Transforming Agrifood Systems in South Asia

CGIAR

Diverse and healthy cropping systems trial protocol

Nalanda District, Bihar
Season: 2022–23

Research Protocol 5, Work Package 2

December 2022

BACKGROUND

On-Farm Research Trials are part of TAFSSA's Work Package 2 (WP2) activities. WP2 emphasizes farm- and landscape-level interdisciplinary research to identify strategies to increase farmers' profits and nutritional yields, conserve resources, and maintain or enhance ecological services, while also mitigating greenhouse gas (GHG) emissions from farms and agricultural landscapes. Going beyond typical agriculture-nutrition programs in South Asia we explore field- and landscape-scale crop and animal farm diversification options supporting multiple benefits, including potential nutritional yield, across environmental and socioeconomic gradients of rice and maize-based farming systems. Nalanda district of Bihar in eastern India has been selected as a learning site based on key information on food and nutrition security gaps, environmental stresses and climate challenges as well as the prevalence of commodities and farming systems that offer the greatest potential to achieve TAFSSA's outcomes.

These On-Farm Research Trials will contribute to the WP2 outputs:

2.1. Evidence informing the development of extension recommendations and materials tailored and appropriate for men, women, and farmers from marginal groups to build profitable, equitable farming enterprises that support nutrition.

2.2. A decision support framework tailored to South Asia's farming systems supporting governments and communities in managing nutrition-sensitive landscapes.

2.3. Landscape- and watershed-level assessments of groundwater use sustainability.

2.4 At least two public-private partnerships supporting farm services provision business models that overcome innovation bottlenecks to socially inclusive income generation.

2.5 Open-access peer-reviewed papers, reports, and datasets.

As per the Theory of change of WP2 the Research Platform Trial at BISA, Pusa Bihar is part of the first impact pathway that focuses on farm diversification and nutrition-sensitive landscapes and will contribute to the outcome "farmers are exposed to innovations and improves management recommendations". This type of action research with national and international research and extension institutes at the national and sub-national levels will facilitate endorsement and use of Outputs 2.1 and

CIMMYT International Maize and Wheat Improvement Center · IFPRI International Food Policy Research Institute · IRRI International Rice Research Institute · IWMI International Water Management Institute · CIP International Potato Center · WorldFish · ILRI International Livestock Research Institute

2.3 in development programs implemented by governments, extension agencies, and large livelihood-, environment-, and nutrition-oriented NGOs. Further, these efforts will be aligned with professional capacity development opportunities for young and women professionals within national research systems to learn about innovative tools and methods for answering complex, multi-scale research questions using interdisciplinary methods.

Test, adapt, target and position agronomic technologies and practices supporting crop (and animal) diversification across the region's farming systems.

In particular, compare and study diverse cropping systems in terms of:

i. agronomic performance
ii. yields and nutritional yields
ii. labor requirements
iii. profitability
iv. environmental impact

RESEARCH QUESTIONS

Research question 1: At the farm level, can crop diversification, biofortification, and animal components be managed to increase production of nutritious foods and improve women's and men's livelihoods while conserving resources and mitigating GHG emissions?

Research question 2: How can foodsheds, watersheds, and airsheds be managed at the landscape level to increase nutritional yields and agrobiodiversity while maintaining or augmenting ecological services?

METHODOLOGY

- Design, test and target the diversified sustainable intensification options to improve system productivity, nutritional yield, resource use and farm profitability.
- Monitor the adaptation behaviour of different crops and cropping systems and their influence on farm animals and nutritional quality.
- Effect of different cropping systems and management practices on soil health, C-budgets, and environmental footprints.

Site characteristics of Nalanda district, Bihar

Nalanda district is located within the Mid-Ganga basin, in the southern margin of the Gangetic plans. It lies between latitude 240 57' 57.78" and 250 27' 39.636" N and longitude 850 9' 54.9" and 850 55' 27.084" E, covering an area of about 2367 km^2 and representing mainly flat alluvium terrain except for the Rajgir hills in the south. The total net sown area in the Nalanda district is 181,130 ha^2. The major cropping systems are rice-based (wheat, potato, pulses) and integrated with livestock.

Weather and climate

The climate of the Nalanda region is comprised of hot summers with hot waves, with the maximum temperature reaching up to 40–44°C in April–June and a minimum temperature of 4°C in December–January. The long-term annual rainfall is about 943 mm of which 80 percent falls during June–September.

Soil characteristics

The soil texture of the Nalanda region is sandy loam to clayey loam with a pH range of 6.5 to 7.8. The district's soils are low-to-medium in nitrogen and phosphorous, and medium-to-high in potash. There is a widespread zinc deficiency in the district.

On-farm trials site selection

The field visit took place over three days (11–13 September, 2022) in five different villages of Harnaut and Noorsarai blocks, Nalanda district, Bihar, facilitated by TAFSSA team, Jeevika team members, BISA and local stakeholders.

Key highlights

- The field visits and focus group discussions with communities and about 535 persons participated with a strong representation of about 269 women, clearly indicated that the major cropping systems in the selected villages of the Nalanda district are rice-based (wheat, potato, mustard, chickpea and lentil) and soybean–wheat, maize–wheat and maize–wheat–mung bean. Seasonal vegetables are also grown on a very small scale and are mostly used for household consumption.
- Collectively, all communities highlighted that monsoon rice is under rainfed cultivation, and dry season winter crops either rainfed or with limited supplementary irrigation access. Timely sowing of paddy is affected as it depends entirely on rainfall, which can result in delays in sowing the wheat crop and ultimately lower productivity of the winter crops (e.g. wheat, mustard, pulses and maize).
- As there is limited access to and a lack of irrigation facilities, farmers are growing nurseries. This is done either at the community level or in groups close to the irrigation water source, or in agreement with tubewell owners, and subsequently planted in their respective fields. However, due to low and delayed rainfall in *kharif* 2022, the rice seedling transplanting was either delayed or a large number of seedlings remained in the field and were not transplanted. In some villages, the paddy area is reduced up to 50 percent this year due to a deficit in rainfall and lack of irrigation facilities.
- In general, field preparation is carried out using a rotavator, either by hiring custom services or using the farmer's own tractor. Most common planting/sowing is then done either by broadcasting or manual dibbling depending on the crop. Harvesting is also carried out manually due to the non-availability of machines and very small land holdings.
- There is limited access to irrigation facility. As a result, farmers tend to apply only supplementary irrigation in dry season winter crops, leading to poor productivity and gross margins. For example, poor yields of wheat because of farmers applied only two irrigations due to limited access.

- Conservation agriculture and sustainable diversified cropping systems have been piloted through the climate resilient agriculture (CRA) program (Bihar Govt. Project lead by Borlaug Institute of South Asia), with participating farmers highlighting better yield and income benefits with more resilience due to it allowing early sowing. Farmers are positive about and expressed a strong interest in increasing areas under these technologies in the coming season.
- The communities highlighted the recent decline in the water table; it has now reached 50 feet below ground level. This presents limited opportunities for surface and shallow tubewell irrigation water, with the only feasible option being a deep tubewell submersible pump. This facility is owned by a few resource-rich farmers who sell water at a minimal charge to nearby fields.

Experimental details

The on-farm field trials were setup from *rabi* 2022–23 (winter season), at the farmers field in four villages (Meyar, Kairi, Porei and Birju Milki) of two blocks (Noorsarai and Harnaut) in Nalanda district. Each village has two cropping system options with business as usual and replicated thrice. Each farmer is treated as a replication. Each treatment can be described as a portfolio of practices, where more than two agronomic interventions are included in each treatment to assess the combined effect of different management agronomic practices.

Design: factorial randomized block design
Cropping systems and management options (scenarios): 5
Replications: 3
Year and season: *rabi* 2022–23 (winter season)

Sustainable diversified intensification options for transforming agri-food systems in the Easter Indo-Gangetic Plain to address food and nutritional security

Treatment	Diverse of change	Crop rotations	Tillage	Crop establishment method	Residue management
1	Business as usual (farmer's practice)	rice–wheat–fallow	PTR–CTW	rice: transplanting wheat: broadcast on flats	partial rice residue burning and complete removal of wheat residue
2	Improved production, income and nutrition through intensification	rice–potato–maize	CTDSR–CTP–CTM	rice: drill seeding on flats potato: manual maize: drill seeding on fresh beds	all crop residues remove
3	Sustainable intensification to address nutrition along with labor, water, and soil health	maize–yellow mustard–mung bean	PBM–PBMS–PBMB	maize: drill seeding mustard: drill seeding mung bean: drill/relay	anchored maize (60%–70%) and mustard (30%–40%) and full mung bean residue retention
4	Sustainable intensification to address labor, water, nutrition	rice–chickpea–proso millet	ZTDSR–ZTC– ZTP	rice: drill seeding chickpea: drill seeding proso millet: drill/relay on flats on permanent beds (pbs)	full (100%) rice; (50%) chickpea and proso millet residue retention
5	Improved production, income, and nutrition through intensification	rice–wheat–mung bean	ZTDSR–ZTW–ZTM	rice: drill seeding wheat: drill seeding mung bean: drill/relay on flats on permanent beds (pbs)	full (100%) rice; anchored wheat (25%–30%) and full mung bean residue retention

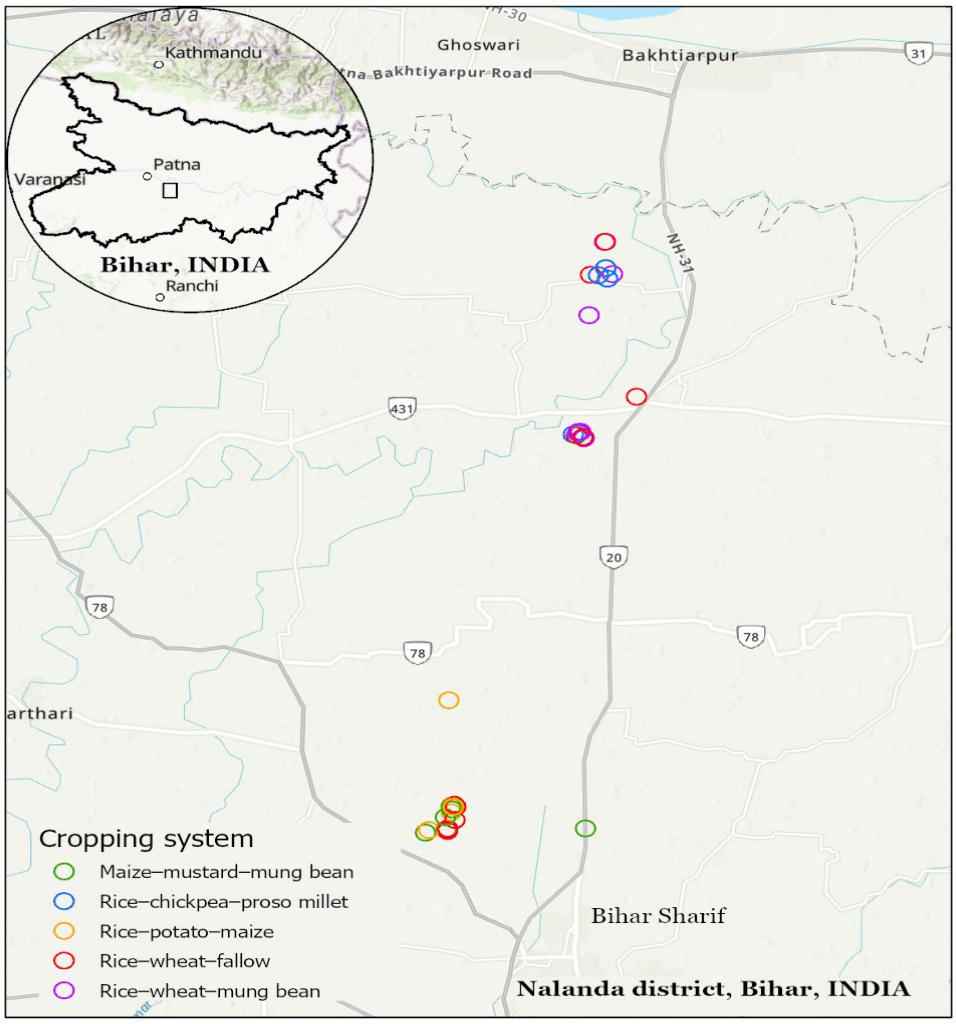
PTR = puddled transplanted rice; CTW = conventional till wheat; CTDSR = conventional till dry direct seeded rice; CTP = conventional till potato; CTM = conventional till maize; PBM =permanent raise bed maize; PBMS = permanent raise bed mustard; PBMB = permanent raise bed mung bean; ZTDSR = zero till dry direct seeded rice; ZTM = zero till maize; ZTMB = zero till mung bean

KEY CHALLENGES ADDRESSED

The research focuses on hot spots of poverty, malnutrition and ecological degradation in TAFSSA's learning locations, activities in the rice-based systems of the Eastern Gangetic Plain, and the mixed farming and rice–fallow systems of eastern India.

·Research will yield insights to support sustainable and nutrition-sensitive landscapes, while also developing business models and pathways for policies supporting income generation.

·The research will also lead to improved knowledge of dietary intake, productivity and income of the participating smallholder farming households.



Above: On-farm participatory trials located in Nalanda districts of Bihar

Table.1 Details of on-farm trials

Sr. No.	Farmer's name	Farmer's father's name	Village	Block	District	Mobile	Latitude	Longitude	Cropping system	Area (acres)
1	Satyaveer Kumar	Rajkumar Prasad	Meyar	Noorsarai	Nalanda	9204390034	25.25362	85.48283	rice–potato–maize	0.25-0.50
							25.25446	85.48736	maize–mustard–mung bean	
							25.25403	85.48766	rice–wheat–fallow	
2	Rajiv Ranjan	Jayprakash Narayan	Meyar	Noorsarai	Nalanda	6205485748	25.25362	85.48283	rice–potato–maize	0.25-0.50
							25.25358	85.48280	maize–mustard–mung bean	
							25.25434	85.48768	rice–wheat–fallow	
3	Akshay Kumar	Vinod Prasad	Meyar	Noorsarai	Nalanda	9386282630	25.25428	85.48351	rice–potato–maize	0.25-0.50
							25.25469	85.51825	maize–mustard–mung bean	
							25.25465	85.48773	rice–wheat–fallow	
4	Ashok Kumar	Gajendra Prasad	Kairi	Noorsarai	Nalanda	8709131974	25.25901	85.48849	rice–potato–maize	0.25-0.50
							25.26056	85.48847	maize–mustard–mung bean	
							25.26047	85.48951	rice–wheat–fallow	
5	Chotelal Prasad	Sohray Mahto	Kairi	Noorsarai	Nalanda	9546736641	25.28885	85.48796	rice–potato–maize	0.25-0.50
							25.25977	85.48862	maize–mustard–mung bean	
							25.25696	85.48931	rice–wheat–fallow	
6	Dharmendra Kumar	Krishna Prasad	Kairi	Noorsarai	Nalanda	9135461277	25.25769	85.48722	maize–mustard–mung bean	0.25-0.50
							25.26102	85.48919	rice–wheat–fallow	
7	Pinku Kumar	Sitasarn Prasad	Kairi	Noorsarai	Nalanda	7362011881	25.26048	85.48896	rice–potato–maize	0.25-0.50
8	Rajmani	Bhola Yadav	Porei	Harnaut	Nalanda	7480867825	25.35876	85.51794	rice–chickpea–proso millet	0.25-0.50
							25.36032	85.51717	rice–wheat–mung bean	
							25.36967	85.52955	rice–wheat–fallow	
9	Shailendra Yadav	Munni Yadav	Porei	Harnaut	Nalanda	7091911731	25.35964	85.51555	rice–chickpea–proso millet	0.25-0.50
							25.35861	85.51788	rice–wheat–mung bean	
							25.35942	85.51621	rice–wheat–fallow	
10	Bhola Ram Yadav	Harkit Yadav	Porei	Harnaut	Nalanda	7494015233	25.35996	85.51656	rice–chickpea–proso millet	0.25-0.50
							25.36032	85.51672	rice–wheat–mung bean	
							25.35891	85.51768	rice–wheat–fallow	
11	Brijesh Kumar	Ranchander Singh	Birju Milki	Harnaut	Nalanda	7250647308	25.41091	85.52248	rice–wheat–mung bean	0.25-0.50
							25.41095	85.52266	rice–wheat–fallow	
12	Amarkant	Ramji Ravidas	Birju Milki	Harnaut	Nalanda	9939227483	25.39138	85.51903	rice–wheat–mung bean	0.25-0.50
							25.40214	85.51935	rice–wheat–fallow	
13	Shambhudas	Ramanand Ravidas	Birju Milki	Harnaut	Nalanda	7631033184	25.40233	85.52421	rice–wheat–mung bean	0.25-0.50
							25.40111	85.52313	rice–chickpea–proso millet	
							25.40394	85.52276	rice–wheat–fallow	
14	Vijay Singh	Ram Lakhan Singh	Birju Milki	Harnaut	Nalanda	9955402230	25.40201	85.52112	rice–chickpea–proso millet	0.25-0.50
15	Laldeep Manjhi	Nathu Manjhi	Birju Milki	Harnaut	Nalanda	9262300128	25.40390	85.52271	rice–chickpea–proso millet	0.25-0.50

RICE

Season	**:**	**kharif (monsoon, June to October)**
Rotations	:	rice–wheat–fallow
Variety	:	Arize (AZ6585ST)
Variety characteristics		
Crop duration (days)	:	120–125 days, seed to seed
Average grain yield (t/ha)	:	7.5 t/ha

Special characteristics (if any)

- hybrid rice variety (Bayer CropScience); higher yielding in early duration segment compared to other varieties grown within a similar ecosystem
- stronger biotic stress tolerance and protection in the fight against pests and diseases, especially bacterial leaf blight
- greater tolerance to abiotic stress; more resilient to adverse climatic conditions

Seed rate (kg/ha)		
Transplanted rice	:	15
Direct seeded rice	:	20

Sowing time (transplanting)	:	Last week of June to first week of July, depending on access to the field and onset of the monsoon
Time of nursery cultivation	:	25 May to 15 June
Age at transplanting	:	Transplant 20–25 day-old seedlings at 1–2 seedlings per hill (seedlings more than 30 days old recover more slowly than younger seedlings, especially if they suffer stem and root injury; seedlings less than 20 days old are too short to be pulled from the soil)
Land preparation Conventional transplanted rice (CT PTR)	:	After harvesting the previous wheat crop in the rice–wheat–fallow system, till the plot either with a cross harrow and one tiller then leave for a few days, or (following the more recent example of farmers) use rotary tillage, employing a cross rotary tiller. Wait for effective rain or apply irrigation water if available, then churn the plot through the wet tillage (puddling) using either a puddling harrow or rotary tillage. Leave the soil to settle for one day before transplanting. Transplant the rice seedlings (as per the farmers practice: 5–6 seedlings per hill and about 30-day-old seedlings).
Conventional directed seeded rice (CT DSR)		After harvesting the previous maize crop in the rice–potato–maize system, till the plot with a cross harrow and one cultivator then press and level it using a wooden planker.
	:	Sow the rice seeds using the inclined plate seed metering system multi-crop planter, placing the seed at a soil depth of about 2–3 cm and with a row spacing of 20 cm. Immediately after seeding, apply light irrigation to ensure proper germination.
Zero-till directed seeded rice (ZT DSR)		At the final mung bean pod harvest and proso millet harvest, under rice–wheat–mung bean and rice–chickpea–proso millet cropping systems keep the whole mung bean and partial proso millet crop biomass in the plot. Spray non-selective herbicide paraquat @ 2 l/ha (500 gm a.i. per ha) or glyphosate (2.5 l per ha) to knock down
	:	existing perennial weeds. If there is insufficient moisture in the soil, apply light irrigation. Sow the rice seed using the inclined plate seed metering system, zero tillage multi-crop planter/Happy Seeder. Place the seed at a soil depth of about 2 cm and with a row spacing of 20–22.5 cm. Immediately after seeding, apply light irrigation to ensure proper germination.

Weed management

Transplanted rice	:	Pre-emergence – within two days of transplanting the rice seedlings, control weeds by applying butachlor or pretilachlor, as recommended in stagnant water. Post-emergence – at 20–25 days of transplanting, depending on the weed flora complex, spray 250 ml/ha such as Nominee Gold (bispyribac) diluted in 375 l of water. This can be combined with Pyrazosulfuron and assessed before applying post-emergence herbicide.
CT DSR	:	Pre-emergence – depending on field access, within 2–3 days of seeding spray a pre-emergence herbicide such as Pendimethalin (40%) @ 3 l /ha diluted in 300–350 l of water.
ZT DSR	:	Post-emergence – within 15–25 days of sowing apply 250 ml of bispyribac sodium and Pyrazosulfuron Ethyl 10% WP 200 g/ha. Pre-planting – if necessary, apply glyphosate (3 l/ha) to knock down existing perennial weeds. Pre-emergence – depending on field access, within 2–3 days of seeding spray a pre-emergence herbicide such as Pendimethalin (40%) @ 2.5 l/ha diluted in 300–350 l of water. Post-emergence –15–25 days after sowing apply bispyribac sodium 250 ml and Pyrazosulfuron Ethyl 10% WP 200 g/ha.
Time of nursery cultivation	:	25 May to 15 June
Age at transplanting	:	Under 'business as usual', rice seedlings are transplanted as per farmers' practice, generally at about 30 days old, varying according to rainfall and other factors. Under improved management practices, seedlings are transplanted at about 21–25 days old.

Nutrient management (TPR)

Nutrient requirements are assessed with reference to local farmers under conventional, business-as-usual practice; this will be updated every two years. The nutrients listed below are applied in conventional rice crop cultivation.

Nitrogen (kg/ha)	:	100
Phosphorus (kg/ha)	:	40
Potassium (kg/ha)	:	20
Any other nutrients	:	Depending on the Zn content, apply ZnSO4 as required. Apply a $^1/_3$ dose of N and full doses of P_2O_5 and K_2O at the time of sowing, and the remaining $^2/_3$ dose of N in two equal splits at 15–20 DAT and 40–45 DAT.

Nutrient management (DSR) Recommended dose of nutrients applied in DSR plots		
Nitrogen (kg/ha)	:	150
Phosphorus (kg/ha)	:	60
Potassium (kg/ha)	:	60
ZnSO4 (21%)	:	25
Any other nutrient	:	With both CT and ZT DSR, apply $^{1}/_{3}$ dose of N and full dose of P_2O_5 and K_2O at the time of sowing and the remaining $^{2}/_{3}$ dose of N in two equal splits at 25–30 DAS and 45–55 DAS. With DSR, also spray 2 or 3 applications of 1% ferrous sulphate solution at weekly intervals to prevent the appearance of iron deficiency (1 kg of ferrous sulphate in 100 l of water per acre); this should be assessed according to rainfall pattern and climate.
Irrigation management		
PTR	:	Keep the water standing continuously in the crop for only two weeks after transplanting so that the seedlings get properly established. After that, apply irrigation at the appearance of hairline cracks (although farmers generally do not apply any irrigation in rice, which is mainly rainfed).
DSR	:	Apply the first irrigation immediately after sowing and the second irrigation 4–5 days after sowing. Subsequent irrigations should be applied at 5–7-day intervals depending on soil type or rainfall. Stop irrigation 10 days before harvesting.
Irrigation method	:	Flood
No. of irrigations	:	Apply supplemental irrigation as per rainfall pattern crop requirements.
Observations to be recorded		
Plant height at harvest (cm)	:	5 plants, 2 locations each plot
No. of tillers at harvest (sq m)	:	2 x 2 m^2 quadrate
No. of grains per panicle	:	5 plants, 2 locations each plot
1000 grain weight (g)	:	Use a seed counter to count out 1000 seeds; weigh with a precise balance and record in grams
Biological yield (t/ha)	:	Carefully mark the 2 m x 2m in each plot by avoiding the borders, and harvest the rice within the marked area at three places in each plot for both biological and grain yield estimation. Take a sub-sample for moisture estimation.
Grain and straw yield (t/ha)	:	After threshing the grain, weigh and deduct the grain yield from the total biological yield (after moisture adjustment). Return all the rice straw to the original (2 m x 2 m) area in each rice plot.

MAIZE (GRAIN PURPOSE)

Season	**:**	**kharif (monsoon, June–October)**
Rotations	:	maize–mustard–mung bean (PB–PB–PB) (all three crops established on fresh beds)
Variety	:	Dekalb 9144
Varietal characteristics		
Crop duration (days)		: 90–100
Average grain yield (t/ha)		: 8–10
Special characteristics (if any)		

- **hybrid maize variety (Bayer CropScience); high yielding compared to other varieties grown within a similar ecosystem**
- **tolerant to low moisture stress; responds to high inputs**
- **bold, attractive grains, good color, good kernel quality**

Seed rate (kg/ha)		20 (75000 to 83000 plants/ha)
Sowing time	:	25 May to 20 June depending on access to the field
Crop establishment methods	:	Permanent beds under a maize–mustard–mung bean diversified system
Sowing method	:	After the chemical (herbicide) knockdown of the previous crop mung bean, carry forward the entire mung bean residue on the surface soil as mulch. Simultaneously reshape and place the maize seed and fertilizer in the center of the bed using the multi-crop inclined plate bed planter. The space between the center of the two beds is 67.5 cm withh an approximate 20 cm spacing maintained between two plants.
Nutrient management		
Nitrogen (kg/ha)	:	120
Phosphorus (kg/ha)	:	60
Potassium (kg/ha)	:	60
Zinc sulphate (21%)	:	25
Application		Apply the full quantity of P and ZnSO4 and ¾ of K at the time of sowing, and $^1/_3$ of N. Top dress the remaining nitrogen in two equal splits at the V6 and V-12 stages and $^1/_3$ of K at the tasseling stage.
Irrigation management		
Irrigation method	:	Apply supplemental furrow irrigation according to the rainfall pattern and when the crop needs water in long dry spells between rainfall events.
Weed management:	:	Assess pre-planting herbicide application after harvesting the mung bean crop; if necessary, apply glyphosate @ 3.0 l/ha diluted in 400 l of water to knock down existing perennial weeds.
	:	At post-emergence, apply Tembotrione (Laudis) or Topramezone selective herbicide @120 g/ha at the 2–3 leaf stage of weeds (15–20 DAS). Follow all-herbicide application guidelines.

Observations to be recorded for grain maize		
Plant height at harvest (cm)	:	5 plants, 2 locations each plot
No. of plant at harvest (sq m)	:	2 beds x 4 m row length
No. of cob/plant	:	2 beds x 4 m row length
Cob length	:	5 cobs from each sample, two samples from each plot
No. of grains per cob	:	5 cobs from each sample, two samples from each plot
100 grain weight (g)	:	100 grain weight (g)
Biological yield (t/ha)	:	2 bed x 4 m length; take a sub-sample to determine moisture
Grain yield (t/ha) and stover yield	:	2 bed x 4 m length; after adjusting for moisture, deduct the grain weight from biological yield to get the total stover weight including cob husk and sheath; after cob harvest, return the remaining 70% of plant biomass to the original harvested area.

WHEAT

Season	**:**	**rabi (winter, November to April)**
Rotations	:	rice–wheat–fallow
Variety	:	HD-2967
Variety characteristics		
Crop duration (days)	:	125–135 days seed to seed
Average grain yield (t/ha)	:	4–5
Seed rate kg/ha	:	120
Sowing time	:	15 November to 10 December
Agronomic practices		
Land preparation		
Conventional tillage wheat (CTW)	:	After harvesting the previous rice crop in the rice–wheat fallow system, remove the rice residue from the plot; irrigate the plot if sufficient moisture is not available. When the moisture conditions are right, till the plot with cross one harrow, one tiller and one rotary tiller. Then broadcast the wheat seed and mix it into the soil using a rotary tiller.
Zero-till wheat (ZTW)	:	At rice harvest, keep the entire rice crop biomass in the plot under the rice–wheat–mung bean cropping system. If there is insufficient residual soil moisture, apply light irrigation as necessary then also apply glyphosate (2.5 l/ha) to knock down the existing perennial weeds. Sow wheat seeds using the Happy Seeder planter at about 5–7 cm soil depth with a row spacing of 22.5 cm.

Weed management		
CTW	:	Post-emergence – within 25–35 days of sowing apply Pinoxaden (Axial) @1 l/ha and Metsulfuron methyl (Algrip) 20% WP @20 g/ha, or other potential recommended post-emergence herbicide combinations as recommended. Record each application and herbicide.
ZTW	:	Pre-planting – if necessary, apply glyphosate (3 l/ha) to knock down the existing perennial weeds. Post-emergence – as above in a conventional system.
Nutrient management (CTW) **Nutrient requirements will be assessed through the nearby farmers under business-as-usual conventional practice; this will be updated every two years. The nutrients below are applied in conventional rice crops.**		
Nitrogen (kg/ha)	:	120
Phosphorus (kg/ha)	:	60
Potassium (kg/ha)	:	40
Application method	:	Apply the entire dose of P and K at the time of sowing; apply N in two equal splits at 22–25 DAS and 42–45 DAS.
Nutrient management (ZTW) **The recommended dose of nutrients applied in ZTW plots**		
Nitrogen (kg/ha)	:	120
Phosphorus (kg/ha)	:	60
Potassium (kg/ha)	:	40
$ZnSO_4$ (21%)	:	25
Application method	:	Apply full doses of P and K at the time of sowing; apply N in two equal splits at 22–25 DAS, and 42–45 DAS.
Irrigation management		
CTW and ZTW	:	Apply first irrigation at the CRI stage 22 x 25 DAS and subsequent irrigations at 20–25 days intervals depending on soil type and moisture condition. Under business-as-usual, this is managed by the farmers according to their own practices.
Observations to be recorded		
No. of tillers at harvest (sq m)	:	CTW: 0.5 x 0.5 m^2 quadrate ZTW: 2 rows x 1 meter row length
No. of grains per spike	:	5 plants, 2 locations each plot
1000 grain weight (g)	:	Count out 1000 seed using a seed counter, weigh with a precise balance and record in grams
Biological yield (t/ha)	:	CTW and ZTW. Carefully mark the 2 m x 2 m plot avoiding the borders and harvest the wheat within the marked area for both biological and grain yield estimation; three quadrates (places) will be harvested in each plot. Take a sub-sample to estimate moisture estimation.
Grain and straw yield (t/ha)	:	CTW and ZTW. Harvested biomass from the marked area (2 m x 2 m), after sundry, threshed the grain carefully by a plot thresher, weigh the grain and deduct the grain yield from the total biological yield (after moisture adjustment).

MUSTARD

Season	**:**	**rabi (winter, October to March)**
Rotations	:	maize–mustard–mung bean (PB–PB–PB) (all three crops established in permanent beds)
Variety	:	Mahyco Ulhas 203
Variety characteristics		
Crop duration (days)	:	100–120
Average grain yield (t/ha)	:	2.5–3.0
Special characteristics (if any)		
• **This is a short-duration yellow mustard variety with good yield and high oil content.**		
Seed rate kg/ha	:	5
Sowing time	:	15 October – 15 November
Agronomic practices		
Method of sowing **After harvesting the maize crop and retaining about 70% of the crop residue as stubble (under a maize–mustard–mung bean rotation), place the mustard seed and fertilizer in two rows on the top of the bed using a multi-crop inclined plate bed planter. Maintain a space of 30 cm between rows and an approximate spacing of 10–15 cm between plants.**		
Weed management	: :	Pre-planting – if necessary, apply glyphosate (2.5 l per ha) to knock down existing perennial weeds. Post-emergence weed control – carry out one-spot hand-weeding (based on weed density) to remove escaped weeds.
Nutrient management		
Nitrogen (kg/ha)		60
Phosphorus (kg/ha)	:	40
Potassium (kg/ha)	:	40
Application	:	Apply full doses of P & K at the time of sowing; apply N in two splits (first split at first irrigation and second split at second irrigation).
Irrigation management		
Irrigation method	:	Apply need-based supplementary pre-sowing furrow irrigation if sufficient moisture is not available at the time of sowing. The first irrigation will be applied at 3–4 weeks after sowing; a further two irrigations were applied at siliqua formation and the flowering stage.
Observations to be recorded		
Plant height at harvest (cm)	:	5 plants, 2 locations each plot
No. of plants at harvest (sq m)	:	Count the plants from 2 bed 4-meter length
No. of grains per pod	:	5 pod, 2 locations each plot
Biological yield (t/ha)	:	harvest the area from 2 bed 4-meter length and weigh immediately. A subsample for moisture estimation will be taken.
1000 grain weight (g)	:	Count the 1000 grain and weight (g)
Grain yield and straw yield (t/ha)	:	Threshed the grain carefully from 2 bed 4-meter length harvested biomass, weigh the grain and adjusted with moisture.

POTATO

Season	:	rabi
Rotations	:	rice–potato–maize (CTDSR–CT–CT)
Variety	:	Kufri Pukhraj
Variety characteristics		
Crop duration (days)	:	Early maturity variety (70–90 days)
Average grain yield (t/ha)	:	35–40
Special characteristics (if any)		
• resistant to early blight; moderately resistant to late blight and immune to wart disease		
• suitable for low input ecosystem		
• suitable for table purposes		
Seed rate t/ha		35–45 mm size, 2.5–3.0 t/ha
Sowing time	:	Last week of October until last week of November
Agronomic practices		
Land preparation		
After harvesting the previous rice crop in the rice–potato–maize system, remove the rice residue from the plot and irrigate if insufficient moisture is available. When appropriate moisture conditions are achieved, till the plot with cross two harrows, two cultivators and two rotary tillers; prepare a fresh ridge bed using a curved/narrow-blade spade ridge planter.		
Method of sowing		
Mechanical: plant the whole potato tuber using the potato planter at 60–65 cm x 20–25 cm row-to-row and tuber-to-tuber spacing respectively.		
Nutrient management		
Nitrogen (kg/ha)	:	150
Phosphorus (kg/ha)	:	80
Potassium (kg/ha)	:	100
Application	:	Apply entire doses of P and K at the time of sowing; apply half of the N dose at sowing and the remaining half dose in two splits (20–25 DAS at earthing up and 40–45 DAS within furrows).
Irrigation management		
Irrigation method	:	Apply light irrigation at 5–6 DAS (days after sowing) as it ensures better germination. Subsequent irrigations should be applied at 10–12-day intervals depending on soil type or irrigation interval, adjusted according to soil moisture conditions. It should be ensured that the irrigation water will not overflow on the ridge beds; it is always recommended to no more than $^{3}/_{4}$ of its furrow height flooded.
Weed management	:	Remove weeds manually by hoeing before applying urea at earthing up.
	:	Post-emergence – within 10 days of sowing, apply metribuzin 70% WP (sencor) 500–625 g/ha.
Observations to be recorded		
No. of plant at harvest (sq m)	:	Count the plants from 1 bed x 1 m length
No. of tuber/plant	:	Count the tubers from 5 plants at 2 locations in each plot
Tuber yield (t/ha)	:	Mark the area of 2 beds x 4 m length, harvest the area by digging the potato and weigh the total tubers weight.
Above-ground plant biomass (t/ha)	:	2 bed x 4 m length (the surface biomass is removed just before the harvest and recorded. Dry biomass is adjusted by taking a moisture sub-sample).

Season	**:**	**rabi**
Rotations	:	rice–chickpea–proso millet
Variety	:	RVG-202
Variety characteristics		
Crop duration (days)	:	102–105
Average grain yield (t/ha)	:	1.8–2.0
Special characteristics (if any)		
• **suitable for late sown conditions**		
• **resistant to wilt**		
• **moderately resistant to dry root rot and collar rot**		
Seed rate (kg/ha)	:	90–92
Sowing time	:	15 October – 15 November
Agronomic practices		
Land preparation **After harvesting the previous rice crop in the rice–chickpea–proso millet system, irrigate the plot if insufficient moisture is available. No preparatory tillage for land preparation will be performed after harvesting of rice and retaining rice residue as a soil surface mulch.**		
Method of sowing **Sow chickpea with a zero till multi-crop planter; place seed at a 6–8 cm soil depth and with a row spacing of 22.5 cm.**		
Nutrient management		
Nitrogen (kg/ha)	:	20
Phosphorus (kg/ha)	:	50
Application	:	Entire doses of N and P at the time of sowing.
Irrigation management		
Irrigation method	:	Flood
No. of irrigations	:	1 irrigation at branching and 1 at the pod formation stage
Weed management	:	Pre-emergence – depending on field access, within 2–3 days of seeding spray a pre-emergence herbicide as Pendimethalin (30%) @ 0.75–1 l/ha diluted in 300–350 l of water.
	:	Post-emergence weed control – carry out one-spot hand-weeding at 23–30 DAS (based on weed density) to remove escaped weeds.
Observations to be recorded		
Plant height at harvest (cm)	:	5 plants, 2 locations each plot
No. of plants at harvest (sq m)	:	2 x 2 m quadrate
1000 grain weight	:	1000 grain weight (g)
Grain yield (t/ha)	:	2 bed x 4 m length
Straw yield (t/ha)	:	2 bed x 4 m length
Biological yield (t/ha)	:	2 bed x 4 m length

MUNG BEAN

Season	**:**	**Summer**
Rotations	:	maize–mustard–mung bean (PB–PB–PB) rice–wheat-mung bean (ZT–ZT–ZT)
Variety	:	IPM02-14
Variety characteristics		
Crop duration (days)	:	60–70
Average grain yield (t/ha)	:	0.8–1.10
Special characteristics (if any)		
• **resistant to yellow mosaic virus**		
• **high yield potential**		
Seed rate kg/ha		30
Sowing time	:	First week of April
Agronomic practices		
Method of sowing:		
Zero-till mung bean (ZTM)	:	At the wheat harvest, retain anchored wheat at about 20 cm height (25%–30%) in the plot under the rice–wheat–mung bean cropping system. If insufficient soil moisture is available, apply light irrigation and if necessary also apply glyphosate (3.0 l/ha) to knock down existing perennial weeds. Mung bean seed is sown using the fluted roller seed metering system, Happy Seeder, placed at a soil depth of about 4–6 cm and a row spacing of 22.5 cm.
Permanent bed mung bean (PBM)	:	After harvesting the mustard crop, keep about 30%–40% of the crop residue under the maize–mustard–mung bean cropping system. Place the mung bean seed and fertilizer in two rows on the top of the bed using the disc-type multi-crop bed planter. Maintain a space between the two rows of 30 cm.
Nutrient management		
Nitrogen (kg/ha)	:	20
Phosphorus (kg/ha)	:	40
Application	:	Entire dose of N and P will be applied at the time of sowing of the crop.
Irrigation management		
ZTM	:	flood
PBM	:	furrow
No. of Irrigation	:	2-3 irrigation is applied depending on soil type and moisture condition.
Weed management		
ZTM & PBM	:	Pre-planting – if necessary, apply glyphosate (3.0 l/ha) to knock down existing perennial weeds
	:	Post-emergence – within 25–35 days of sowing, apply quizalofopethy (Targa Super) @ 1l/ha.
Observations to be recorded		
No. of seed /pod	:	5 pods, 2 locations each plot
1000 grain weight	:	1000 grain weight (g)
Biological yield (t/ha)	:	2 bed 4 m row length (bed planting) 2 m x 2 m in case of flat
Grain yield (t/ha)	:	2 bed x 4 m row length (bed planting) 2 x 2 m (flat)

PROSO MILLET

Season	**:**	**Spring**
Rotations	:	Rice–chickpea–proso millet
Variety	:	PMV442
Variety characteristics		
Crop duration (days)	:	Short duration variety (65–90 days)
Average grain yield (t/ha)	:	2.5–3.0 t/ha
Special characteristics (if any)		
• **dwarf stature, nonlodging and short duration**		
• **moderately tolerant to shoot fly damage**		
• **exhibits a higher crude fiber and calcium content**		
Seed rate kg/ha		10
Sowing time	:	15 March–15 April
Agronomic practices		
Method of sowing **After harvesting the chickpea crop, keeping 100% of crop residue under rice–chickpea–proso millet cropping system. Place the proso millet seed and fertilizer in 1 row on the top of the bed using the multi-crop bed planter. Drop the seed mix with DAP through a fluted roller to ensure uniform distribution in the field. Maintain 25 cm space between rows and an approximate 10–12 cm spacing plant-to-plant.**		
Nutrient management		
Nitrogen (kg/ha)	:	20
Phosphorus (kg/ha)	:	10
Application	:	Entire dose of P at the time of sowing; N is applied in two splits (first split at first irrigation and second split at second irrigation)
Irrigation management		
Irrigation method	:	Furrow irrigation
No. of irrigations	:	Apply 1–2 irrigations depending on soil type and moisture conditions. Apply the first irrigation 25–30 days after sowing and the second irrigation about 40–45 days after sowing. Due to the shallow root system of proso millet, heavy irrigation is not advisable.
Weed management	: :	Pre-emergence – depending on field access, within 2–3 days of seeding spray a pre-emergence herbicide such as Pendimethalin (40%) @ 2.5 l/ha diluted in 300–350 l of water. Post-emergence weed control – carry out one-spot hand-weeding at 30 DAS (based on weed density) to remove escaped weeds.
Observations to be recorded		
Plant height at harvest (cm)	:	5 plants, 2 locations each plot
No. of tillers at harvest (sq m)	:	2 bed x 4 m length
No. of head plant^{-1}	:	5 plants, 4 locations each plot
1000 grain weight	:	1000 grain weight (g)
Grain yield (t/ha)	:	2 bed x 4 m length
Straw yield (t/ha)	:	2 bed x 4 m length
Biological yield (t/ha)	:	2 bed x 4 m length

MAIZE

Season	**:**	**Summer**
Rotations	:	rice–potato–maize
Grain maize		
Variety	:	Pioneer 3355
Variety characteristics		
Crop duration (days)	:	90–100
Average grain yield (t/ha)	:	7–8
Special characteristics (if any)		
• **high yielding hybrid**		
• **tolerant to low moisture stress; responds to high inputs**		
• **bold attractive grains; good colour; good kernel quality**		
Seed rate kg/ha		20 (75000–83000 plants/ha)
Sowing time	:	Second fortnight of February to mid-March
Crop establishment methods	:	Conventional till planting under rice–potato–maize diversified system
Sowing method	:	After harvesting the previous potato crop in the rice–potato–maize system, remove the potato crop residue from the plot; irrigate the plot if sufficient moisture is not available. When the plot reaches the appropriate moisture condition, it should be tilled with cross 2 harrows, 2 cultivators and 2 rotary tillers. Next, place the maize seed and fertilizer in one row on the top of the bed using the multi-crop bed planter, with a space between the center of the beds of 67.5 cm and maintaining an approximate 20 cm spacing between two plants.
Nutrient management		
Nitrogen (kg/ha)	:	100
Phosphorus (kg/ha)	:	60
Potassium (kg/ha)	:	40
Zinc sulphate (21%)	:	25
Application		At the time of sowing, apply the entire quantity of P and K and $^1/_3$ of N. Top dress the remaining nitrogen in two equal splits at the V10–12 stage and pre-tasseling stage.
Irrigation management		
Irrigation method	:	Apply supplemental furrow irrigation according to rainfall pattern and when a crop needs water in long dry spells between rainfall events.
Weed management:	:	Assess pre-plant herbicide application after harvesting the potato crop; if necessary, apply glyphosate @ 2.5 l/ha in 400 l of water to knock down existing perennial weeds.
	:	Post-emergence – Tembotrione (Laudis) selective herbicide @120 g/ha will be applied at the two-three leaf stage of weeds (15–20 DAS), following all-herbicide application guidelines
Observations to be recorded for grain maize		
Plant height at harvest (cm)	:	5 plants, 2 locations each plot
No. of plants at harvest (sq m)	:	2 beds x 4 m row length
No. of cobs/plants	:	2 beds x 4 m row length
Cob length	:	5 cobs from each sample, two samples from each plot
No. of grains per cob	:	5 cobs from each sample, two samples from each plot
100 grain weight (g)	:	100 grain weight (g)
Biological yield (t/ha)	:	2 bed x 4 m length, with a sub-sample taken to determine moisture
Grain yield (t/ha) and stover yield	:	2 bed x 4 m length; after adjusting for moisture, deduct the grain weight from the biological yield to get the total stover weight including cob husk and sheath; after the cob harvest, return the remaining 70% plant biomass to the original harvested area.

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