the crop cycle within a limited favourable period. In flood-prone eastern Uttar Pradesh, appropriate crop and variety selection has also been associated with improved productivity and profitability (Singh *et al.*, 2001). Thus, selection of suitable varieties and crop duration can reduce production risk and improve economic resilience in the Tarai region<sup>[18]</sup>.

#### Introduction of fodder crops

In Kushinagar, Jowar variety Anant was introduced as a catch crop and the project records reported 908.33 q ha<sup>-1</sup> fodder production, with net returns of ₹26,691 for farmers with buffaloes and ₹19,027 for farmers with cows (Table 2). The difference in reported returns indicates that the economic benefit of fodder production may vary with livestock type and fodder utilization. Fodder sorghum can increase on-farm green fodder availability and may provide an additional source of income through livestock-based farming systems.

#### Compensatory crop introduction

In Gonda district, the introduction of toria as a compensatory crop was associated with a reported 29.44% increase in production and a 47.99% increase in net return. Compensatory crops can reduce the risk of leaving fields fallow following flood-related damage and may improve income stability by providing an alternative crop in the same agricultural season (Table 2).

Toria is a short-duration oilseed crop that can be used to utilize land when the sowing window for the main crop is shortened or delayed. Its inclusion as a compensatory crop can help reduce the possibility of leaving land fallow after flood-related crop damage and provide an additional source of farm income. Rice-fallow studies in eastern India have highlighted the potential of short-duration oilseed crops for improving land-use efficiency and farm returns (Kumar *et al.*, 2019). Therefore, toria can serve as a risk-management and income-diversification option in flood-prone areas of the Tarai region<sup>[8, 10]</sup>.

**Table 2:** Reported performance of climate-resilient crop interventions

| District   | Intervention            | Crop or variety               | Reported result                                                                                |
|------------|-------------------------|-------------------------------|------------------------------------------------------------------------------------------------|
| Gonda      | Flood-tolerant variety  | Samba sub <sup>-1</sup> rice  | Production +27.85%; net return +52.85%                                                         |
| Bahraich   | Flood-tolerant variety  | Swarna sub <sup>-1</sup> rice | Yield +43.78% under 15 days of stagnant water                                                  |
| Kushinagar | Short-duration variety  | Virat green gram              | Production +51.24%; net return +42.50%                                                         |
| Bahraich   | Medium-duration variety | NDR-2065 rice                 | Production +23.48%; net return +17.64%                                                         |
| Kushinagar | Fodder crop             | Jowar, Anant                  | Production 908.33 q ha <sup>-1</sup> ; net return ₹26,691 with buffaloes and ₹19,027 with cows |
| Gonda      | Compensatory crop       | Toria                         | Production +29.44%; net return +47.99%                                                         |

### 3.4 Agronomic adaptation strategies

#### Intercropping

Project records indicate that Kushinagar district adopted trench-method intercropping of sugarcane with onion. Sugarcane productivity was 642 q ha<sup>-1</sup> without intercropping, while the intercropped system produced 117.67 q ha<sup>-1</sup> of onion and 726 q ha<sup>-1</sup> of sugarcane. Net return increased by 11.26%. The intercropping system therefore had a higher combined reported crop output than sole sugarcane and generated an additional marketable crop (Table 3).

The higher reported productivity and net return under sugarcane-onion intercropping may be associated with better utilization of available land and other resources and the additional marketable yield of onion. Studies in India have reported improved productivity and economic returns from sugarcane-onion intercropping compared with sole sugarcane (Kumar *et al.*, 2014). Thus, trench-method sugarcane-onion intercropping can be considered a diversification option for flood-prone Tarai farming systems<sup>[9]</sup>.

**Table 3:** Reported performance of sugarcane-based intercropping in Kushinagar

| Cropping system   | Sugarcane (q ha <sup>-1</sup> ) | Onion (q ha <sup>-1</sup> ) | Total reported crop output (q ha <sup>-1</sup> ) |
|-------------------|---------------------------------|-----------------------------|--------------------------------------------------|
| Sugarcane alone   | 642                             | 0                           | 642                                              |
| Sugarcane + onion | 726                             | 117.67                      | 843.67                                           |

#### Green manuring

Project records indicate that Maharajganj district adopted green manuring followed by paddy cultivation of variety PBT-5204. The available records indicate increased production and net return, but exact numerical values were not available in the records used for this analysis. Green manuring may improve soil structure, nutrient cycling and soil-water relations, which are relevant to flood-prone soils.

Green manuring can improve soil fertility by adding organic matter and enhancing nutrient cycling. Incorporation of green manure may also improve soil structure, water-holding capacity and nutrient availability, which can support crop growth under variable moisture conditions. Such improvements are relevant to flood-prone Tarai soils, where maintaining soil quality and efficient nutrient cycling is important after periods of excess water. Green manuring can therefore contribute to soil-quality

improvement and greater resilience of rice-based production systems (Prasad *et al.*, 2017)<sup>[13]</sup>.

### Mulching

In Gonda district, project records associated the use of mulch in sugarcane with increases of 8.90% in production and 13.66% in net return. Mulching can help maintain soil moisture, reduce weed competition and improve soil conditions.

The improvement may be attributed to better soil-moisture conservation, reduced weed competition and improved soil conditions under mulching. Crop residues or other mulch materials can reduce evaporation and moderate soil temperature, thereby supporting crop growth during periods of moisture stress. Mulching can also suppress weeds and improve resource-use efficiency, contributing to higher productivity and economic returns (Kumar *et al.*, 2020). Therefore, mulching can serve as a low-cost soil and moisture conservation practice for improving the resilience of sugarcane production in the Tarai region<sup>[11]</sup>.

## 3.5 Agriculture and allied sectors

### Vermicomposting

In Gonda district, project records reported vermicomposting productivity of 6.70 kg unit<sup>-1</sup> and a net return of ₹3,925 unit<sup>-1</sup> (Table 4). The reported economic return indicates that vermicomposting may provide an opportunity for diversification of agricultural livelihoods and recycling of farm residues.

Vermicomposting converts biodegradable farm residues into nutrient-rich organic manure, thereby supporting waste recycling and diversification of farm-based livelihoods. It can reduce dependence on external inputs and provide an additional source of income, particularly for smallholder farmers. Studies have reported positive economic returns from vermicompost production and its use in crop production (Kumar *et al.*, 2018). Therefore, vermicomposting can contribute to resource recycling, income diversification and livelihood resilience in the Tarai region<sup>[7]</sup>.

### Household kitchen gardens

In Kushinagar, project records reported that kitchen gardening provided an earning of ₹3,436 ha<sup>-1</sup>, with productivity of 286 g ha<sup>-1</sup> over a total area of 12 ha (Table 4). Because this productivity unit is unusually low for a kitchen-garden production measure, it should be verified against the original project record before final publication.

Kitchen gardens can improve livelihood resilience and household food security by providing fresh vegetables for consumption and surplus produce for sale. They also diversify household production and can generate supplementary income with relatively small land requirements. Thus, kitchen gardening can be a useful low-cost livelihood diversification strategy for farm households in flood-prone areas (Galhena *et al.*, 2013)<sup>[4]</sup>.

**Table 4:** Reported performance of allied agricultural interventions

| District   | Intervention             | Productivity               | Net return                |
|------------|--------------------------|----------------------------|---------------------------|
| Gonda      | Vermicomposting          | 6.70 kg unit <sup>-1</sup> | ₹3,925 unit <sup>-1</sup> |
| Kushinagar | Household kitchen garden | 286 g ha <sup>-1</sup>     | ₹3,436 ha <sup>-1</sup>   |

## 4. Conclusion

The present study compiled and synthesized reported agricultural adaptation interventions implemented in six flood-prone districts of the Tarai plains of Uttar Pradesh. The project records included improved machinery, flood-tolerant and short-duration varieties, intercropping, green manuring, mulching,

vermicomposting and kitchen gardens, with reported increases in agricultural productivity and/or economic returns for several interventions.

The reported increases in production and net returns highlight the relevance of location-specific adaptation strategies. Machinery interventions may support timely sowing and reduce the burden of land preparation, while resilient varieties and compensatory crops may reduce production risk. Intercropping and allied agricultural activities may contribute to income diversification and food security.

However, the current findings are based on incomplete project records and should be considered preliminary. The absence of complete control data, replication, sample sizes, cultivation costs and statistical tests limits the ability to establish causal relationships or statistically compare interventions. A complete district-wise dataset is required to validate the reported findings and assess the economic performance of individual strategies.

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