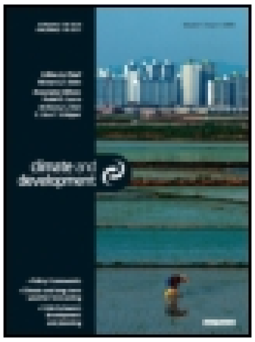

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RESEARCH ARTICLE

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Intensification of rice-fallow cropping systems in the Eastern Plateau region of India: diversifying cropping systems and climate risk mitigation

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ABSTRACT

This article reports research from 2013 to 2016 with tribal smallholders, which evaluated technological interventions, aimed to diversify and intensify cropping systems and improve the climate resilience of the farming systems using modelling and participatory evaluation process. The options on providing access to irrigation water, strategic use of irrigation, and better crop husbandry practices were evaluated for their potential to impart climate resilience in farming systems. Irrigation trials revealed that, in the event of delayed rainfall, irrigation of 229-267 mm ensured timely transplanting and resulted in higher paddy yields (7.0 t ha^{-1}). Supplemental irrigation during a mid-season dry spell increased paddy yield to from 0.64 to 6.1 t ha^{-1}. Better vegetable cultivation practices viz. drip irrigation, polythene mulch, nursery raising in seedling trays and raised bed cultivation exhibited great potential to build climate resilience in the farming systems of the region. The study highlights the need for investments in small water harvesting structures and the promotion of alternative ways of cultivating and irrigating paddy during different climatic situations. The study suggests effective ways of engaging communities coupled with appropriate technological interventions to understand climate change and adaptation needs of the rice-fallow ecosystems in eastern India.

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Rice-fallow; crop intensification; direct-seeded rice; water-productivity; participatory research; climate change adaptation

1. Introduction

Rice-fallow is a major cropping system in South Asia. It covers 14.6 M ha, 80% of which is in India, mostly in the undulating to hilly Eastern Plateau region comprising the states of Jharkhand and Chhattisgarh and parts of Bihar, Odisha, and West Bengal. The Eastern Plateau is one of the least developed and poorest regions in India, with little 'traditional irrigation' via large dams, canal networks and deep tube wells, which are not feasible for topographical, geological and geo-hydrological reasons (Srivastava et al., 2009). In the rice-fallow system, rainfed rice is grown in the wet season (*kharif*) and the land lies fallow during the subsequent dry winter (*Rabi*) and summer periods, except for weeds that are grazed.

Traditionally, transplanted rice has been grown on lowlands adjoining the drainage lines where the crop is favoured by seepage and runoff, but the population pressure has forced it onto less favourable terraced hillslopes ('midlands') which comprise >80% of the rice area, and the only rice land for many families (Pangare & Karmakar, 2003). Rice yields on the Plateau vary widely from year to year, but on average they are low (<2 t ha^{-1}; Aggarwal et al., 2008) and have shown little improvement over time (IRRI, 2017). The Plateau region is characterized as having frequent climate aberrations like dry spells and droughts but also has a great potential (Sikka et al., 2009) because the high average precipitation (1100–1600 mm) can support 'rainwater harvesting' for irrigation to overcome the climate-related risks (Pangare & Karmakar, 2003; Sikka et al., 2009; Verma, 2007). As the development of 'traditional' irrigation schemes is also constrained (Srivastava et al., 2009), there is a need for less risky and more productive cropping systems based on the existing or newly developed water resource, to build climate resilience and develop opportunities for cropping in the *Rabi* and summer season.

The reasons for low yield and slow adoption of improved practices have received little attention. However, recent research on the eastern fall of the Plateau (Cornish, Karmakar, Kumar, Das, & Croke, 2015; Cornish, Choudhury, et al., 2015) showed that variable yields and periodic failures of transplanted rice are inevitable on medium-uplands because the requirement for ponding is often not met due to climatic abnormalities. Predictions made for eastern India have shown a significant decrease in the number of rainy days and heavy rainfall days, while an increased frequency of heavy rainfall events is predicted to occur at sporadic locations in eastern India (Guhathakurta, Shreejith, & Menon, 2011). Given the risks posed by climate change many international organizations have called developing national development plans with an inclusion of climate change adaptation strategies (World Bank, 2010). Recognizing these negative impacts of climatic aberrations, researchers are focusing on the diversification of cropping systems as aan adaption major to build resilience into agricultural systems. Crop diversification has the potential to reduce exposure to climate-related risks and increase the flexibility of farm production to changing climatic conditions (Gebrehiwot, van der Veen, & Van Der Veen, 2013; Smit & Skinner 2002).

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Studies relating the crop diversification to mitigate the climate abnormalities are very limited. Given the context of extreme weather events, there is a need to develop participatory mechanisms to influence the farmer decisions on crop planning. Recent studies have confirmed the effectiveness of the participatory approaches in building local empathy, a local knowledge base and empowering farming communities to join towards climate adaptation action (Nkoana, Verbruggen, & Hugé, 2018; Ross et al., 2015). This research examines crop diversification as a means of climate change adaptation and evaluated different management practices in a participatory approach. Experiments were conducted on farmers' fields in two tribal villages, Hundru and Chhotaghagra, located on the outskirts of Ranchi. These villages represent the agro-ecological and social conditions of the Eastern Plateau region for villages with ready access to major population centres. The research commenced with socio-economic assessment and water resource development and proceeded to participatory on-farm research supported by water balance modelling, with the objectives of (i) evaluating rice cultivation practices for building climate resilience and reducing risk, (ii) identifying profitable crop options for midlands and uplands, and (iii) evaluating the participatory learning process. The paper examines the possible linkages with ongoing government schemes for out-scaling of the research findings.

2. Materials and methods

The project was initiated in 2013, which was devoted to the characterization of socio-economic conditions, soil properties, agricultural production systems, and problem identification and model parameterization. Technological interventions were evaluated during 2014 and 2015. The work focused on Tribal farmers, who are socially the most disadvantaged in the region, and formed a large majority in the research villages.

2.1. The Eastern Plateau and hill region

The Eastern Plateau and hill region forms the northeastern part of the peninsular plateau of India and extends from 21°58' N to 25°18' N latitudes and 83°22' E to 87°57' E longitudes. The Chotanagpur plateau begins with the contour line of 150 m just south of Bihar plains and has average elevations varying from 308 to 924 m above the mean sea level.

The region consists of a series of hillocks with drainage lines and low-lying areas near streams, collectively classified as lowlands, where paddy has been traditionally cultivated. In areas represented by the present study, lowlands extend about 60–150 m horizontally with local relief of 2–3 m above the drainage line. These areas remain waterlogged for prolonged periods after the end of the monsoon season. The soils drain and become workable in January. The area midway between lowlands and relatively planer uplands is categorized as midlands (Figure 1), which have local topographic relief of about 2–7 m above the drainage line. Much of the original hill slope area (midland) has been terraced and bunded to convert it to paddy fields. The upper non-terraced and non-bunded planer areas generally have shallower, light-textured soil. Local water resources are not available to support irrigation in uplands.

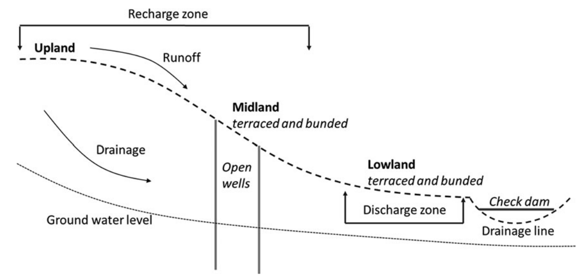

Figure 1. Landscape schematic showing upland, midland and lowland areas (Redrawn from Cornish, Karmakar, et al., 2015).

Uplands typically lie at an elevation range >7 m above the drainage line. There are some village 'fringe areas' on the stream banks which are marginal uplands having a high slope, rocky terrain with high runoff. These are not used for agricultural production. Groundwater recharge mainly occurs in the uplands and the midlands (bunded paddy fields), while the low lands are the major discharge areas. The acid, infertile soils are developed mainly on gneiss or granite parent materials and are mainly Alfisols and Inceptisols (Agarwal, Kumar, & Shahi, 2010).

The major cropping seasons comprise the summer (March to May/June), monsoon (June to September/October) and winter (November to February). Warm-season crops are grown in the *Kharif* (monsoon season), whilst cool-season crops are grown, infrequently, in the *Rabi* (winter).

2.2. Case study villages

Research was undertaken in the fields of 160 tribal families in the adjoining villages of Hundru and Chhotaghagra, which were selected to provide a contrast to the villages reported by Cornish, Karmakar, et al. (2015) in Purulia. The villages lie on the outskirts of Ranchi at an altitude of 640 m with an average annual rainfall of 1,430 mm at the nearby airport. In these villages about 74% of the population is tribal. These villages have a combined area of 321 ha of which 25% is in lowlands, 40% in midlands and 35% in uplands. Overall, 273 ha of the villages is arable (potentially cultivated). Soils of the uplands are mostly 'sandy' in texture, while midlands and lowlands tend towards 'loam'. The analysis of 57 soil samples collected from farmers' fields revealed that the soils were acidic (pH 4.4–5.2) and infertile, being deficient in the available nitrogen (N by alkaline permanganate, <100 mg kg^{-1}), available phosphorus (Bray-P, 4–6 mg kg^{-1}) and boron (0.07–4.48 mg kg^{-1}). These descriptions are similar to those of other villages across the Plateau region (Cornish, Choudhury, 2015; Kumar, Kumar, & Cornish, 2015).

Rainfed transplanted rice is the most important crop, with farmers reporting yields of 1.2–4.6 t ha^{-1}. Rice-fallow is the major cropping system with rice infrequently followed by vegetables. Farmers reported that the transplanted rice had failed in 2006 due to the severe drought and yield had been severely reduced in 2010 due to the delayed onset of the monsoon. This highlights the need to build climate resilience in the *Kharif* crop as well as develop irrigation and better cropping options for the second cropping in the *Rabi* season.

2.3. The research approach

Participatory action research was used to simultaneously advance scientific insight and facilitate complex changes in the way farmers understand and manage their resources. Farmers were involved in problem identification, formulation of research questions, treatment implementation and interpretation of results. We began by sensitizing men and women farmers to potential technologies through exposure visits and interactions with earlier success stories, early-adopting farmers and research institutions. With the background knowledge of the benefits, advantages and disadvantages of potential technologies, farmers were then engaged in meetings at which they selected the technologies they believed would be good for them. This was a very dynamic process, as the choice of technology kept on changing as per the crop and weather conditions. Farmers were exposed to only a limited range of options, ensuring that each option was replicated across a number of families.

In view of the rainfall-related risks with transplanted rice and the need for irrigation to develop *Rabi* cropping, initial emphasis was given to developing water resources. The focus of agronomic interventions in the *Kharif* was on timely transplanting, 'rescue irrigation' of rice, cultivation of direct-seeded rice, and vegetable production in uplands and poorer midlands (converted from rice). Other interventions focusing mainly on the *Rabi* included crop diversification. Work on vegetable crops included training on the advanced methods of nursery raising and management and early summer season cultivation. After technologies had been accepted for trial, the project team laid out experiments in the farmers' fields. Evaluation was carried out in a participatory manner.

2.4. The water balance model

The daily root zone water balance model, as described in Cornish, Karmakar, et al. (2015), was used to gain insight into growing-season conditions and treatment responses. This model was developed in MS Excel™ for rice-fallow in midlands and it allows for ponding with transplanted rice. The available water on a day (AW_{t2}) is estimated from the available water on the previous day (AW_{t1}) as follows:

$$AW_{t2} = AW_{t1} + (R + I) - (ET + RO_o + DP)$$

where R and I are the daily rainfall and irrigation (mm), respectively; ET is the evapotranspiration (mm); RO is the runoff (mm) and DP is the deep percolation (mm) beyond the root zone. ET is estimated as a function of potential evapotranspiration (E_o) and soil water (Allen, Pereira, Raes, & Smith, 1998). The model assumes that lateral inflows are balanced by outflows and there is no upward flux from a shallow water table, so it does not apply to all of the landscape. It is a point model, so outputs of deep drainage and runoff cannot be directly scaled up to the watershed. The model was parameterized for water holding capacity using values from Hundru and Chhotaghagra villages. The saturation, field capacity and wilting point values were 320, 250, and 100 mm/m for midlands and 320, 200, and 80 mm/m for the upland soils, respectively. Maximum pond depth was 100 mm and maximum DP was 3 mm d^{-1} following sensitivity testing (1–9 mm d^{-1}). The model was parameterized for uplands by removing ponding, reducing plant available water for the sandier soil, and increasing DP to 15 mm d^{-1}. Model outputs for four years were evaluated in two focus group meetings held with farmers. Farmers reported on their date of nursery sowing and transplanting and any need of rescue irrigation, as well as gave an overall rating for each year with brief reasons for their assessment.

2.5. Description of interventions

2.5.1. Access to irrigation water

Given the limited water supplies during dry season, farmers were keen to access water for 'rescue irrigation' for rice in the *Kharif*. After the analysis of the hydrological and biophysical situation in the villages, hydrologists in consultation with the farmers constructed a check dam on the Doranda stream flowing adjacent to Hundru village in a participatory way. In midlands, where the conveyance of stream water was not possible, the consensus was built seven small diameter (1.5 m) open wells to tap seepage flow for irrigating dry season crops. Construction of the dam and open wells was completed before the monsoon of 2014 and the water was first made available for the season *Kharif* 2014. To facilitate irrigation, electric centrifugal pumps of 2Hp capacity were provided to the farmers with the agreement that pumps will be used in rotation among the identified group of users.

2.5.2. Timely transplanting of paddy

In general, paddy nurseries are prepared during the first week of July through to the first week of August, but this varies depending upon the onset of monsoon rains. Failure to receive sufficient rain will delay transplanting, and farmers may even abandon their paddy crop. During 2014, despite timely onset of monsoon, there was a prolonged dry spell which delayed the transplanting until the second week of August, providing an opportunity for participating farmers to evaluate the use of supplementary irrigation from check dam and wells. Since rice field preparation with supplemental irrigation was a new practice for most of the farmers, this needed participatory evaluation. The experiment included four treatments comprising three transplanting times (the fourth week of July, the first week of August and the second week of August) with supplemental irrigation, plus the farmers' practice with transplanting in the third week of August. Each treatment was replicated 3–6 times in a completely randomized design with individual fields comprising a block. Seeds of the hybrid rice variety Tez were provided to the farmers to remove variety as a source of variation. Paddy yield was recorded from the 19 participating farmers' fields and subjected to analysis of variance. The quantity of water applied in land preparation and supplemental irrigation was obtained by multiplying the discharge of the delivery pipe and the time of water application noted down in the daily diary of the farmers.

2.5.3. Direct sown rice and planting a second crop

Initial dry spell in 2014 represented the classical case of water shortages for transplanting and demonstrated the need for an alternative practice of rice establishment. To overcome this kind of situation the effectiveness of DSR was tested. The practice of DSR with sowing in the fourth week of July (DSR_t) and delayed sowing in the second week of August (DSR_d) was compared with farmers' practice viz. timely transplanting in the first week of August (TR_t) and delayed transplanting in the third week of August (TR_d). There were two replicates of each treatment, with each farmer hosting a single replicate of a treatment. The variety 'Tez' was directly sown using the seed drill with a seed rate of 60 kg per hectare in eight fields.

After the harvest of paddy, fields were sown to bottle gourd (timely rice) or peas (delayed crops). Bottle gourd was planted at a plant to plant spacing of 0.5 m and the inter-row spacing was 2.5 m. Each row was irrigated using a 40 cm wide-furrow that covered the root zone of the plants. Garden pea was planted at a plant to plant spacing of 15 cm and a row to row distance of 30 cm which was irrigated using the check basin method. Records on the volume of water applied were used in the estimation of water productivity of the crops. The amount of residual water following rice was reckoned from the simulated soil water balance on the date of the paddy harvest. The yields obtained under different cropping sequences were compared using a common index 'Paddy equivalent yield (PEY)'. Results were statistically evaluated using ANOVA.

2.5.4. Supplemental irrigation during dry spells

Normal onset of monsoon in 2015 helped the farmers in timely completion of paddy transplanting (the third week of July). However, there was a dry spell during the fourth week of July to the first week of September and farmers considered that supplemental irrigations were essential. This provided the opportunity for researchers to evaluate the use of 'rescue irrigation' in transplanted rice. Farmers having access to open wells applied 10–12 irrigations (average 50–55 mm/irrigation), but ponding of water was not possible due to the limited water storage in the wells. The farmers, who used water from the check dam, were able to provide 4–6 irrigations with ponding for at least 2 days following every irrigation event. Treatments included 10–12 supplemental irrigations (T1), 4–6 supplemental irrigations (T2) and completely rainfed crop as control (C). Data were collected from five farmers' fields where the same variety (*Tez*) was cultivated and transplanting was completed in the third week of July. To showcase the impact of supplemental irrigations on paddy yields, comparisons were made with the yields obtained under completely rainfed conditions of the midlands.

2.5.5. Vegetable crops as an alternative to paddy

As indicated by the modelling exercise, the moisture availability in the uplands and the midlands for the *Rabi* season is so meagre that cultivation of vegetable is not possible without irrigation. Given the climate-related risks involved in paddy, farmers agreed to give up their low yielding paddy crop during the *Kharif* season and opt for vegetable crops with better cultivation practices. The aim here was to convert the most risky paddy to a safer, more profitable alternative.

Keeping in view the success of drip irrigation system at research farms (Mali, Jha, Singh, & Meena, 2017), the drip irrigation with plastic mulch was evaluated in 20 farmers' fields covering 1.6 ha area. Irrigations were scheduled in accordance with the crop water requirements estimated using the approach suggested by Allen et al., 1998. Tribal farmers always had an inclination for mixed cropping. This gave us an opportunity to evaluate the performance of different mix cropping systems under drip irrigation (Table 1). The research team made available the seeds of improved vegetable varieties of selected vegetables for cultivation under drip irrigation. Adoption of different improved vegetable cultivation practices led to following treatments in three major vegetable crops viz. bottle gourd, sponge gourd and cow pea.

Table 1. Treatments on improved vegetable cultivation practices evaluated in farmers' fields.

Bottle gourd
1. Early Rabi season cultivation in poly tunnel with covering the seed with transparent polythene
2. Early summer season cultivation in poly tunnel and plastic mulch
3. Pro-tray nursery and raised bed cultivation with plastic mulch
4. Traditional practice (furrow cultivation)
Sponge gourd
1. Raised bed with plastic mulch
2. Traditional practice
Cow pea
1. Nursery raising in pro-tray and transplanting on mulched raised beds
2. Direct sowing on mulched raised bed
3. Direct sowing in furrow (traditional practice)

3. Results and discussion

3.1. Current socio-economic status and problem identification of tribal families

The distribution of land-use and the annual income from agricultural and non-agricultural activities is summarized in Table 2. The average arable landholding was 0.58 ha, of which only 28% was the lowland favoured for rice. *Kharif*-season paddy was cultivated on all lowlands, but it was grown on only 57% of midland and 52% of arable unbunded upland (Table 2). So, around half of the arable midland and upland was either leased out or lay fallow in the Kharif, despite this being the main cropping season. A significant part of total family income (average 43%) is derived from migrated daily wage labour. As identified by the farmers, lack of irrigation infrastructure and poor technological know-how were major drivers for migration to the nearby cities.

3.2. Rainfall

The annual rainfall for the study period ranged from 963 to 1188 mm (Table 3), while the long-term average annual rainfall of the study area was 1418 mm. Rainfall in all the study years was below average, with 2014 recording initial dry spell, whereas 2015 witnessed a severe within-season dry spell (Figure 2).

3.3. Soil moisture availability and crop-related decisions

The soil water balance model was run for the study period (2013–2016). Deep drainage rate was varied over a range from 1 –to 9 mm day^{-1}; however, a rate of 3.0 mm day^{-1} showed of the best agreement between responses of farmers (dates of nursery sowing, transplanting, sense on delayed or

Table 2. Seasonal distribution of cultivated land (ha) and income pattern of tribal farm families[a].

		Kharif			Rabi			Summer		
Landscape	Arable land (ha)	Self-cultivated	Leased out[b]	Fallow	Self-cultivated	Leased out	Fallow	Self-cultivated	Leased out	Fallow
Lowland	0.16	0.16	0.00	0.00	0.16	0.00	0.00	0.11	0.05	0.00
Midland	0.19	0.11	0.04	0.04	0.06	0.03	0.10	0.04	0.02	0.13
Upland	0.23	0.12	0.07	0.04	0.06	0.00	0.17	0.03	0.00	0.20
Total	0.58	0.39	0.11	0.08	0.28	0.03	0.27	0.18	0.07	0.33
Annual income by source (₹.)		Agriculture 35,380			Non-agriculture 26,723			Total 62,103 (43% non-farm)		

[a]average of all the surveyed families ($n = 47$).
[b]Leased out to non-tribal farmers.

timely transplant and overall rating of the year) and model predictions across the four years. Model results showed that soil water content in the midlands was above field capacity for the longer part of the year (July to Nov) (Figure 2(a)). During 2014, ponding duration was 102 days, while the prolonged dry spell in 2015 reduced the ponding duration to only 42 days under midland conditions (Table 4). More than 90-day ponding was deemed necessary for good yields of medium-duration rice (Cornish, Karmakar, et al., 2015).

Table 3. Rainfall during the study period and long-term average (mm).

Rainfall (mm)	2013	2014	2015	2016	Long-term
Jun–Sept (Monsoon)	710	856	827	858	1150
May (Pre-monsoon)	24	35	67	58	54
Oct (Post monsoon)	244	4	56	20	63
Annual	1188	1005	1101	963	1418

The modelling results highlighted that paddy cultivation bears considerable risk in the midlands and farmers need technological support not only for the cultivation of the second and third crop but also for the *Kharif* paddy. Midlands exhibited substantial soil moisture availability at the end of the paddy season (≃190 mm) requiring only supplementary irrigations for the *Rabi* season crops and full irrigation for summer crops unless they are in lowlands and benefit from seepage inflow. The simulated soil water balance for uplands showed that between about January and late June the soil water content is below wilting point (Figure 2(b)) and cultivation of crops is not possible without irrigation. Arable uplands get an average of 132 days of plant available soil water during the *Kharif* season (Table 4), which is more than enough for a short-duration field crop or even vegetables. Modelling showed that the monsoon rainfall is sufficient even in dry years for a variety of rainfed crops to be grown in uplands with appropriate management.

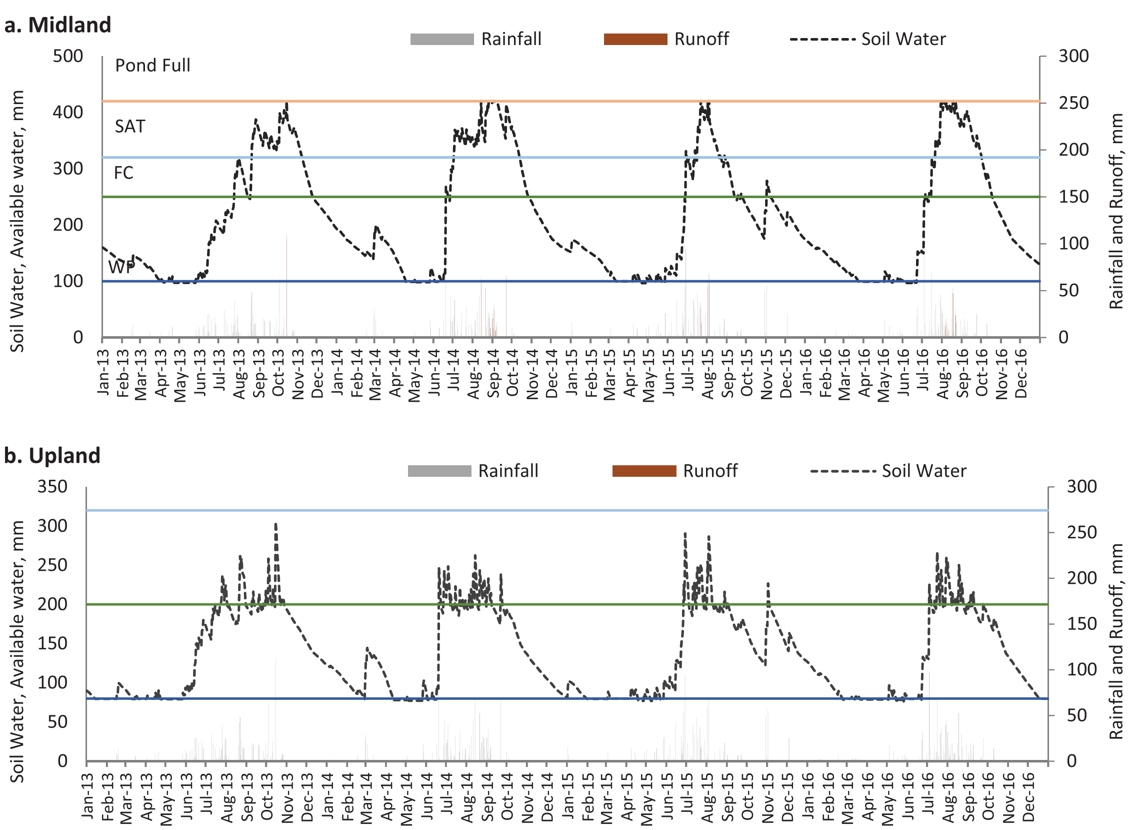

Figure 2. Simulated soil moisture dynamics in the midlands (a) and uplands (b) of the eastern plateau region.

Table 4. Modelled water balance components for the rice-fallow systems in midland areas.

	Midland					Upland				
Year	2013	2014	2015	2016	Mean	2013	2014	2015	2016	Mean
Annual ET, mm	536	650	676	593	614	477	565	598	529	542
Rice ET, mm	259	268	335	351	303	259	348	341	350	324
Predicted runoff, mm	106	160	148	123	134	0	0	0	0	0
Predicted drainage, mm	356	376	254	292	319	521	622	458	482	521
Ponding duration, days	79	102	42	73	74	0	0	0	0	0
Duration of soil water availability for plant, days	194	195	190	138	179	177	134	161	116	147
Available water at rice maturity, mm	230	156	208	181	194	142	109	162	116	132

3.4. Impact of planned interventions

3.4.1 Timeliness of paddy transplanting

Despite initial dry spell in 2014, irrigations from the check dams and open wells made it possible to transplant the paddy on time in 2014. The yield of the timely transplanted paddy (the first week of August) was 7.28 t ha^{-1} (Table 5). Delayed transplanting (the second or the third week of August) reduced the paddy yields by 41 and 77%, respectively. In the present study, 267, 229, and 172 mm of water were used in land preparation activities for transplantation in the fourth week of July and the first and second weeks of August, respectively. High yields with the two earliest dates of transplanting reveal the benefits of supplemental irrigation to ensure early transplanting in the event of initial dry spell. Interpretation of the results in interactions with farmers highlighted that staggered nursery raising (multiple times in a relay) can ensure healthy seedling at the time of transplanting under delayed monsoon scenario. Adoption of DSR instead of transplanted paddy would avoid the excessive water required for puddling and land preparation.

3.4.2 Direct-seeded rice (DSR) and succeeding crop

Duration of transplanted crops was about three weeks longer than with DSR (Table 6). Early harvest of paddy under DSR$_t$ and DSR$_d$ provided an opportunity for the growth of the early *Rabi* season bottle gourd and mid-season Rabi garden pea. Late harvests in the case of TR$_t$ and TR$_d$ provided for main-season bottle gourd and late-season garden pea as *Rabi* crops. In the best treatment (DSR$_t$) the paddy yield was 6.42 t ha^{-1} (Table 6). Fields with delayed transplanting recorded the lowest average paddy yield (2.16 t ha^{-1}). The yield of the succeeding *Rabi* crops (bottle gourd and garden pea) was significantly higher where early cultivation was possible under DSR$_t$ and TR$_t$ treatments (Table 6). Cultivation of garden pea after the harvest of timely sown rice (DSR$_t$) resulted in higher yield (6.23 t ha^{-1}), and consequently the highest PEY among all the treatments.

Table 5. Effect of transplanting dates on paddy yield during 2014.

Date of transplanting	Number of fields	Water for land preparation (mm)	Yield (t ha^{-1})
The fourth week of July 2014	5	267	6.80 ± 1.61^{a*}
The first week of August 2014	3	229	7.28 ± 2.19^{a}
The second week of August 2014	6	172	4.32 ± 1.08^{b}
The third week of August 2014	5	0	1.61 ± 0.64^{c}

*difference in values with same superscript is statistically insignificant ($p < 0.05$).

The model estimated residual soil moisture of 233 and 195 mm at the time planting of the second crop supported the establishment and growth of the second crop after timely and late DSR, respectively. The modelling showed that rainfed crops can be safely grown in the Kharif for at least 140–150 days, even in dry years. So rainfed Kharif cropping is possible, but not rainfed *Rabi* cropping. The Water Use Efficiency (WUE) for DSR$_t$ + bottle gourd sequence was 42.0 kg ha^{-1} mm^{-1} which was higher than the TR$_t$ + bottle gourd mainly because of higher yields of DSR and bottle gourd crops.

3.4.3 Impact of supplemental irrigation

Application of supplemental irrigation during dry spells had a significant impact on paddy yields (Table 7). Despite good rains in June and July (523 mm) which triggered transplanting, rainfall during the rest of the growing season was only 234 mm (1st August to 17th October). The prolonged dry spell meant the requirement for standing water in transplanted paddy was not met. The yields obtained with 12, 10, and 6 irrigations were not significantly different (average 6.23 t ha^{-1}), but they were significantly greater than yields under treatment with 4 irrigations (289 mm). This not only demonstrated the value of supplementary irrigation with transplanted rice in a dry year but also showed the propensity for farmers to over-irrigate and waste the water. Six irrigations (≃360 mm) were sufficient for maximum paddy yields. The water productivity for the best treatment (10 irrigations) was 7.01 kg ha^{-1} mm^{-1} which slightly exceeded WUE values observed with 12 irrigations.

Earlier studies have shown that transplanted rice yields decline if soil water drops below saturation (Bouman & Tuong, 2001) and that the period around, anthesis is the

Table 6. Comparative performance of different cropping system under midland conditions.

Planting	Duration of rice (week/month)	Paddy yield (t ha^{-1})	Vegetable crop grown after rice	Duration of vegetable crop (week/month)	Vegetable yield (t ha^{-1})	Total paddy equivalent yield (PEY) (t ha^{-1})	Water productivity, PEY^/TWU† (kg ha^{-1} mm^{-1})
DSRt	4th/Jul to 1st/Nov	6.42 ± 1.96a	Bottle gourd	3rd/Nov to 2nd/Apr	11.43 ± 2.16	20.29a	42.0
DSRd	2nd/Aug to 3rd/Nov	4.31 ± 1.02b	Garden pea	3rd/ Nov to 2nd/Feb	6.23 ± 1.31	14.10b	32.3
TRt	1st/Aug to 4th/Nov	4.48 ± 1.16b	Bottle gourd	3rd/Dec to 2nd/May	13.63 ± 2.87	16.16b	33.5
TRd	3rd/Aug to 2nd/Dec	2.16 ± 0.47c	Garden pea	2nd/Dec to 2nd/March	5.83 ± 0.94	9.06c	17.5

^PEY of the cropping sequence, †TWU = Total Water Use for the cropping sequence.

Table 7. Yield and water productivity of rice under different irrigation scenario during 2015.

Water source	Number of irrigations	Depth of water applied(mm)	PASW† for the growing period, mm	Average Yield (t ha^{-1})	Crop Water productivity (kg ha^{-1} mm^{-1})
Open well	12	485	959	$6.38 \pm 1.83^{a*}$	6.65
Open well	10	413	886	6.21 ± 2.01^{a}	7.01
Check dam	6	360	833	6.10 ± 1.45^{a}	3.72
Check Dam	4	289	762	3.98 ± 1.03^{b}	5.22
Rainfed	no irrigation	0	473	0.64 ± 0.22^{b}	1.35

*difference in values with same superscript is statistically insignificant ($p < 0.05$). †Plant available soil water as estimated from the simulated soil water balance.

most sensitive to rainfall deficits (Garrity & O'Toole, 1995). Maintaining soil water at saturation is a major challenge for areas with variable rainfall, like the Plateau region, especially in midlands that do not benefit from seepage inflows. For rice on midlands that are susceptible to 'drought', it is important that farmers adopt cultural techniques that do not require ponding. During the period of deficit rainfall, arranging logistics for frequent irrigation was a major challenge for the farmers which was overcome through building check dam and open wells. These findings have implications forming appropriate policies with a special focus on water resource development in the plateau region to support agriculture during dry spells.

3.4.4 Impact of better vegetable cultivation practices

Research with vegetables focused on extension processes and adoption of new technologies, rather than the development of technology *per se*. This co-learning experience aimed to build technical knowledge, skills and challenge farmers' perceptions about the value of certain land and self-perceptions as farmers.

3.4.4.1. Impact of micro-irrigation. Two farmers took the opportunity in 2014–2015 to evaluate intensive vegetable production on land that was originally used for upland paddy, which had failed on many occasions. Irrigation water was sourced from the open well. From a land of 0.10 ha area, farmer-1 earned ₹ 46,890 by mixed cropping of vegetables in two seasons (Table 8). Farmer-2 earned ₹ 82,090 from his land of 0.50 ha area. This is a substantial income when it is considered that average family income from all sources in this village is only ₹ 62,103. These results indicated the feasibility of increasing the profitability of agriculture in uplands with vegetable cultivation using drip irrigation. Compared to traditional furrow systems, drip systems ensured optimum irrigation even during years with limited water supplies highlighting that vegetables can be successfully grown as a better alternative to paddy in uplands where traditional paddy crop fails on many occasions. The results confirm drip irrigation as a better option to build response capacity of the agriculture to climate change (FAO, 2012).

3.4.4.2. Impact of improved cultivation practices. The details of the technological options evaluated and the responses of bottle gourd, sponge gourd and cow pea to these technologies are presented in Table 9. Early sowing of the bottle gourd in November and covering it with transparent polythene sheet and poly-tunnel cultivation resulted in maximum yield (3.18 t ha^{-1}) and gross income (₹ 38,400 per ha). Transplanted sponge gourd on mulched raised bed resulted in maximum yield (8.15 t ha^{-1}) and gross income (₹ 85,000 per ha) which was 27 and 12% higher than the yield and income obtained under the direct sowing method. Increase in yield under transplanted crop may be attributed to optimum and uniform plant population in the field and considerable reduction in the incidence of downy mildew. Cultivation of cowpea on plastic mulched raised beds resulted in a significant ($p < 0.05$) increase in the yield over traditional practice during both the seasons. In the case of summer cow pea, the increase in yield and water productivity was remarkably higher (76.24% and 67.84%, respectively) than that of traditional practice.

Although some crops required irrigation at the initial stage of crop establishment, the increase in yield and gross income was convincing enough for the farmers for adoption of improved practices. The crop management practices like mulching with plastic helped in conserving soil moisture. The problem of excessive soil moisture due to heavy rain can be overcome by growing crops on raised beds, as reported by La Pena and Hughes (2007). The best treatments required less water and showcased huge potential to overcome the

Table 8. Crop yields and income from drip-irrigated cropping sequences.

Total Area	Crop Season	Cropping sequence	Growing Period	Crop	Yield (t ha^{-1})	Income (₹)	Gross income, ₹
Farmer 1	*Kharif*	sponge gourd + cowpea	May–Sept 2014	Sponge Guard	10.38	18,690	46,890
Area: 0.10 ha				Cowpea	4.79	7670	
		indeterminate tomato +	Oct 2014–Feb 2015	Tomato	7.31	8780	
	Rabi	capsicum + cowpea		Capsicum	3.65	6950	
				Cowpea	2.66	4800	
Farmer 2	*Kharif*	cowpea + cucumber	July–Oct 2014	Cowpea	2.43	4680	82,090
Area: 0.50 ha				Cucumber	5.58	10,050	
		bitter gourd	July–Oct 2014	Bitter gourd	11.36	12,500	
		cowpea + sponge gourd	Jul–Oct 2014	Cowpea	2.86	6890	
				Sponge gourd	5.92	18,650	
	Late *Kharif* to mid *Rabi*	chilli	Aug–Dec 2014	Chilli	3.86	12,560	
	Rabi	cabbage	Oct 2014–Jan 2015	Cabbage	6.83	4260	
		brinjal	Oct 2014–Feb 2015	Brinjal	13.4	12,500	

Table 9. Yield and WUE and income of vegetable crops as affected by cultivation practices.

Cultivation practice	Number of farmers	Duration of crop in field	Average Yield (t ha^{-1})	Irrigation water productivity (kg ha-mm^{-1})	Gross Income (₹ ha^{-1})
Bottle gourd					
Early summer season cultivation by covering the seed with transparent polythene and poly-tunnel cultivation	3	Nov–Mar	3.18^{a}	47.3	38,400
Early summer season cultivation in poly-tunnel and plastic mulch	3	Dec–Mar	2.62^{b}	44.1	31,400
Pro-tray nursery and raised bed cultivation with plastic mulch	8	Feb–May	1.81^{c}	36.3	16,000
Traditional practice (furrow cultivation)	19	Feb–May	1.43^{c}	24.8	12,600
Sponge gourd					
Nursery raising in pro-tray and transplanting on mulched raised beds	4	Jul–Oct	8.15^{a}	23.62	85,000
Direct sowing on mulched raised bed	3	Jul–Sept	6.40^{b}	17.39	76,000
Direct sowing in furrow (traditional practice)	8	Aug–Oct	4.18^{c}	14.17	59,500
Cow pea					
Raised bed cultivation with plastic mulch	3	Jul–Sept	7.38^{a}	26.51	81,666
Traditional practice	11	Jul–Oct	5.61^{b}	16.34	62,300
Raised bed with plastic mulch	2	Feb–May	4.60^{b}	12.32	38,000
Traditional practice	8	Feb–Apr	2.61^{c}	7.34	18,600

*difference in values with same superscript is statistically insignificant ($p < 0.05$).

climate-related irregularities due to delayed transplanting or sowing of *Kharif* crops and making efficient use of limited water supplies.

3.5. Post-project analysis and learnings on climate proofing

A post-project village-level survey (2016) revealed a substantial increase in the area under vegetables in the *Kharif*, *Rabi* and summer season, with a gross cropped area, increasing from 449 ha in 2013 to 532 ha in 2015. With increased irrigation from check dams and open wells, the area under *Kharif* vegetables increased from 73 ha in 2013to 83 ha in 2015 (16% increase). During the *Rabi* and summer season, the area under vegetable crops increased by 31 and 39%, respectively. The area under *Kharif* paddy did not vary significantly from 2013 to 2015, suggesting that farmers increased the scale of agricultural activity rather than simply substitute one enterprise for another.

Many researchers (Gurr, Wratten, & Luna, 2003; Krupinsky, Bailey, McMullen, Gossen, & Turkington, 2002; Lin, 2011) have stressed on crop diversification as a better management strategy to avert or escape the adversities of climate and is a high priority adaptation measure in both irrigated and non-irrigated areas. In this study, access to irrigation water provided an opportunity for crop diversification, wherein farmers could grow 12 types of vegetables as against 2–3 types before the inception of the project. The study highlighted the extent of crop diversification, increased income levels and improved understanding on better options that lead to climate proofing of agriculture in the eastern plateau region. Increased income enhanced the capacity of the farmers to cope up with the adversities in climate by enabling dynamic adoption of practices to such changes. With the introduction of better technologies and providing access to irrigation water, areas that remained fallow prior to the project had largely given way to more profitable vegetable crops. A small intervention on the provision of irrigation pump to small and marginal farmer led to climate proofing of the crops in the events of dry spells and delayed rainfall situations, consequently increasing the area under summer vegetable cultivation.

A large majority of the farm families agreed that the increase in income was because of increased agricultural productivity after interventions. The change was due to the improvement in the productivity of paddy and *Rabi* season crops. The area brought under cultivation during the *Rabi* season was the major reason cited for the improved incomes. This highlights the need for appropriate policy interventions to increase the access to irrigation water which can be transformed into improved incomes and better livelihoods to the tribal farmers of the region. Especially for villages which face water shortages due to climatic variations, this study has successfully evaluated the efficacy of management practices viz. (i) rainfed DSR, (ii) Rabi cropping on residual water, (iii) opportunities to convert poor midlands and uplands from paddy to vegetables, and (iv) wells in midlands to capture shallow groundwater for supplementary irrigation of Rabi crops.

3.6. Evaluation of participatory approach

The participatory approach paved the way for farm innovations by the farmers. The research team was able to evaluate the water productivity and profitability of technological interventions in farmer's fields. These innovations led to mutual learning and knowledge sharing between institute and farmers. Our learnings on water productivity of different rice–vegetable production systems evaluated under this programme was possible due to the adoption of the participatory approach. The participatory approach enabled the farmers to link with the research institutions. This linking has facilitated seed purchase from the research institutes which was very limited before the project. Apart from the technological implementation there has been a lot of capacity building of the farmers on making beneficial use of fallow lands. Women are empowered to make decisions regarding farming activities. The mutual trust built with the tribal farmers has enabled the research institute to take up further research activities in their fields beyond the project period. Our experience indicated that the involvement of local self-government institutions (e.g. village panchayat, etc.) during the entire process of decision making could have improved the extent of participation.

4. Conclusions and policy implications

Rice-fallow of the East Indian Plateau leads to widespread poverty and insecure livelihood. With variable rainfall and apparently more frequent dry spells, agriculture bears considerable climate risk. Farmers' response to this risk is governed by attitudes and the nature of the technology. Risk avoidance becomes an internal household strategy and many households persist with familiar crops and known technology (and yields) (Dorjee, Broca, & Pingali, 2003). Risk aversion in a variable climate leads to low inputs in order to minimize losses in poor seasons, but this limits the capacity to respond in good seasons. The participatory action research approach used in the project (Section 2.5) provided for participants to evaluate and adopt potential new technology as well as new beliefs and attitudes, for example to the risk and the value of particular classes of land.

Participants learned how to increase productivity and reduce the climate risks involved in paddy production by using supplementary water for irrigation or, in its absence, by direct-seeding rice (DSR) without the need for puddling and ponding. Farmers evaluated and readily adopted better management practices of *Rabi* crops (mainly vegetables) and substantially increased the area grown. The research allowed farmers to extend vegetable cropping to suitable uplands. Some farmers introduced more profitable and less risky alternatives to transplanted rice in poor midlands.

Whilst partial or full irrigation is necessary for some of these developments, the research shows that relatively small local water resources can be developed and the water used strategically to manage risk and increase production. Large-scale irrigation schemes and even full watershed development are not pre-requisites for development, as research elsewhere in the region has also shown (Cornish, Karmakar, et al., 2015; Cornish, Choudhury, et al., 2015; Srivastava et al., 2009). The present government initiatives are making it possible for famers to develop their local water resources. These include the Government of Jharkhand initiative to build Birsa Munda Pucca Check Dams in Jharkhand and the MGNREGA scheme in which open wells and ponds may be constructed.

The results offer promising options to reduce the risks and intensify the rice-fallow ecosystems of the Eastern Plateau and Hill region and to increase household income. Following the withdrawal of the project, farmers continued to innovate with, for example, by cultivating new vegetable crops without any intervention from the project team. This indicates a sustained positive change in farmers' attitudes arising from the participatory approach.

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