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Article:

Shah, Hassnain, Siderius, Christian and Hellegers, Petra (2020) Cost and effectiveness of in-season strategies for coping with weather variability in Pakistan's agriculture. Agricultural Systems, 178. ISSN 0308-521X

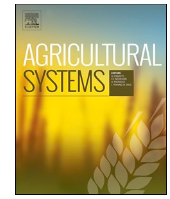
https://doi.org/10.1016/j.agsy.2019.102746

Agricultural Systems 178 (2020) 102746

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy



Cost and effectiveness of in-season strategies for coping with weather variability in Pakistan's agriculture

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ARTICLE INFO

Keywords:
Coping
Crop stages
Weather variability
Critical moments
Compounded impacts

ABSTRACT

Crops are vulnerable to weather hazards throughout the growth season, with periods of heightened risk described as critical moments. Farmers have a number of ex-ante and in-season options for coping with these events, and ex-post adjustments to farm-household portfolios to further limit the impact on livelihoods if these options fail. Adaptation-related research has focussed mainly on ex-ante or ex-post coping strategies, because in-season approaches tend to be seen as a given, meaning their cost effectiveness is ignored. Based on detailed survey data collected from 287 households in four of the main cropping systems in Pakistan, this study evaluates the impact pathways of hazards and the cost effectiveness of in-season coping strategies. Yield losses varied by 10–30% for 43% of the cases and by 31–50% for another 39%, with the most severe losses caused by the compounding effect of two hazards in one crop season or if both crops in a multi-crop rotation were affected simultaneously. In-season coping options were mostly restricted to the early crop stages and constrained by a short window of time for the response. The application of in-season coping strategies resulted in a yield recovery of 40–95%, with an additional cost of 4–34% of the value of recovered yield. The major critical moments identified were the harvest season, with farming often affected by un-seasonal precipitation, and the germination stage, with an additional high risk for low temperatures at high altitude. A better understanding of the differentiated risks and effectiveness of in-season coping strategies could support the promotion of sustainable crop production in similar agro-ecologies. Moreover, the effectiveness of present-day coping strategies, rather than the use of coping approaches itself, could signal a potential ability to adjust to future climate change.

1. Introduction

Crop production is an uncertain business, particularly for the poor (Clarke, 2016; Dercon, 2005). Any departure from optimum growing conditions, such as too much or too little rainfall, too high or too low temperatures, increased cloudiness or sudden wind or hailstorms, can affect crop yields in both rainfed and irrigated conditions (Bhatta and Aggarwal, 2016; Gobin, 2018; Hatfield et al., 2018; Hollinger and Angel, 2009). The timing of weather hazards is important; while strong winds might not matter during the development states of a crop, it can lodge a full-grown crop close to harvesting, leading to severe yield loss. Similarly, a mature crop with a well-developed root system might cope with a period of drought that would wilt a small seedling. Critical moments (CMs) are periods of heightened risk within the production season, when crops are more sensitive to certain weather conditions, whether biophysically or due to management or operational constraints (Shah et al., 2019).

Farmers have developed a variety of ways to cope with weather variability. Three generalised types of coping approach can be distinguished; ex-ante (e.g., adjustments in sowing time, leaving land fallow when rains have been insufficient (Siderius et al., 2016; Siderius et al., 2014), or choice of crop or crop diversification in the crop planning stage (Roesch-McNally et al., 2018)), in-season (e.g., adding or withholding inputs such as irrigation or fertilizer, or delaying activities such as harvesting during the crop growth season (Mishra et al., 2013; Rurinda et al., 2013)) and ex-post (e.g., taking loans or selling assets after harvest (Berman et al., 2015; Landicho et al., 2015; Nazir et al., 2018)). Ex-ante and in-season options are mostly performed at the field-scale, while ex-post post options relate to the household level and are often a last resort if ex-ante and in-season options have failed.

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https://doi.org/10.1016/j.agsy.2019.102746
Received 31 May 2019; Received in revised form 10 October 2019; Accepted 10 November 2019

In season, farmers undertake many intermediate steps to recover yield loss. These traditional risk-spreading and impact-mitigation strategies (Cooper et al., 2008), are often complex due to the need for rapid response and have uncertain trade-offs between expected yield recovery and the extra costs involved. The in-season possibilities for avoiding or responding to damage vary; for example, shifting to another crop is often difficult after a crop has been planned (Schlenker and Roberts, 2006). Even if the option to switch or replant is available, the mechanisms to support this flexibility are not developed enough in many countries, and new or additional seed or seedlings or other resources (labour, machinery) may be unavailable within the given time to respond. In multi-cropping systems, farmers are further limited; any change in planting date might affect the subsequent crop growing season or conflict with crop management practices (Ortiz-Monasterio et al., 1994).

There is less written in the literature on in-season coping than on other aspects of climate risk management, such as utilising savings or credit, or selling assets (as in Below et al., 2012; Birkmann, 2011; Pandey et al., 2017). Household survey-based impact studies mainly relate coping and adaptation strategies to household characteristics, livelihood assets and market access (Berman et al., 2015; Landicho et al., 2015; Nazir et al., 2018). The type of coping strategies emphasised also has an epistemological explanation; biophysical impacts and field-scale ex-ante coping strategies are more frequently highlighted in climate impact studies relying on models, in which the exploration of the potential of seasonal weather forecasting is an expanding research field (Asseng et al., 2016; Ramírez-Rodrigues et al., 2016). Despite these insights, it often remains uncertain to what extent forecasts benefits farmers (Meinke and Stone, 2005; Roudier et al., 2014). Workability issues (Iizumi and Ramankutty, 2015) and conflicts of time management in cropping systems (as in Tomasek et al., 2017) and other pre-requisites of beneficial forecast use (Hansen, 2002) are less commonly described. Details on when farmers are vulnerable, their options for coping and the effectiveness of coping strategies for specific CMs is generally lacking.

Unusual weather during a particular cropping season imposes a management cost or yield loss (Moore and Lobell, 2014). The cost-effectiveness of coping is a factor of the yield recovered and the extra costs a farmer will incur to achieve this recovery. Climate research is mostly focused on adaptation (the ex-ante adjustments) or ex-post coping, making empirical evidence on the cost and effectiveness of in-season coping - those tactical risk management strategies during the crop season to cope with weather hazards - scarce. Though farmers respond to within-season weather anomalies, little has been reported about the effectiveness of different coping and yield mitigation strategies in terms of their costs, potential for yield recovery and the possible trade-offs and synergies.

The aim of this study is therefore to assess; i. farmers' CMs, when they feel most at risk; ii. which coping strategies they apply; iii. the costs of these strategies and iv. the effectiveness of the coping strategy, in terms of the amount of yield loss recovered. We will also address the limitations on using coping strategies, including the non-availability of inputs or management issues such as conflicts in the allocation of labour, land or machinery. We mainly focus on in-season coping strategies and their cost and effectiveness, while also taking into account ex-ante strategies for dealing with weather hazards close to the start of the cropping season. A distinction is made between coping and adaptation, with coping considered to be a response to present-day hazards within given conditions and adaptation considered to include autonomous or planned changes in anticipation of, or in response to, long-term and gradual change (Agrawal, 2008; Birkmann, 2011). For example, a one-off or occasional choice to change to a drought-tolerant variety due to un-seasonal weather conditions is captured as coping, while a permanent shift to a late-sowing variety in response to the changing weather conditions over the past few years is considered an adaptation. In this study, we will only look at those approaches considered to be coping strategies for in-season hazards.

A purely crop-based analysis obscures the complexity of the multi-crop rotations dominating Pakistan's agriculture. In an agricultural context, compounding effects can either be multiple hazards leading to a more severe impact, or a single hazard impacting multiple crops in overlapping crop rotations, leading to a more severe impact overall. In addition, cascading effects can occur, whereby a single event can lead to reactions and subsequent events, cascading risk in an interconnected system, leading to potentially much larger impacts (Pescaroli and Alexander, 2016; Zaidi, 2018). A systems perspective will therefore be applied to the multi-crop context of Pakistan, which is an extension of current work in this field.

2. Material and methods

2.1. Approach

We investigated farmers' experiences in coping with the most common hazards, focussing on 2008–2018. Primary data were collected from 287 farm households in Pakistan. A cause-effect chain analysis, originally developed by Kaoru Ishikawa in 1943 (Kiprutto et al., 2015; Kuster et al., 2015), was adopted to explore the different levels of cause and effect, from hazard to yield loss, as well as the coping strategies and their effectiveness in terms of the amount of yield loss recovered. Cause-effect chain analyses are a useful tool for understanding the impact of weather hazards that lead to moderate impacts, in contrast with large-scale but less frequent disasters (Zaidi, 2018). Monitoring and the identification of causal factors provide opportunities to not only prepare for negative outcomes, but also to inform the types of coping intervention by location and time (Dilley and Boudreau, 2001).

Similar to Gobin (2018) and Schaap et al. (2011), the yield impacts of hazards and farmers' coping strategies were recorded for the most common hazards by crop stage. First, the impacts of individual hazards on crop yield were differentiated for the various loss-causing pathways, which enabled the identification of CMs. Second, the cost-effectiveness of each coping strategy was evaluated in terms of yield recovery and additional cost. Considering the importance of cropping systems (Nendel et al., 2018; Reidsma et al., 2015; Toffolini et al., 2017), the limitations on coping strategies and the conflicts between coping options were identified from a system perspective rather than for crops individually.

The individual respondents were asked to estimate their yield after each hazard i without coping strategies (Y_i, ton/ha), the yield with coping strategies applied ($Y_{c,i}$) and the yield in a season without any particular hazard (Y_{norm}). We estimated the yield loss without coping as:

$$Y_{loss} = Y_{norm} - Y_i \tag{1}$$

And the yield loss recovered with coping as:

$$Y_{rec,i} = Y_{c,i} - Y_i \tag{2}$$

The effectiveness of each coping option, EoC, was then estimated as a percentage of the yield loss recovered with using the following formula:

$$EoC_i = (Y_{rec,i}/Y_{loss,i})\,100 \tag{3}$$

The estimates are based on the responses from farmers involved in crop management practices and decision-making, mostly household heads. To ensure the accuracy of estimates, farmers' responses on Y_{norm} were also crosschecked with district level crop yield data and consensus developed during focus group discussions. Values that appeared extreme were validated through cross-questioning with respondents regarding their crop management practices, soil conditions and input use level during the field survey. The total cost for each coping strategy adopted by each individual farmer was measured as the sum of cost of all inputs involved in Pakistani rupees (Pak Rs.) per unit area.

Opportunity cost was included if their own resources (labour or input) were used. Contrary to the cost-effectiveness analysis used to identify the least costly intervention by comparing the alternatives (Bambha and Kim, 2004), we evaluated the effectiveness of the current coping option to each of the hazard pathways in terms of the yield loss recovered. The benefits of a coping strategies from the yield recovered with its adaption were also valued in Pak Rs. using the average farm gate prices reported by sample farmers at each site. To compare the cost with benefits, the cost as percentage of the value of the recovered yield was also estimated.

The costs and effectiveness of a coping strategy can vary by the loss-causing pathway. A few coping strategies required no additional costs, including late sowing to avoid unfavourable temperatures at the time of sowing. Still, such decisions were included as coping strategies rather than being considered standard variation in agricultural operations because they constituted a deliberate effort to recover yield that would otherwise have been lost.

A distinction was made between farmers who are not able to cope because they have no coping possibilities and those who decide not to cope, for example because of the high coping costs, short time to respond or the unavailability of required input. Limitations to coping were derived in a qualitative manner based on focus group discussions conducted at each study site and from informal discussions with the sample respondents. These discussions were also helpful in identifying the compounding effects of simultaneous events (for example, drought coupled with heat) or the occurrence of more than one hazard affecting crops grown in sequence during the different seasons of the year. In the context of the multi-crop system of Pakistan, cascading effects originated from the impact of a hazard on the first crop, triggering a coping response such as delayed harvesting, which then adversely affected the growing conditions, or complicated the management, of the next crop within an agricultural calendar. Conflicts caused by the overlap in harvesting one crop and planting the next, either in terms of limitations in land, labour or other operational issues, are specifically addressed.

2.2. Study area and sample design

We focused on agriculture in the Indus basin in Pakistan, where agriculture contributes 18.9% of the GDP and employs 42.3% of the labour force (GoP, 2018). The Indus basin covers most of Pakistan's agricultural regions and the combination of climate change, population growth, limited investments in agriculture and existing water stress in this region poses severe challenges to agriculture and threatens the food security of > 200 million people (Biemans et al., 2016; Malik, 2013; Parry et al., 2013; World Bank, 2011). A multi-stage stratified random sampling framework was employed to achieve a representative sample of farmers, using a climate- and physiography-based agro-ecological classification of the country as the basis for the stratification of the study population. Pakistan is divided into 10 main agro-ecological zones (Fig. 1), which are categorised based on climate, geography and cropping patterns (Pakistan Agricultural Research Council, 1980). Three of them were considered for the further selection of study sites, each representing a distinct but important cropping system, transecting from the high mountains to the rainfed mid-hills and irrigated plains (respectively, agro-ecological zones VII, V and IVa). In each zone, the dominant cropping system was selected based on its contribution to food security and similarity in growing season and crop management practices, and was considered one stratum. In the high mountains, there is a clear distinction between cropping systems in the main valleys and those higher up, so a fourth stratum was added to include cropping system at higher altitude in the mountains. Multiple cropping with two major crops is practiced in all four selected cropping systems. Wheat (*Triticum aestivum*) is grown as the staple food crop across all systems, with the second food crop grown mostly for commercial purposes. Wheat is grown in a multi-crop rotation system with potato (*Solanum tuberosum*) in the high mountains (HM), maize (*Zea mays*) in the mountain valleys (MV), groundnut (*Arachis hypogaea*) under the rainfed conditions in the mid-hills (MH) and rice (*Oryza sativa*) in the irrigated plains (IP). The characteristics of the strata are shown in Table 1.

For each cropping system, one study site comprising a cluster of 6–9 villages with the same cropping system was selected, located within a radius of 10 km to ease data collection. Pakistan is a highly diverse country in terms of geography, ecology and climate, with the three selected agro-ecologies being important ecologies within the country and across the Hindu-Kush-Himalayans and the Indo-Gangetic floodplain. The study sites represent particular climatic and farming conditions with distinct cropping systems that are not only important in terms of food security but have variable vulnerability to climate change due to site specific climatic features.

2.3. Sampling and data collection

Farm households in the four case study sites were selected with the help of local agriculture research and development experts. A total of 7–12 farm households were randomly selected from each village. Overall, 287 farmers, mostly household heads, were interviewed. The sample size and characteristics of the various respondents in the case study sites are shown in Table 2. A structured questionnaire was developed based on an a preliminary study (Groot et al., 2017). In the second round, the questionnaire was pretested by interviewing eight individual farmers and improved in light of field observations and insights from a focus group discussion with a group of farmers. In-house trained enumerators, who spoke the local dialect and were familiar with the use of local units and terminology, received two days of field training at each site, and were then responsible for guaranteeing the homogeneity and consistency of the questioning and the avoidance of repetition. In light of field observations during this training, minor modifications in the questionnaire were made by including site-specific events and practices. The formal survey was conducted through face-to-face interviews followed by the central cross-checking of each questionnaire on a daily basis.

Information was collected on socio-economic farm and household characteristics, land allocation, cropping pattern and crop management practices, farmer experiences of weather hazards and coping practices (see the full questionnaire in Appendix A). To select from the multitude of small and moderate hazards that might have affected farming over the past decade, we asked farmers about the most common hazards by crop stage. From these, we then asked about the frequency of occurrence and the opportunity for and cost effectiveness of coping strategies for the most recent hazard. At each crop stage, details of only one hazard (the most recent) were recorded and analysed for the two main crops grown in a year.

In total, 1834 responses regarding exposure to hazards at various crop stages over the agricultural calendar were recorded from the sample households (Table 3). The cost and effectiveness of the coping strategies were calculated when the farmer had actually adopted a coping option. Numbers presented in the results refer to the subset of farmers that reported using a particular type of coping for the most recent hazard. The cost and effectiveness of similar coping strategies reported by multiple farmers are presented as averages. For some of the hazards and impact pathways, few responses were available because very few farmers were exposed to, or adopted a coping strategy during, the last event; for example, the losses of potatoes near maturity due to freezing during a sudden decrease in temperature was reported by four farmers. In those cases, we highlight insights as examples.

3. Results

3.1. CMs, impacts and coping strategies

Hazard pathways vary by cropping system and crop stages at each of the study sites (Fig. 2). Moisture stress due to less precipitation from a

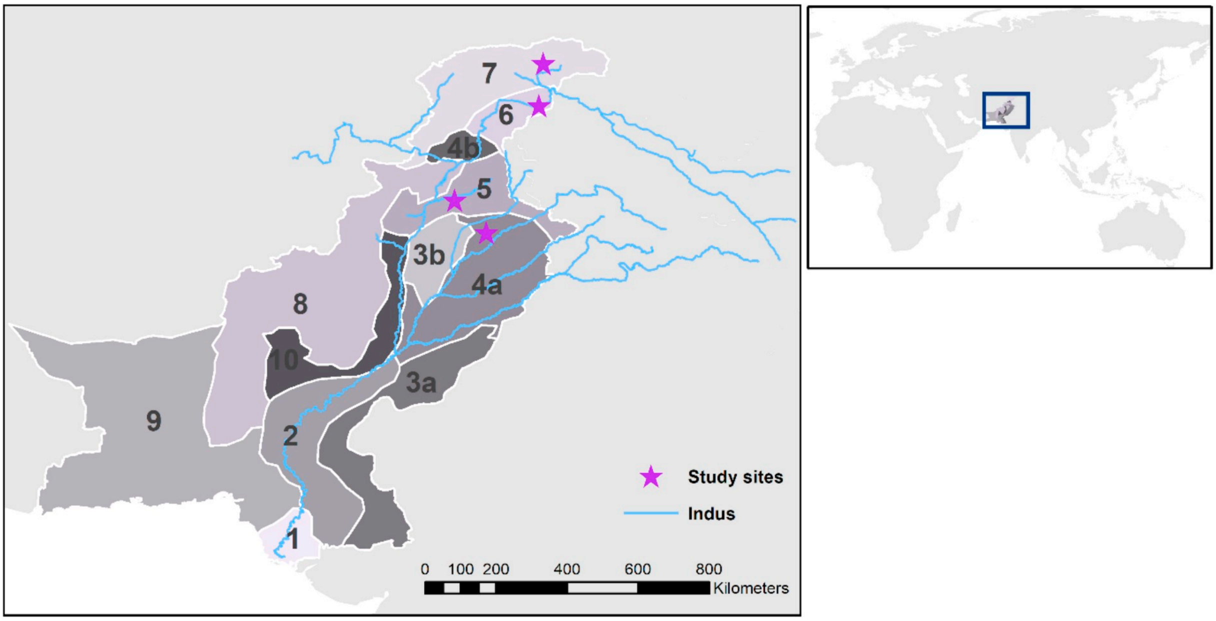

Fig. 1. Case study sites and agro-ecological zones within the Indus basin (source: Pakistan Agricultural Research Council, 1980).

Table 1
Characteristics of the four selected strata.

Sites/Description	Irrigated plains (IP)	Mid-hills (MH)	Mountains valleys (MV)	High mountains (HM)
Agro-ecological zones	Northern Irrigated Plains (IVa)	Barani Lands (V)	Northern Dry Mountains (VII)	Northern Dry Mountains (VII)
Location of study sites	Bhera-Bhulwal (Sargodha)	Talagang (Chakwal)	Jaglot valley (Gilgit)	Gojal valley (Upper Hunza)
Cropping system	Rice-wheat	Groundnut-wheat	Maize-wheat	Potato-wheat
Geographical regions	Low lands Plains	Mid hills Pothwar region	High lands Hindukush region	High lands Karakorum Range
Altitude range (m)	200	450–500	1600–1800	2500–3000
Crop season	2 crops - 2 seasons	2 crops - 2 seasons	2 crops - 2 seasons	2 crops - 1 season
Land parcel	Same in sequence	Separate in sequence	Same in sequence	Separate & parallel
Source of irrigation water	Canal + tube well	NA (rainfed)	Snow- and glacier meltwater	Glacier meltwater
Rainfall (mm)	~ 200–300	~ 250–350	~150–200[a]	~150–200[a]

[a] Snowfall (~1000 mm) in mountains is main source of water. Source: (Hashmi and Shafiullah, 2003; Pakistan Agricultural Research Council, 1980).

below average rainfall or no rainfall, issues of un-seasonal rains during early crop stages, and heat stress during grain formation were common in IP and MH. In MV and HM, sowing was often delayed due to low temperatures associated with reduced water supply and less snowmelt during early crop stages, while crops were also affected by moisture stress caused by damage to water supply channels during flash floods. Insect and disease infestation under hot and humid weather was common in MV and HM during the reproductive and grain formation stages. The harvesting season was affected by un-seasonal precipitation in all cropping systems. Comparatively, the pre-sowing and sowing crop stages were less exposed to hazards, in terms of the number of events

Table 3
Sample of farmer responses by crop stage.

Site/Crop stage	IP	MH	MV	HM	Overall
Pre-sowing	36	117	0	0	153
Sowing	82	39	17	21	159
Germination	122	123	8	89	342
Vegetative	54	93	38	78	263
Reproductive	89	80	87	51	307
Grain formation	113	99	72	66	350
Harvesting	74	102	35	49	260
Total	570	653	257	354	1834

Table 2
Sample size and characteristics of respondents.

Site/variables	IP		MH		MV		HM		Overall	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Education (years)	5.85	4.88	8.08	3.81	8.33	5.14	7.96	4.79	7.54	4.75
Age (years)	50.52	10.53	51.33	11.97	48.49	12.91	50.71	12.03	50.29	11.86
Farming experience (years)	24.96	9.72	24.25	9.83	23.04	10.23	25.54	10.04	24.46	9.94
Family size (#)	7.85	3.23	9.03	5.27	11.78	5.27	7.72	3.42	9.06	4.66
Operational land holding (ha)	5.39	5.13	3.89	3.29	0.78	0.61	0.52	0.36	2.68	3.71
Sample size (#)	73		73		69		72		287	
Sample size (%)	25.4		25.4		24.0		25.1		100	

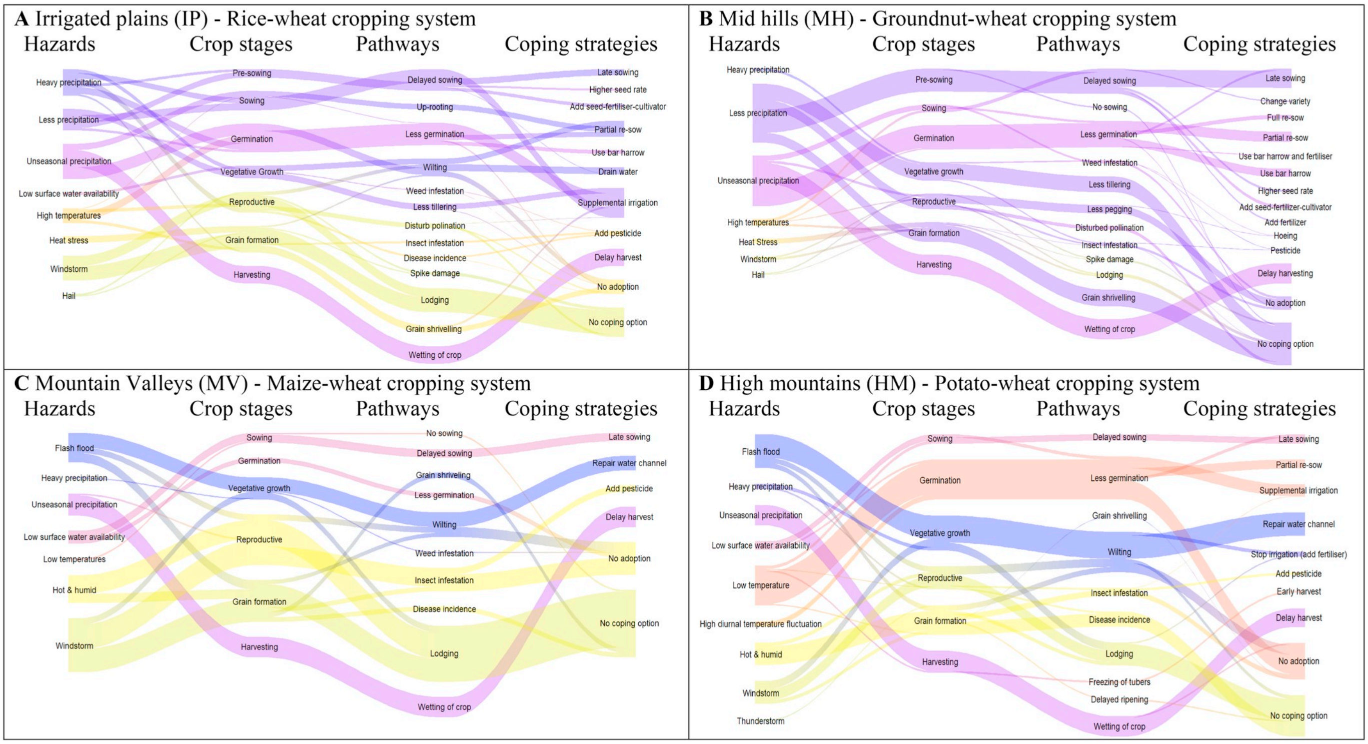

Fig. 2. Sankey diagrams of the cause and effect pathways by crop stage. A. IP, from 570 responses. B. MH, from 653 responses. C. MV, from 257 responses. D. HM, from 354 responses. The width of the pathway is based on the (relative) number of responses.

reported during these phases (150–160), than the germination, reproductive and grain-formation stages (300–360 hazards), when considering both crops grown within the agricultural calendar.

The frequency of occurrence of different hazards for the individual crop stages ranged from once in five years to once in two years, with most occurring once every three to four years, implying a high probability of more than one hazard affecting farming during a single agricultural year. Higher frequencies were reported for decreases in water supply (canal and snowmelt), seasonal drought, temperature fluctuation (high at low altitude and low at high altitude) and un-seasonal rains during critical crop stages. Higher levels of hazard diversity were reported during later crop stages at all sites, particularly during the reproductive and grain formation stages, due to the different weather hazards being associated with various loss-causing pathways (insect, disease, disturbance in reproductive process, wilting and grain shrivelling or no ripening) (see Appendix B for details).

The same hazard occurring at different crop stages could cause losses through different pathways. In IP, heavy precipitation during the sowing stage of wheat causes a delay in sowing; higher weed infestation during the vegetative stage, or wilting and subsequent harvest loss, while in rice it causes wilting and submergence during germination and insect attack at the reproductive stage. In HM, low temperatures during the start of the sowing season reduce snowmelt and cause water shortages, delaying the sowing of both wheat and potato. A decrease in temperature during wheat germination causes the seedlings to wilt, while a sudden decrease in temperature during potato germination reduces seed vigour and affects its germination. The yield loss varied by 10–30% for more than half of the hazards, and by 31–50% for one third of the hazards (see Appendix B for details). In a few cases (8%), the hazards led to a complete crop failure, such as when sowing was impossible due to dry conditions, or when the crops were submerged or wilted due to a shortage of water. The impact of the hazards varied in their intensity, by the associated pathways causing losses and by the crop stage across cropping system.

The coping options differed per pathway, with multiple coping options available for some situations. In IP, farmers adopted a range of coping strategies to break the soil crust following a light rain before the germination of wheat. Among these choices, 43% applied supplemental irrigation, 36% used bar harrows (light cultivator or planking), 12% adopted a partial re-sowing and 10% opted for a full re-sowing. During rice transplanting, the majority of farmers avoided losses from moisture stress by adopting supplemental irrigation using tube well water (71%), delayed sowing until the start of the rains (21%), or used a higher number of seedlings (8%). Late sowing, the use of additional inputs and partial re-sowing (re-transplanting in case of rice) were the main coping strategies for temperature- (high) and moisture-related (dry/wet) issues during early crop stages. Farmers applied frequent supplemental irrigation to avoid wilting during the germination and vegetative stages of rice. Farmers could not cope with heat stress at the reproductive and grain-formation stages, with the exception of a few farmers who applied supplemental irrigation and evapotranspiration, which releases excess heat to reduce its impact on wheat yield (Fig. 2A).

In MH, with its dominant rainfed ecology, farmers had limited coping options during most CMs, but showed diversity in applying the coping options that were available (Fig. 2B). To avoid losses from crust formation before the germination of wheat, many farmers (46%) adopted a partial re-sowing, with others (25%) opting for a full re-sowing. Some chose to use a bar harrow (22%), while others (8%) used additional fertilizer in combination with the bar harrow. For the groundnut crop, most farmers (54%) used a light cultivator followed by a partial (38%) or full (8%) re-sowing.

At higher altitudes, in MV (Fig. 2C) and HM (Fig. 2D), farmers delayed sowing during periods of low temperature or low water supply to avoid losses during the early crop season. If these stresses continued for extended periods, farmers could only plant one crop and suffered a harvest loss for the other. Farmers used pesticides against insect attack in maize and potato during periods of hot-humid weather (locally called as "*lome*"), although they did not have access to coping strategies for diseases in wheat caused by similar weather conditions. Flash floods from a heavy shower disturbed the water supply system in the

Table 4
Description of the coping strategies.

Coping strategies	Description
Add fertilizer	Additional fertilizer use than common practice in normal season
Add seed fertilizer	Additional seed and fertilizer use than common practice in normal season
Changed variety	Changed variety than planned for normal season
High seed rate	Higher seed rate than recommended to maintain planting density
Late sowing	Late sowing than recommended sowing time
No coping	No coping strategy at all (if none of the farmer in study area practiced a coping)
Supplemental irrigation	Additional irrigation to avoid loss from high temperature, seasonal drought/frost
Add cultivator + fertilizer	Additional ploughing and use of additional fertilizer than normal practice
Drained water	Draining excess water by natural flow or by pumping out from the field
No adoption	Farmer did not adopted a coping when other farmers practice for the same hazard
Partial re-sowing	*Re*-sowing in the same field with less seed (25–35%) than initial sowing or filling gaps with new seed/seedlings on patches where it has not germinated/established
Bar harrow	Use of bar harrow or light cultivator to break the crust
Bar harrow + fertilizer	Bar harrow used to break the crust with application of additional fertilizer
Hoeing	Manual hoeing for weeding or breaking hard surface to facilitate pegging
Pesticide use	Use of pesticides (including insecticide, weedicide or fungicide)
Repair w. channel	Repaired water channel destroyed by flash flood (heavy rain) in mountains
Stop irrigation	Stop irrigating fields when fields are too wet after a heavy rain or crop lodging
Drying	Drying of harvested crop in case of rain before crop is threshed
Delayed harvesting	Delaying crop harvesting (wet field or crop not matured due to low temperature)
Early harvesting	Early harvesting than normal to minimize loss from low temperature (in potato)

mountains and caused moisture stress, which sometimes led to crop failure if farmers were unable to repair the water channels quickly. A description of coping strategies is given in Table 4.

3.2. Coping possibilities and adoption rate

There was no coping strategy possible for 22% to 45% of the events reported in the different study sites. For most of the hazards at later crop stages, which caused lodging, disturbed pollination, damaged spikes or shrivelled grains, farmers had hardly any coping options available. Lodging is a sudden issue caused by strong winds, rain, hailstorms, while delays in harvesting or threshing could result from lodging or rain affecting mature or harvested crops across all sites. Drying harvested crops is the only option to decrease losses and costs during harvesting and threshing. A lack of precipitation prevents sowing or leads to permanent wilting, often causing a complete loss of yield with limited coping options available in MH.

If coping options were available, the adoption rate varied from 60% in MV to 86% in IP. Coping strategies with high levels of adoption were typically related to making adjustments to sowing in response to moisture availability, crust breaking, weeding, the use of pesticides and the drying of harvested crops. Among all sites, farmers in IP showed the highest rate of adoption (86%), which can partly be explained by to the commercial nature of the crop farming, higher level of input use, larger average farm sizes and greater availability of an alternate irrigation sources compared with the other study sites. In IP specifically, a coping option for most of the pathways related to moisture and heat stress involved accessing an alternate irrigation source. Also in MH as compared to the other two mountainous sites, a high adoption rate (85%) was reported, with the risk of crop failure in rainfed farming reported as the explaining factor. In MV, the lowest adoption rate (60%) was attributed to the dual purpose maize crop and the lower dependence of the farmers on local wheat for food security. Maize was converted to fodder if it was wilted by water shortage or affected by insects. Only 20% of farmers used pesticides during an insect attack. Severe cases of water channel destruction during flash floods were not repaired in a timely manner in about 40% of cases in MV. In HM, though land holdings were very small, commercial crop farming was practiced, with potatoes as a cash crop. An adoption rate of 69% of available coping strategies was reported at this site (see Appendix C for details). Overall, in 45% of the stress events, farmers were unable to cope with a certain hazard either because of non-availability of a coping option (30%) or they chose not to adopt (15%) among the available options. Hence, the coping with in-season hazards was mainly constrained by non-availability of a coping option (Fig. 3).

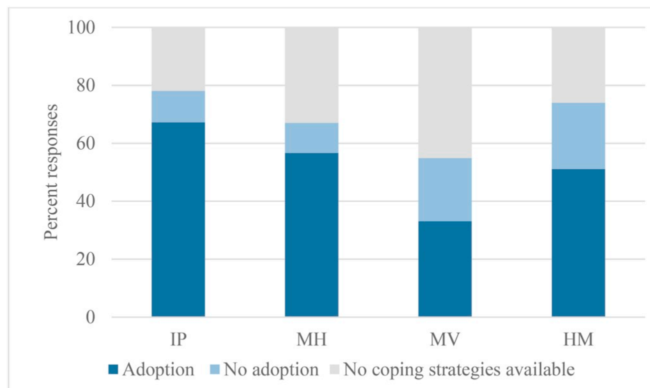

Fig. 3. Coping strategy availability and adoption rates at the four study sites.

3.3. Cost effectiveness of coping strategies

The effectiveness of a coping strategy was measured in terms of the percentage of potential yield loss recovered by adopting a coping strategy. The yield loss recovery varied from 40% to 95% of the potential yield loss caused by a hazard, with an average recovery of around 77% (Table 5). The cost of in-season coping strategies varied from 4% to 34% of the recovered yield value, with an average of 19% with significant differences ($P < .0001$) among the study sites due to differences in output prices, cost of inputs involved and variations in yield recovery. A higher cost ratio was found in IP, mainly due to higher cost of the most popular coping strategies (Appendix D). Each hazard had its own implications, as farmers could not recover the full yield loss even if they were able to adopt a coping strategy.

Farmers reported response time as an important factor for effectiveness; for example, the effectiveness of draining excess water under wet conditions following heavy rain in IP ranged from almost zero (complete loss) when delayed to 90% for timely drainage. Similarly, repair to damaged water channels after flash floods in MV and HM were much more effective if repaired in time.

The effectiveness of coping also varied by the level of input use for a

Table 5

Cost of coping strategies (Pak Rs./ha), benefits as value of the recovered yield (Rs./ha) and effectiveness (% of the yield loss recovered) by study sites.

Coping strategies	IP				MH				MV				HM				Overall			
	Cost (Rs./ha)	Benefits (Rs./ha)	Effectiveness (% of Y recovered)	n	Cost (Rs./ha)	Benefits (Rs./ha)	Effectiveness (% of Y recovered)	n	Cost (Rs./ha)	Benefits (Rs./ha)	Effectiveness (% of Y recovered)	n	Cost (Rs./ha)	Benefits (Rs./ha)	Effectiveness (% of Y recovered)	n	Cost (Rs./ha)	Benefits (Rs./ha)	Effectiveness (% of Y recovered)	n
Stop irrigation													0	17,036	39	8	0	17,036	39	8
Add cultivator + fertilizer	3,089	11,425	76	4	3,562	18,826	105	16									3,404	16,359	95	20
Add fertilizer					1758	19,565	65	8					7,989	70,846	90	3	3,835	36,659	73	11
Add seed fertilizer	6,002	10,510	85	10													6,002	10,510	85	10
Bar harrow	1,599	24,782	81	16	1,659	40,161	75	41									1,639	35,035	77	57
Bar harrow + fertilizer					4,003	24,031	87	5									4,003	24,031	87	5
Changed variety					1,606	17,480	70	6									1,606	17,480	70	6
Drained water	2,034	28,031	72	31													2,034	28,031	72	31
Drying	2,903	9896	79	74	2,100	11,832	80	102	1,977	8,067	70	35	1,693	9308	90	41	2,279	10,138	80	252
High seed rate	1,730	9630	67	8	729	17,480	70	11									1,396	12,246	68	19
Hoeing					5,498	35,630	73	5									5,498	35,630	73	5
Partial re-sowing	5,906	28,718	85	64	6,005	39,718	89	52					7,016	31,202	79	20	6,309	33,213	84	136
Pesticide use	3498	11,617	73	18	3,120	25,740	74	6	2,113	9,803	92	11	5,766	46,189	78	5	3,647	22,874	76	40
Repair w. channel									1,932	20,579	80	25	2,855	36,098	56	52	2,436	29,044	67	77
Early harvesting													0	93,739	88	4	0	93,739	88	4
Re-sowing	7,598	27,535	90	4	10,594	49,436	95	20									9,596	42,136	93	24
Supplemental irrigation	2,544	14,341	80	127									200	35,301	72	27	1,919	19,931	78	154
Total	3,275	17,973	78	570	4051	29,205	81	653	1,964	17,252	81	257	3,200	37,283	69	354	3,359	25,724	77	1,834

n = Number of responses.

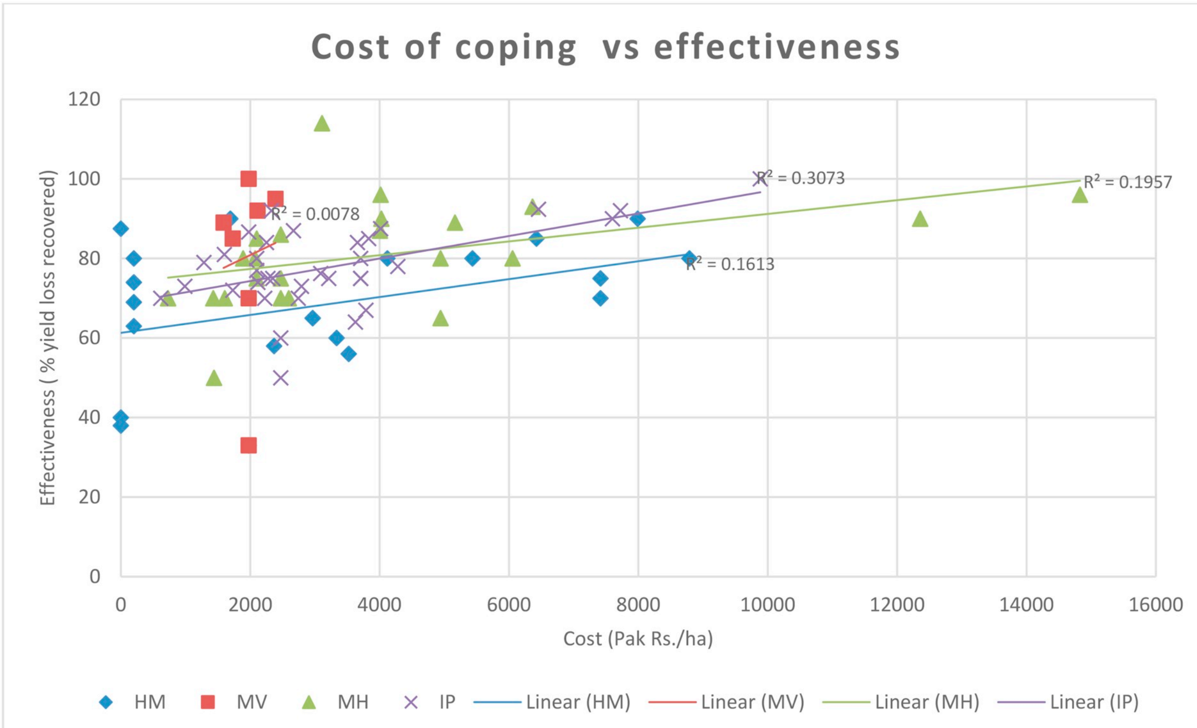

Fig. 4. Scatterplot of the cost and effectiveness of coping strategies at the four study sites. Each dot represents the mean cost and effectiveness of a coping strategy during a crop season.

similar pathway. Using higher seed rate along with additional fertilizer was more effective at maintaining a plant population and improving germination than only applying a higher seed rate to cope with delayed sowing. Similarly, the yield recovery varied with input use level. For example, the yield recovery was higher when full seed rate with cultivation and additional fertilizer was used as compared to partial seed rate with alight cultivator and without additional fertilizer in case of re-sowing to cope with crust formed due to an un-seasonal rain after sowing (see Table 4 for a description of coping strategies). Occasionally, coping strategies using increased inputs resulted in a higher yield than would have been expected under normal conditions; for example, in MH under rainfed conditions, when an un-seasonal rain delayed sowing, the farmers who applied additional fertilizer ($n = 16$) benefitted from the additional moisture and recovered a 5% higher yield.

A weak positive correlation was found between cost of a coping strategy and its effectiveness across all four sites (Fig. 4). In MH, several high-cost coping strategies (re-sowing, partial re-sowing, hoeing, additional fertilizer and seed) resulted in relatively high yield recoveries. The effectiveness of using additional seed and fertilizer in IP was less than for MH, mainly due to differences in moisture levels and the base input levels, which were already higher on average. Farmers in MH coped by using higher inputs only if additional moisture was available after an un-seasonal rain during the sowing period. The cost of coping varied mainly due to differences in the prices of inputs involved in a coping approach. Farmers in IP incurred higher costs for supplemental irrigation using tube wells, while water was available at no added costs in MH and HM. In HM, however, the cost of repairing a water channel damaged by flash floods was highly variable, depending upon the level of damage, the hours of labour required to repair the damage and the urgency of the repairs, with cheap hired labour and machinery absent in these remote areas. The costs also differed by crop, with the costs of seed for re-sowing wheat, rice and maize much lower than for potato and groundnut. Similarly, considerable differences in sowing and transplanting costs were reported for the different crops. Several coping options came without additional cost, such as a late sowing due to high temperatures in IP and MH or due to low temperatures in MV and HM, or the halting of irrigation after heavy rains to avoid loss from wilting and insect attack. Potatoes could be harvested early with no additional cost to avoid loss from low temperatures, since night frosts make potatoes fluffy and unmarketable. Each of these decisions constituted a deliberate response and resulted in partial yield recoveries.

3.4. Compounding and cascading impacts

The occurrence of two moderate hazards in one crop season can generate compounding impacts and more extreme yield losses (IPCC, 2012). Similarly, the impacts accumulate if a single hazard affects two crops grown in a sequence in a multi-cropping system. In our sites, we found that a delay in rice harvesting due to un-seasonal rain or lodging affected both rice yields and wheat yields because of delays in sowing (Fig. 2A). The impact worsens if operational costs are accounted for alongside crop yield and quality.

Similar examples were also found in other cropping systems; for example, rain during the harvesting stage of wheat (causing a 5.8% yield loss) led to a crust formation that affected groundnut germination (leading to heavy losses of up to 50%) in MH. Similarly, heat stress at the wheat grain formation stage caused a 17% wheat yield loss, but also led to a 14% loss of groundnut yields due to the early sowing and subsequent wilting of this second crop caused by the higher evapotranspiration and moisture stress it experienced during germination. Moisture stress affected groundnut yields at the pod formation stage (with a 35% reduction in yield), which affected the pre-sowing stage of wheat during which farmers conserve moisture in fallow lands. Low or no rainfall during this pre-sowing period leads to a delay in sowing, partial fallowing or even harvest loss, especially on marginal soils with less water-holding capacity. Heavy rain at the harvesting/threshing stage of groundnut (pre-sowing of wheat) has a contrasting effect, reducing groundnut yields (7%) and quality, causing a price decline (10–30%) and incurring higher threshing costs, but increasing wheat yields due to the better moisture conditions supporting the timely sowing and enhanced germination of this crop (Appendix B).

In the mountains (Fig. 2 C&D), compounding impacts were found for crops grown in sequence or side-by-side. Rainfall and/or low temperatures delay wheat maturity and harvesting, pushing maize back to late in the season and negatively affecting its grain ripening, meaning it is often only usable as fodder. Warm and humid weather affects both wheat and potato grown in same season around the grain/tuber formation stage by increasing disease infestation in wheat, leading to reduced grain formation and insect attacks in potato, causing up to a 40% yield loss in wheat and 30% in potato. Flash floods, occurring mostly from the vegetative to grain formation stages, damage water channels and impact the water supply, affecting both wheat and potato simultaneously.

Coping with in-season hazards was perceived to be more difficult when a hazard led to multiple impact pathways requiring a different coping strategy, often at the same time. In MH, seasonal drought at the reproductive stage of groundnut induced insect attack and hindered pegging, decreasing peg viability and reducing pod set (Haro et al., 2011). Similar examples were found in IP, where high temperatures affected reproductive and grain formation processes, as well as inducing insect attack in rice. In HM, a decrease in temperature during wheat germination caused the seedlings to wilt and decreased the water supply (snowmelt), meaning farmers required more water to supplementary irrigate as a coping option. The complexity further increased because farmers in HM also require water for the concurrent sowing of potatoes. Coping with these exacerbating hazards in intensive multicropping systems within a single crop season becomes challenging, and even a single hazard can generate an extreme condition if assessed from a system perspective. The situation was aggravated when farmers had no coping strategies available at all (for example, for crop lodging, moisture stress under seasonal drought, grain shrivelling due to heat stress) or did not have timely access to labour (for manual hoeing to encourage pegging in MH) or input (additional rice seedlings in IP or potato seed in HM for re-sowing/re-transplanting) beside the cost of coping.

3.5. Operational conflicts and short turnaround between crops

The use of coping strategies is often constrained by the short time farmers have to respond. *Re*-transplanting rice seedlings if partially uprooted, applying timely supplemental irrigation in case of drought or heat stress, re-sowing wheat or groundnut if germination affected from crust formation and repairing water channels after a flash flood to maintain the water supply before crop wilt all require timely action. The timely availability of resources including farm machinery and the ability to purchase additional seed, fertilizer and labour during such moments is critical. Timely re-transplanting rice was found to be 92% effective and had acceptable additional costs for purchasing seedlings and labour. Delays in re-transplanting or a difference in seedling age or variety led to differential ripening at maturity, causing harvesting and threshing problems and impacting rice quality and prices. Unfortunately, the availability of the required seed (quantity and variety) in such situations, either leftover from the farmer's own stock or purchasable from the market, was reported to be problematic, and the shortage of labour was challenging.

A multi-crop rotation poses additional challenges. Overlapping labour or land demands strongly limit the coping options for cropping systems with a short turnaround (Fig. 5). In IP, for example, the time between rice harvesting and the optimum period for wheat sowing is very short (Fig. 5A). Farmers reported that even a minor weather hazard, most commonly wind for mature rice (75%) or un-seasonal rain during harvesting (38%), leads to a workability conflict and delay in wheat sowing, causing an 8–18% decline in wheat yields. The demand for resources (labour, machinery, and cash) to complete rice harvesting and wheat sowing within a short window of time is high. In addition to the direct impact of lodging due to wind and rain on rice yields and the following impact on wheat yields, higher costs were also reported, since lodging slows maturation and hampers mechanised harvesting.

In MH, there is no conflict regarding land; wheat is planted on lands left fallow during the monsoon rains in the summer to conserve soil moisture, while groundnut is planted mainly on lands left fallow during the winter season. Despite this, there is some overlap between the wheat harvesting and groundnut sowing periods (Fig. 5B), causing a labour and machinery conflict in the case of an un-seasonal weather pattern. The rains during the wheat maturation period normally provide moisture for groundnut sowing. Insufficient rains during the pre-sowing period for groundnut lead to a delay in sowing and, when followed by delayed rains during wheat maturation, this pushes farmers to complete groundnut sowing to avail the available moisture, generating conflicts of labour and machinery with the wheat harvesting and threshing tasks.

In MV, wheat and maize are sequentially grown in the same field, with a 2.5-month break between maize harvesting after the 1st week of November and the start of wheat sowing from mid-January. This shortens the growing period of the crops and farmers have to quickly switch from wheat to maize, making this a critical period (Fig. 5C). Usually, due to the small scale of farms and small plot sizes, farmers manage to complete the farm operations within the short time available; however, a decrease in temperature often coincides with rainfall during the wheat harvesting stage, causing a delay, which in turn delays maize sowing. If maize sowing is delayed, the crop does not mature in time and it can only be used for fodder.

In HM, sowing begins at the start of spring as the ice melt starts to flow. Here, subsistence farmers rely mostly on family labour, with agriculture practiced on very small land holdings (< 0.5 ha). Wheat and potatoes are planted on separate plots, and are sown and harvested simultaneously one after the other in the same season, from the last week of March to the middle of October, with a two week gap between the sowing of both crops (Fig. 5D). A delay in the onset of spring results in a delay in sowing. Farmers reported they had few coping options to mitigate such losses. Starting the sowing of wheat early to avoid conflict with the next crop often led to reduced germination or wilting due to the low temperatures or even snowfall, which required re-sowing and caused further delay. Fluctuations in temperature at the initial crop stages also led to trade-offs in the allocation of scarce water resources. If sowing of wheat is disturbed by low temperature, farmers cope by a delay in sowing and they tend to apply irrigation during the early germination stage to avoid loss from wilting of seedlings under these conditions. However, this increases water demand when irrigation water is also needed to provide irrigation for the sowing of potato crops. Water scarcity further increases as low temperatures also mean less melt water, thereby limiting supply of water. Under such conditions, partial fallowing or not sowing any wheat are common strategies to avoid the yield loss of potato, which is the cash crop. Over the past 10 years, temperatures were generally reported to have increased, yet temperature fluctuations were perceived to have increased and low temperature stress during sowing and germination was still reported by half of the farmers.

4. Discussion

A farm household survey was conducted to assess the cost effectiveness of in-season techniques used to cope with adverse weather conditions in four main cropping systems located in the Indus basin, Pakistan. Methods to cope with weather variability have previously been discussed largely from an adaptation angle, including recommendations for changes in land use, cropping patterns, variety selection or ex-post coping techniques such as credit and migration (Bhatta and Aggarwal, 2016; Hussain and Mudasser, 2007; Thamo et al., 2017). In the present study, we used field evidence to provide a clear distinction between the impact pathways of similar hazards, differences in coping requirements and the possibility of coping during

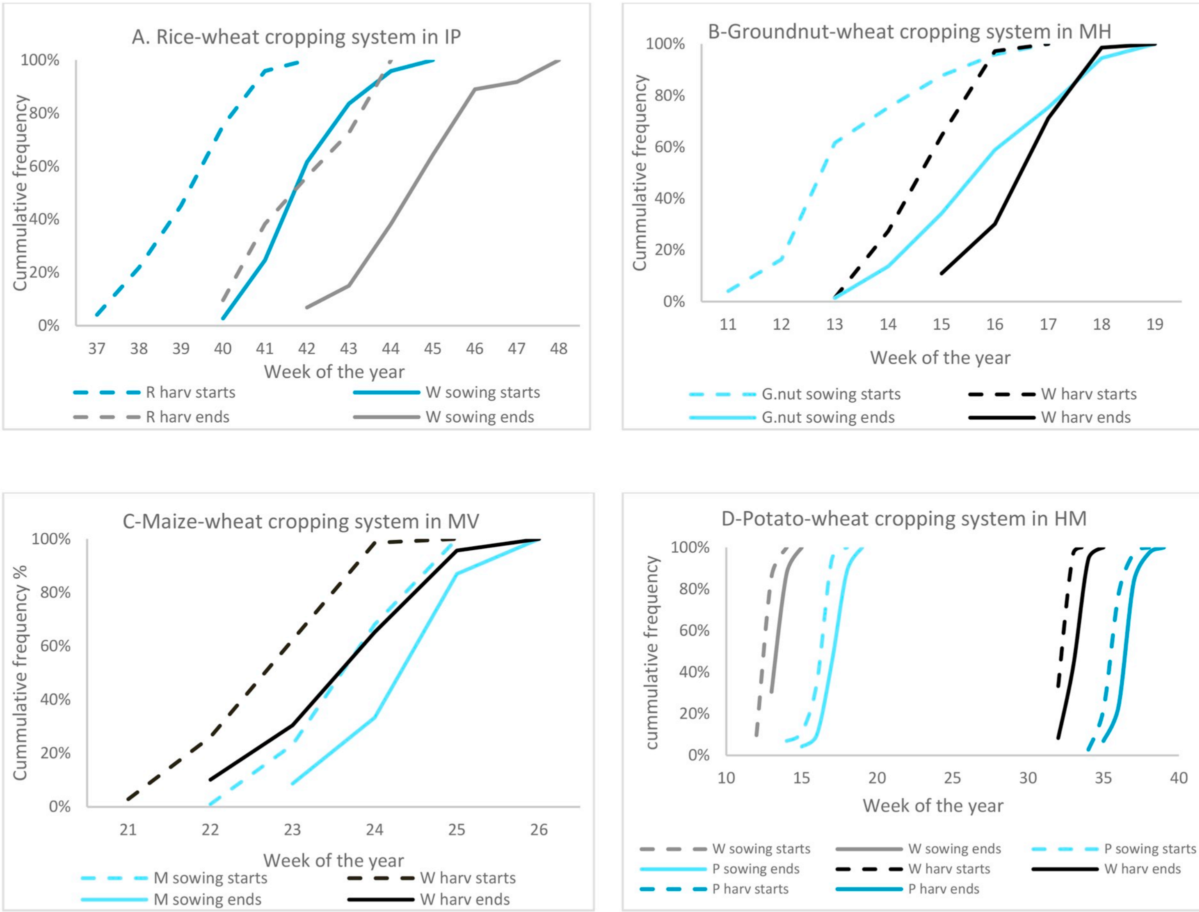

Fig. 5. Conflicts in land and labour allocation in multi-cropping systems; A. IP, showing land and labour conflict between rice harvesting and wheat sowing. B. MH, showing labour conflict between groundnut sowing and wheat harvesting. C. MV, showing land and labour conflict between wheat harvesting and maize sowing. D. HM, no land or labour conflict.

different crop stages. This study thereby provides new insights into the effectiveness and costs of coping strategies, crop-stage-specific coping requirements and farmer coping practices. Farmers had more flexibility and ability to cope during early crop stages because they had access to a wider variety of coping strategies than they did at later crop stages, during which there were no coping strategies available for some of the hazards, such as heat stress or lodging. As a result, the adoption rates at early crop stages were higher. Higher adoption rates were also found in cropping systems with access to irrigation water resources, with supplemental irrigation from tube wells used to cope with both moisture and heat stress.

With the multitude of moderate hazards, impacts and coping strategies defining farming, any questionnaire on these aspects in terms of crop stage faces time limitations. In cases where two or more different hazards were reported for the same crop stage by the same respondent, details on costs and yields for only the most recent hazard were included in the survey. This helped to improve the quality of the data (based on memory recall and by limiting the required interview time and the associated response fatigue), although it meant that details of other common hazards that may have occurred previously were missed. Despite the detailed questionnaire with > 1800 responses regarding hazard-impact pathways, only a few responses were recorded for some hazards. These were reported merely in an illustrative context. For questions on the cost and effectiveness of coping, the number of responses reduced further; in nearly half of the reported impact pathways, farmers were unable to cope, either because no coping strategies were possible or because they chose not to adopt them.

Each of the coping strategies involved additional cost. Interventions resulting in significant yield improvements are not adopted if they do not meet economic rationale (Shah et al., 2011). While a cost ratio of 18.81% of the recovered yield seems to make the decision to cope rational, even to risk-averse farmers, and explains the high adoption rate, these extra costs have to be put in perspective against the overall low marginal returns in farming and the low net income of smallholder farmers in Pakistan (Bhutto and Bazmi, 2007; Malik et al., 2016). A timely response was considered important for increasing the effectiveness of coping strategies, but a shortage of labour, machinery or required inputs often prevented such a response. The cost-effectiveness of coping strategies depended mainly on the cost of inputs and the field conditions rather than the yield recovery.

Assessing coping or adaptation options individually or under controlled test conditions does not take the actual limitations into account, especially in regions dominated by complex multi-cropping systems. The analysis of various multi-crop systems shows various land, water and management (labour and machinery) conflicts. Rice and wheat, staple crops for hundreds of millions of people, are sequentially grown on the same land throughout Indo-Gangetic plain, which brings complementary as well as conflicting practices (Timsina and Connor, 2001). Wheat sowing in this region is already delayed because of the dominance of long-duration late-maturing Basmati rice varieties, shortage of mechanical harvesters (Tahir et al., 2008) and the time required for residue management through intensive tillage (Hussain et al., 2012). Due to these, wheat sowing is already spanning the optimal time limit (mid-November); almost half of the sampled farmers began wheat sowing after mid-November, even under normal weather conditions. Wheat yields were previously shown to decline by 10% if planting is delayed from 10th November to 25th November in Punjab, Pakistan (Khan et al., 2004). Weather hazards such as heavy rain or wind during the rice maturation period caused lodging, leading to a delay in rice harvesting and wheat sowing that cause yield losses, additional costs and eventually a loss of income. Our estimates of an 8–18% reported wheat yield decline due to a weather hazard causing delay in sowing are similar to the earlier finding on effect of late sowing on wheat yield (Ali et al., 2010; Ortiz-Monasterio et al., 1994). The compounded impacts and operational conflicts in multi-cropping systems can be better understood when studied as a connected system.

Climate change is expected to have a big impact on agriculture in Pakistan and the Indus basin (Biemans et al., 2019; Hussain and Mudasser, 2007). Insights from this study are particularly relevant given the expectation that climate variability will increase, affecting future crop yields (Ashok and Sasikala, 2012; Camargo and Marcelo, 2009; Cooper et al., 2008; Van Aalst et al., 2008) and posing considerable risks to the sustainability of agriculture in many regions (Barasa et al., 2015; Lansigan, 2007; Sivakumar et al., 2005). A global lack of preparedness regarding increasing climate variability has been highlighted by the Intergovernmental Panel on Climate Change (IPCC), with a reduction in vulnerability to present-day climate variability considered a first step towards effective climate change adaptation (Field et al., 2014). While efforts are now shifting towards the development of ever more regionalised or even local scenarios (Lopes and Aguiar, 2008), farm-level coping mechanisms are still often overlooked (White et al., 2011). By explicitly addressing the effectiveness of coping strategies during CMs, this study adds a new angle to a growing literature on the characterisation of weather hazards and ways to improve resilience at the farm level (Füssel, 2007; Heltberg et al., 2009; IPCC, 2012; Wilby and Dessai, 2010; World Bank, 2015).

Supporting effective in-season coping goes beyond the farm level and requires broader policy support and investment, such as improved weather and early warning information, technical guidance, rapid access to production inputs or finance through a functioning market system. For about one fourth to nearly half of the cases in the four cropping systems studied, farmers were unable to cope with in-season hazards due to non-availability of a coping option. This requires a policy shift to direct R&D efforts to fulfil this gap. Often, inputs were not available in time, which indicates markets should be strengthened. Effectiveness strongly dependent on response time. Advisory and support services needs to be aligned with these challenges to respond timely. Understanding effectiveness of current and alternate coping options for different CMs provides opportunity for devising viable and cropping system compatible coping options.

5. Conclusion

A multitude of moderate hazards affects each of the cropping systems studied, with the frequency of occurrence ranging from once in five years to once in two years. In-season coping strategies were available for 55–78% of the hazard events in different cropping systems. When a coping option was available, the adoption rate varied from about 85% in plains and mid hills to as low as 60% in the mountain valley site. Coping strategies were found to be strongly constrained by the limited amount of time to respond and the availability of the required inputs.

The effectiveness of coping varied from 50 to 90% at the cost of 4–34% of the value of recovered yield. This study shows how compounding and cascading impacts can lead to conflicts in the allocation of time, land, labour, machinery and other resources in multi-crop systems. Our results emphasise the need to address farmer coping strategies from a system perspective. A better understanding of the differentiated risks and the effectiveness of in-season coping strategies could support the promotion of sustainable crop production in similar agro-ecologies.

Disclaimer

The views expressed in this work are those of the creators and do not necessarily represent those of the UK Government's Department for International Development, the International Development Research Centre, Canada or its Board of Governors.

Declaration of Competing Interest

None.

Acknowledgement

This work was carried out as part of Ph.D. Research funded by the Himalayan Adaptation, Water and Resilience (HI-AWARE) consortium under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) with financial support from the UK Government's Department for International Development and the International Development Research Centre, Ottawa, Canada.

Appendix A. Full questionnaire

Questionnaire on exploration of critical periods due to climate variability during a crop calendar.
Part-1. Questionnaire identification and site classification.
Module 1: Location (Identification and classification by agroecology and farming system).

Date of interview	Village
Tehsil	District
Name of enumerator	Start Time

Module 2: Household Demographic Information.
2.1. Respondent information

Name of respondent	Contact # of respondent
Education of the Respondent (Years)	Age of respondent
Farming experience of the Respondent (years)	Present involvement in farming 1 = full time 2 = part time
Respond. Relation to H.H. Head[a]	Education of HH Head (years)

(a) 1 = Self 2 = Brother, 3 = Son, 4 = Uncle, 5 = Father, 6 = Other (specify/spy).

2.2 Family type, size and employment

Type of farm family 1 = Joint family, 2 = Single family	Total family size (no)

2.3 Family employment (Adult family members)

	Adult (16–60)	
	Male	Female
Working on farm full time (#)		
Working on-farm part time		
Working off-farm full time (job, labour, or business) (#)		
Working off Farm part time		
Off-farm income contributed to family of **all** persons working off-farm (part time + full time) (Rs./Month)		
Working Abroad (#)		
Remittances (Rs./Year)		
Retired from govt. services (#)		
Sum of pension of all retired persons (Rs./Month)		

Income of HH from other sources not mentioned above (rent of tractor/building etc.*) (Rs./Year)*________.
Permanent **Hired Farm Labor** #_____ @ _____ Rs./month (including all in- kind benefits).
Module 3. Household and farm assets owned by the HH*

Assets	Number	Assets	Number	Assets	Number
Tractor		Refrigerator		Car/Jeep	
Drill/ Ridger/Bed planter		Washing Machine		Motorcycle	
Trolly		Computer		Cycle	

*(for adaptive capacity differential by asset endowment).
Module 4: Land Resource and its Management (land utilization, allocation, output and income)
4.1. Land owned and cultivated (in Acre), put '0' if no and 'X' if not relevant)

Total own land (acres)	Own cultivated	Own uncultivated
Leased in/ Share in	Leased out/ Shared out	Lease **Rate** Rs./acre/year
Operational Land Holding	Operational Rainfed	Operational Irrigated
Irrigation sources 1 = tube well/Turbine for underground water 2 = pumped from pond/mini dam/stream 3 = surface supply from canal 4 = surface supply from stream/pond/dam 5 = Other specify		
Power source for irrigation system 1 = Electric motor 2 = Peter engine 3 = Tractor 4 = Solar 5 = Other -		

** Not in use for crop/forest farming (gravel, saline, waterlogged).
4.2 Utilization of irrigated and un-irrigated land resources for crops production (Cropping Pattern, Intensity)

Rabi crops 2015–16 (name season if different)	Area (acre)		Kharif crops (2016) (name season if different)	Area (acre)	
	Irrigated	Rainfed		Irrigated	Rainfed
Wheat			Rice		
Mustard/sarsoon/ canola			Maize (grain)		
Berseem			Sorghum/Millet /maize (fodder)		
Oat			Groundnut		
Lentil			Guar		
Gram			Potato		
Vegetables*			Vegetables*		
Orchard (area or plant #)			Orchard		
Other crop (specify)			Other (specify)		
Other (specify)			Other (specify)		
Fallow**			Fallow		

*(H. Consumption +commercial) ** Land kept fallow for 4–6 months other than non-intercropped orchard area.
Note: Give names and period of crop season if different than rabi/kharif in plains.

4.3 Income from Horticulture, sale of tress and livestock (milk or animal sale) (ON AN AVERAGE)

Source	Income Rs./Year	Source	Income Rs./Year
Vegetables production (Rs/year)		Orchard/Fruits (Rs/year)	
Sale of trees		Any other	

4.4. Livestock Animals

Large ruminants/dairy animals (young stock + adult) #	Small Ruminants #
Ave. Monthly income from Milk (Rs./Month)	Annual Income from sale of animals (Rs./Year)

Module 5. Farmers' Perceptions about Climate Change

5.1. Temperature pattern has changed due to climate change. What do think about the followings?

(During the about last 10–20 years what is your observation about changes in temperature in your area?)

Overall temperature has 1 = increased 2 = decreased 3 = no change			
Summer temperature now as compared to that it used to be 20 years ago	1 = More hot, 2 = Less hot, 3 = Same	Winter temperature now as compared to that it used to be 20 years ago	1 = More cold, 2 = Less cold, 3 = Same
i) Summer season is ii) Summer days are iii) Summer nights are Summer stresses (Intra-seasonal) i. Number of extremely hot days in summer has ii. Number of extremely hot nights in summer has iii. Windstorm in summer iv. Hailstorms v. Any other vi. Any other	1 = Increased, 2 = Decreased, 3 = No change	i) Winter season is ii) Winter days are iii) Winter night are Winter stresses (Intra-seasonal) i. Number of extremely cold days in winter has ii. Number of extremely cold nights in winter has iii. Frost nights in winter iv. Hailstorms v. Foggy days has vi. Any other	1 = Increased, 2 = Decreased, 3 = No change

5.2. Experience shows that seasons have changed. What do you think about the followings?

i. Summer season:	1 = Early, 2 = Late, 3 = No change	No of days (0,1,2, …)	ii. Winter season:	Early = 1; Late = 2; No change = 3	No of days (0,1,2, …)
1) Summer starts*			1) Winter starts**		
2) Summer ends**			2) Winter ends*		

*/** Coincide with each other.
Write notes and reasoning for any unusual responses ____.

____

____.

5.3 What have you noticed about the changes in rainfall pattern due to climate change over last 20 years?

Summer/monsoon rains:	Winter rains:
Shift observed in onset of rainy season 1 = Early, 2 = Late, 3 = No change	Shift observed in onset of winter rainy season 1 = Early, 2 = Late, 3 = No change
Shift observed in occurrence of pre-moon soon rains 1 = Early, 2 = Late, 3 = No change	
Frequency of rains 1 = Increased 2 = Decreased 3 = No change	Frequency of rains 1 = Increased 2 = Decreased 3 = No change
Number of heavy rainfall events has 1 = Increased 2 = Decreased 3 = No change	Number of heavy rainfall events has 1 = Increased 2 = Decreased 3 = No change
Number of light rainfall events has 1 = Increased 2 = Decreased 3 = No change	Number of light rainfall events has 1 = Increased 2 = Decreased 3 = No change
Events of untimely rains has 1 = Increased 2 = Decreased 3 = No change	Events of untimely rains 1 = Increased 2 = Decreased 3 = No change
Total rainfall (quantity of water) has 1 = Increased 2 = Decreased 3 = No change	Total rainfall (quantity of water) has 1 = Increased 2 = Decreased 3 = No change
Events of continuous rainy days (*jharri*) has 1 = Increased 2 = Decreased 3 = No change	Events of continuous rainy days (*jharri*) has 1 = Increased 2 = Decreased 3 = No change

Canal/stream water supply has 1 = Increased 2 = Decreased 3 = No change	Canal/stream water supply has 1 = Increased 2 = Decreased 3 = No change
Ground water table has 1 = Increased 2 = Decreased 3 = No change	How much water table has change (ft)
Under ground water quality has 1 = deteriorated 2 = improved 3 = no change	Reason for change in quality ———
Over time soils has become 1 = more saline 2 = less saline 3 = no change	Reasons for this change in salinity ———
Over time soils has become 1 = more waterlogged 2 = less waterlogged 3 = no change	Reasons for this change in water logging ———

Write NA (Not Applicable) if not relevant to concerned farm/site

5.4 Rank following climate change aspects in terms of increasing challenge for crop production c (Ranke 1 as most serious and 4 less as an inter comparison among the four options)

Climate change issues	Rank 1 to 4
Increase in temperature (Global warming) overall as compared to 10–20 years ago	
Decrease in rainfall as compared to 10–20 years ago	
Unpredictable weather (temperature and rain) at different crop stages	
Extreme climate events (floods, droughts)	

Do you consider the following seasons in terms of weather as: **1 = normal 2 = good 3 = bad**

Winter 2015–16 ______ Summer (Kharif) 2016 _______ Winter 2016–17 _______

Has Crop Yield increase over last 20 years 1 = increased 2 = no change 3 = Decreased_____

Has crop yield increased over last 5 years 1 = increased 2 = no change 3 = Decreased_____

Ground water table ———Ft. Soil condition: 1 = normal 2 = Slightly saline 3 = saline ———

Field condition: 1 = Well drained 2 = low drained ———

Soil Type 1 = loam, 2 = sandy loam 3 = clay 4 = clay loam 5 = sandy ———

Module 6 Critical stress periods (What is your opinion on the effects of any experienced stresses due to clime change?)

6.1: Shift in weather and changes in cropping seasons (if both crops overlap write period with months name eg April-Oct)

	Rabi (Winter) –Period mm-mm———		Kharif (Summer) period mm-mm———	
Crops (For major/common cropping practices)	**Wheat**		1 = Potato (Hunza) 2 = Groundnut (Pothwar) **3 = Rice (irrigated Plains) 4 = Maize (hunza)**	
The sowing (as per your common practice) starts from (wk/mm)	**Week# _____ Month#_____**		**Week# _____ Month#_____**	
The sowing (as per your practice) completes (wk/mm)	**Week# _____ Month#_____**		**Week# _____ Month#_____**	
The harvesting (as per your practice) starts from (wk/mm)	**Week# _____ Month#_____**		**Week# _____ Month#_____**	
The harvesting (as per your practice) completes (wk/mm)	**Week# _____ Month#_____**		**Week# _____ Month#_____**	
Major area of this crop planted after 1 = Fallowing 2 = –———Name of crop				
Stages	**Sowing**	**Harvesting**	**Sowing**	**Harvesting**
Is there shift in sowing/harvesting stage due to changes in seasonal patterns as compared to **10 years or more 1 = yes 2no**				
If answer above is (1) **yes** it is shifted to earlier or late **1 = earlier 2 = later**				
How many days it has shifted				
Impact of this shift in sowing/harvesting stage on crop yield (in case of no adaptation or change of variety 1 = Positive 2 = Negative 3 = no change				
If answer of above is 1 or 2: How much change in yield is observed (mds/acre) due to this shift				
If shift has negative impact on yield; what are your adaptation practices to avoid yield loss due to shifts: 1 = change variety 2 = increase fertilizer doses 3 = partial shift to some other crop 4 = higher seed rate 5 = did nothing 6 = adopted short duration variety 7 = other (specify) ———				
Cost of above adaptation strategy(s) (Rs./Acre)				
Looking at past CC trend in which direction season will move (Future expectations for shift in season. (1 = season will start early 2 = start late 3 = end early 4 = end late 5 = no change/ further shift)				
How will you adjust to this expected shift 1 = Change variety 2 = change crop 3 = high fert 4 = no other viable option except to continue same practices 5 = high seed rate 6 = other				
What are the constraints to adapt for the above expected shifts (specify)				
If farmer identify that shift in season will continue: upto what time he may adjust sowing and harvesting as compared to present practice (after that threshold reaches and has to switch some other crop).	**Wk#___Month#_____**	**Wk#___Mh#___**	**Wk#___Mh#_____**	**Wk#___Mh#____**
Is this shift creates conflicts with inputs required and next cropping season? If so please identify **A- Inputs (shortage of labour, machinery, seed tec) B=Shortage of Water or moisture evaporation; C– Delay in next crop D- Other (specify)** ——				
Describe the details of conflicts				

6.2. Critical Stress Period: occurrence of stresses and impact by stages

	Rabi (Winter) (Period ————————)						
Crops	**Wheat**						
Crop stages	**Pre-sowing (1)**	**Sowing (2)**	**Germination (3)**	**Tillering & Veg. growth (4)**	**Reproductive (5)**	**Grain formation (6)**	**Harvesting (7)**
6.2.1 Main unusual weather changes experienced by stage (during last 10 years) that results in change in yield (give # from below list) —option may be > 1.							
1 = Higher temperature than normal season 2 = Lower temperature than normal season 3 = Increase in frost days 4 = Decrease in frost days 5 = Increase in foggy days 6 = Decrease in foggy days 7 = Heavy rain 8 = Light rain 9 = No rains (seasonal drought) 10 = Delayed rains (after critical stage)- 11 = Early rains 12 = Decrease in surface water supply 13 = Windstorms 14 = Hailstorms 15 = Short heat spikes (heat stress) 16 = Low Moisture 17 = less rains (less than required) 18 = others							
6.2.2 Most common weather stress at each stage (if answer is more than one in 6.2.1) (give details for most recent in case frequency of two CP is same)							
Frequency of occurrence of most common weather change at each stage (during last 10 years)							
PART-A BIOPHYSICAL IMPACTS: (for most common)							
Impact on crop yield 1 = Positive 2 = Negative 3 = no change							
Minimum change in yield experiences (mds/acre) *in case lower intensity (if frequency > 1)during last 10 years*							
Maximum change in yield experienced (mds/acre) in case higher intensity of weather change during last 10 years							
Year of occurrence of last stress event by stage (write as season as 2015–16 or 2011–12)							
Decrease in yield during last stress event (Mds/acre)							
Normal season yield Mds/acre – if no stress during the season							
PART-B Pathways causing yield loss/increase 1 = more weed infestation 2 = insect attack 3 = disease 4 = less germination 5 = crust formation (poor germination) 6 = decrease in tillering 7 = flowering/reproduction disturbed 8 = grain shrivelling due to heat stress 9 = lodging 10 = reduced time period for grain formation (small grains) 11 = delay in sowing 12 = additional moisture 13 = wetting of grains/crop 14 = harvesting/threshing losses 15 = other – (Ref of CP 6.2.2)							
Share of produce (grain + straw) that was affected by quality (%) (0 if no effect on quality)							
If it affected quality what was the effect observed: 1 = change in taste 2 = change in color 3 = decrease grain size 4 = other (specify)							
Decrease in prices of grain due of quality deterioration (%)							
Decrease in prices of straw due of quality deterioration (%)							
Area Affected during last event (%)							
Area Left Unsown during last event (%)							

—

Crop stages	**Pre-sowing (1)**	**Sowing (2)**	**Germination (3)**	**Tillering & Veg. Growth (4)**	**Reproductive (5)**	**Grain formation (6)**	**Harvesting (7)**
PART-C ADAPTATION adopted to avoid losses from such weather hazards: Adaptations options given below (may be more than one for a stress)							
Adaptation options to avoid/reduce expected losses: 1 = *Re*-sowing of same crop 2 = Sowing of alternate crop 3 = High seed rate 4 = Low seed rate 5 = Adopted heat/ moisture stress tolerant new variety 6 = Planted old/traditional variety 7 = Supplemental/additional irrigation 8 = Changed cropping pattern (adjusted new crop) 9 = Changed sowing method 10 = Additional/higher dose of inputs/fertilizer 11 = Grow low input crop (taramera/pulses) 12 = Introduced intercropping 13 = Changed crop rotation 14 = early sowing 15 = late sowing 16 = Left land fallow 17 = Improved crop production practices 18 = Started planting trees at boundaries for supplemental income 19 = Shifting from crop to livestock 20 = Diversification towards HVA 21 = Check/follow weather forecasts for adjusting production practices 22 = ploughed fields to prepare land for early sowing of next crop 23 = availed insurance 24 = use of weedicide 25 = supplemental irrigation 26 = Bar harrow/light cultivator to break crust 27 = Drying of harvested crop 28 = no sowing at all 29 = Planted old variety 30 = Any other specify							
Which of above you adapted (most often or last one)							
Cost of this adaptations (Rs./acre) (combine cost if more than one adaptation opted at one stage)							
How much was this adaptation effective % (recover % income or reduce loss compared if not opted this adaptation)							
What are your expectations for future regarding such stresses by stage (1 = increase 2 = decrease 3 = no change 4 = no response							
If frequency of stresses increases in future, How you will cope with it? 1 = current adaptations are sufficient 2 = drastically change farming practices 3 = stop sowing this crop 4 = had no option except to continue current practice/crop 4 = other							
PART-D Did you opt any of the coping strategy to sustain livelihood due to severe losses from CP during last 10 years							
List of coping/ adaptation strategy 1 = Sold livestock animals 2 = Improve food storage facility 3 = Sold part of land for alternative business 4 = Leased /out part of land for alternative income 5 = use of savings 6 = Sold other assets 7 = Sold trees 8 = Started off farm labor/Employment in local area 9 = Some family member migrate out for other employment to supplement family income 10 = Support from existing Non-farm business 11 = Other (specify)							

What would be possible adaptation strategies to sustain your livelihood/food security against increasing climate stresses 1 = Crop diversification 2 = Increase livestock 3 = Shift to HVA 4 = Off/non-farm activity 5 = water source development (tube well) 6 = Any other (specify——)

What are the major constraints to adapt to stresses as discussed at different stages under CC 1 = financial 2 = technical (technology and knowledge) 3 = other

PART E: Supply demand aspect; Do the losses from weather hazards result in changes in overall production (supply side variability) significantly that also affect prices 1 = yes 2 = no

If yes; How much this prices increase (due to low production/supply) compensate for the yield loss to balance net income 1 = Not at all 2 = Partial 3 = Fully

How often you have to purchase this commodity for your household consumption during last ten years due to losses from critical period (#)

6.3 Critical Stress Period: occurrence of stresses and impact by stages

	Kharif (Summer)						
Crops (encircle)	**1 = Potato (Hunza valley) 4 = Maize 2 = Groundnut (Pothwar) 3 = Rice (irrigated Plains)**						
Crop stages	**Pre-sowing (1)**	**Sowing (2)**	**Germination (3)**	**Tillering & Veg. growth (4)**	**Reproductive (5)**	**Grain formation (6)**	**Harvesting (7)**
6.3.1 Main unusual weather changes experienced by stage (during last 10 years) that results in change in yield (give # from below list) —							
1 = Higher temperature than normal season 2 = Lower temperature than normal season 3 = Increase in frost days 4 = Decrease in frost days 5 = Increase in foggy days 6 = Decrease in foggy days 7 = Heavy rain 8 = Light rain 9 = No rains (seasonal drought) 10 = Delayed rains (after critical stage)- 11 = Early rains 12 = Decrease in surface water supply 13 = Windstorms 14 = Hailstorms 15 = Short heat spikes (heat stress) 16 = Low Moisture 17 = other							
6.3.2 Most common weather stress at each stage (if answer above is > 1)							
Frequency of occurrence of most common weather change at each stage (during last 10 years)							
PART-A BIOPHYSICAL IMPACTS: (for most common) Impact on crop yield 1 = Positive 2 = Negative 3 = no change							
Minimum change in yield experiences (mds/acre) *in case lower intensity (if frequency > 1)during last 10 years*							
Maximum change in yield experienced (mds/acre) in case higher intensity of weather change during last 10 years							
Year of occurrence of last stress event by stage							
Decrease in yield during last stress event (Mds/acre)							
Normal season yield Mds/acre – if no stress during the season							
PART-B Pathways causing yield loss/increase 1 = more weed infestation 2 = insect attack 3 = disease 4 = less germination 5 = crust formation (poor germination) 6 = decrease in tillering 7 = flowering/reproduction disturbed 8 = grain shrivelling due to heat stress 9 = lodging 10 = reduced time period for grain formation (small grains) 11 = delay in sowing 12 = additional moisture 13 = wetting of grains/crop 14 = harvesting/threshing losses 15 = other – (Ref of CP 6.3.2) (stress may be more than one at one stage							
Share of produce that was affected by quality (%) (0 if no effect on quality)							
If it affected quality what was the effect observed: 1 = change in taste 2 = change in color 3 = decrease grain size 4 = other (specify)							
Decrease in prices due of quality deterioration (%)							
Decrease in prices of straw due of quality deterioration (%)							
Area Affected during last event (%)							
Area Left Unsown during last event (%)							

—

Crop stages	**Pre-sowing (1)**	**Sowing (2)**	**Germination (3)**	**Tillering & Veg. Growth (4)**	**Reproductive (5)**	**Grain formation (6)**	**Harvesting (7)**
PART-C ADAPTATION adopted to avoid losses from such weather hazards: Adaptations options given below (may be more than one for a stress)							
Adaptation options to avoid/reduce expected losses: 1 = *Re*-sowing of same crop 2 = Sowing of alternate crop 3 = High seed rate 4 = Low seed rate 5 = Adopted heat/ moisture stress tolerant new variety 6 = Planted old/traditional variety 7 = Supplemental/additional irrigation 8 = Changed cropping pattern (adjusted new crop) 9 = Changed sowing method 10 = Additional/higher dose of inputs/fertilizer 11 = Grow low input crop (taramera/pulses) 12 = Introduced intercropping 13 = Changed crop rotation 14 = early sowing 15 = late sowing 16 = Left land fallow 17 = Improved crop production practices 18 = Started planting trees at boundaries for supplemental income 19 = Shifting from crop to livestock 20 = Diversification towards HVA 21 = Check/follow weather forecasts for adjusting production practices 22 = ploughed fields to prepare land for early sowing of next crop 23 = availed insurance 24 = use of weedicide 25 = supplemental irrigation 26 = Bar harrow/light cultivator to break crust 27 = Drying of harvested crop 28 = no sowing at all 29 = Planted old variety 30 = Any other specify							
Which of above you adapted (most often or last one)							
Cost of this adaptations (Rs./acre) (combine cost if more than one adaptation opted at one stage)							
How much was this adaptation effective % (recover % income or reduce loss compared if not opted this adaptation)							
What are your expectations for future regarding such stresses by stage (1 = increase 2 = decrease 3 = no change 4 = no response							
If frequency of stresses increases in future, How you will cope with it? 1 = current adaptations are sufficient 2 = drastically change farming practices 3 = stop sowing this crop 4 = had no option except to continue current practice/crop 4 = other							

PART-D Did you opt any of the coping strategy to sustain livelihood due to severe losses from CP during last 10 years
List of coping/ adaptation strategy 1 = Sold livestock animals 2 = Improve food storage facility 3 = Sold part of land for alternative business 4 = Leased /out part of land for alternative income 5 = use of savings 6 = Sold other assets 7 = Sold trees 8 = Started off farm labor/Employment in local area 9 = Some family member migrate out for other employment to supplement family income 10 = Support from existing Non-farm business 11 = Other (specify)
What would be possible adaptation strategies to sustain your livelihood/food security against increasing climate stresses 1 = Crop diversification 2 = Increase livestock 3 = Shift to HVA 4 = Off/non-farm activity 5 = Any other (specify——)
What are the major constraints to adapt to stresses as discussed at different stages under CC 1 = financial 2 = technical (technology and knowledge) 3 = other
PART E: Supply demand aspect; Do the losses from weather hazards result in changes in overall production (supply side variability) significantly that also affect prices 1 = yes 2 = no
If yes; Do prices increase (due to low production/supply) compensate for the yield loss to balance net income 1 = yes 2 = no
How often you have to purchase this commodity for your household consumption during last ten years due to losses from critical period (#)

Module 7. Adaptive Capacity

What strategies/options (Planned) you are considering to cope with perceived weather changes for future

Options	(1 = yes 2 = No)		(1 = yes 2 = No)
Change in cropping Pattern		Use of improved seed	
Changing crop mixes		Improving soil health through fallowing/ improved tillage/drainage	
Change Irrigation management at plot level (time, qty., ferq)		Investment in water conservation and rainwater harvesting	
Change Irrigation methods		Invest in irrigation facility (tube well/HEIS)	
Improve moisture conservation –crop cover inter cropping, deep ploughing		Shift towards livestock	
Shift towards horticultural crops		Shift towards non-farm activities	

How farmer consider important the following factors to adapt to critical stress periods

Rank as 1 = Highly Important, 2 = Important, 3 = Neutral, 4 = Less Important 5 = Not important at all

Information on weather forecast	Technical guidance	Technology	Alternative crops	Crop Insurance	Other Specify

Factors that support flexibility to cope with critical stress periods at individual level

You have or can easily hire machinery (tractor, harvester etc.) if required for re-sowing or harvesting due to some critical stress period within the required time period 1 = yes 2 = no	You can manage (have access) additional irrigation water (own or rented tube well, pond, stream etc.) required during stress like seasonal drought or heat stress or frost 1 = yes 2 = no
You can hire farm labor to do some crop management practices to avoid losses in face of some uneven weather events 1 = yes 2 = no	You can arrange finances for input timely to respond to weather stresses (e.g. seed, additional fertilizer, supplemental/additional irrigation, pesticides etc.) 1 = yes 2 = no
Seed of possible alternate crops (sowing of alternate crop in case of crop failure due to some weather stress) is easily available to you from local market 1 = yes 2 = no	Required variety is also available to you from local/district level 1 = yes 2 = no
Are new varieties resistant to moisture stress 1 = yes 2 = no	Are new varieties more resistant to heat stress 1 = yes 2 = no
Are new wheat varieties of short duration 1 = yes 2 = no	Are new rice varieties of short duration 1 = yes 2 = no
You can get credit to invest at farm or meet HH requirements from 1 = relatives/friends 2 = formal sources 3 = commission agents /input dealers 4 = private money lender 5 = other (answer may be more than one)	Community members participate in collective action (in terms of labor, finances and resources) to manage common resources (irrigation, grazing lands) 1 = yes 2 = no
Are you in contact with extension agent (1 = yes 2 = no)	If yes what type of service you get from extension staff 1 = technical advice 2 = literature 3 = inputs 4 = weather forecast 5 = other (may be more than one)
From whom did you get weather forecast most often1 = relative/fellow farmer 2 = extension deptt 3 = TV 4 = Mobile application 5 = website 6 = other	How often do you get weather forecasts from this source? 1 = daily 2 = Weekly 3 = fortnightly 4 = monthly 5 = once or twice in a season
Did you use any of the advice and information about when to plant crops from this source 1 = yes 2 = no	Is such information helpful to make adjustment in crop management to minimize risk 1 = yes 2 = no
Possible adaptations/coping mechanisms are proposed for different crops along with such information 1 = yes 2 = no	If yes; do you consider such information for planning and implementing proposed adaptations 1 = yes 2 = no
If yes; are such adaptations effective to cope with such stresses 1 = yes 2 = no	Is weather forecast accurate 1 = yes 2 = no

If farmer is willing to spare more time please get cost of production per acre

8. Crop Management practices as per last cropping season (two to three major selected crops from each study sites)

Operations	Units	Price Rs./unit	Wheat	Rice/Potato/maize/g.nut
Previous season crop at the main plot 1 = fallow 2 = cropped (write name of crop)				
Name of Variety				
Land preparation				
Main power source 1 = tractor 2 = animal				
Deep tillage/MB plow	No./acre			
Cultivator	No./acre			
Planking (sole)	No./acre			
Rotavator/disc plow	No./acre			
Seed bed Preparation				

Cultivator	No./acre			
Planking (sole)	No./acre			
Puddling	No./acre			
Sowing method: 1 = Drill, 2 = Broadcast 3 = Bed planting 4 = Ridges 5 = transplanting				
Seed rate	Kg/acre			
Seed Price	Rs./kg			
Planting cost (labour)	Rs./acre			
Planting cost (Tractor)	Rs./acre			
Seed treatment cost (Rs/acre) (0 if no treatment)				
Planting date	Week/Month			
Irrigation Total	No./acre			
Tube well/ pumped water	No/acre.			
Canal/stream	No./acre			
Conjunctive use	No./acre			
Irrigation method 1 = Flood 2 = Furrow 3 = Other ————				
Fertilizer use: Basal dose				
DAP	(Bags/acre)			
Urea	(Bags/acre)			
Others (Specify)	(Bags/acre)			
Top dressing				
Urea	(Bags/acre)			
Others (Specify)	(Bags/acre)			
Others (Specify)	(Bags/acre)			
Operations	**Units**	**Price Rs./Unit**	**Wheat**	**Rice/Potato/maize/g.nut**
Animal FYM	(Trollies/Acre)			
Poultry manure	(Trollies/acre)			
Manual weeding	(Rs./acre)			
Chemically weeding	(Rs./Acre)			
Insecticide use	(Rs./Acre)			
Harvesting method 1 = Manual 2 = Reaper 3 = Combine				
Harvesting cost (Machine + Labour)	Rs/acre			
Harvesting cost	Mds/are			
Threshing method 1 = Manual 2 = Tractor 3 = Combine				
Thresher cost	(Rs/acre)			
Threshing cost	(share in % of yield)			
Threshing labour cost	Rs./acre			
Grain **yield**	(Mounds/ac)			
Grain prices	(Rs/md)			
Dry stalk/ straw production	Mds/acre			
Dry stalk prices	(Rs/ md)			
Grains kept for home consumption/seed etc. (mds/year)				

Comments and field notes for important changes wrt CP and adaptations:
____.
____.
____.
____.
Edited by: _________ Signature _________date____.
Cross checked by: ___________ Signature _________date____.
Data entered by: ___________ Signature _________date____.

Appendix B. Impacts on crop yield by cropping systems

The potential damage measured as average yield loss from each of the pathways of a hazard under no coping situation is summarized by pathways and crop stages in Table B.1.

In the IP, rice crop though planted under irrigated conditions, rainfall was still an important factor affecting crop yield and farmers crop management decisions throughout rice season. A delayed start of summer rains (monsoon)/decrease in surface water supply caused delay in rice sowing leading to 15% yield decline. Farmers experienced such events almost once in three years. A heavy rain shower plus wind if coincides with completion of rice transplanting time (day), results in uprooting of seedlings. Farmers had experienced such events twice in a decade and on an average it resulted in one third yield decline. Dying of seedlings just after transplanting due to high temperature was causing 26% yield decline. The rice crop was also prone to high temperature during vegetative stage resulting in wilting of plants leading to 20% yield decline. Submergence of rice fields at low lands due to events of heavy (continuous) rains and localized floods was a common issue that caused wilting leading to heavy loss (harvest loss) if farmers could not cope. Even if farmer could drain out excess water, yellowing of leaves with 10–20% yield loss was reported. About 15% lower yield was associated to less tillering in case of less rains during vegetative stage. Heavy/continuous rains, heavy winds, high temperature and hailstorm during rice reproductive stage affected reproduction process and caused lodging leading to harvesting and threshing losses. Disease incidence due to higher temperature and continuous rains (hot humid weather) at reproductive and grain formation stage caused poor grain filling/ empty grains. The yield loss from higher temperature varied from 15 to 40% during reproductive and grain formation stages in rice. The yield loss from lodging due to rain at maturity stages varied for 9% to 32% depending upon the intensity of the hazards beside rice quality deterioration and additional cost of drying, harvesting and threshing. The over wet conditions due to rain or flooding around rice harvesting had worse impacts as delay in harvesting and loss in rice could not be avoided while harvest loss due to no wheat sowing was reported for low lands with less drainage.

Farmers considered early vegetative stage of wheat more sensitive to the moisture excess in R-W cropping system. It caused higher level of yield loss (68%) in wheat after rice at low lands during vegetative as compared to reproductive (38%) and grain formation stage (48%). There were also some commonalities in hazards and their impacts on wheat crop in R-W and G-W cropping systems. Moisture stress led to 10% yield loss during vegetative stage in IP while 27% in MH due to less tillering and lower plant growth under rained conditions. Increasing frequency of less moisture (low water supply and less rains) was reported as compared to excess moisture from a heavy or continuous rains for wheat crop. The yield loss from an un-seasonal rain just after wheat sowing (pre-germination stage) caused from 35 to 40% yield loss because of crust formation once in four years. Short heat spike and higher temperature than normal at grain formation was one of the common hazards with increasing trend and caused grain shrivelling leading to 20 to 25% yield loss in rice, groundnut and wheat. Rain at harvesting stage for rice, wheat and groundnut led to 5–10% yield loss due to wetting of crop. Though it causes minor yield loss but creates operational difficulty and require more time for threshing that increases cost. Higher risk of storage losses for wheat due to high moisture contents and higher losses (upto 30%) from price decrease in groundnut due to quality concerns if it rains during harvesting stage.

A seasonal drought during pre-sowing stage of groundnut caused delay in sowing resulting in 20% yield decline. A heavy rain at sowing also caused delay in sowing but relatively less yield loss than moisture stress. Higher temperature during sowing, germination stages and pod formation (especially under dry weather) affects groundnut yield. A yield decline by 14% during sowing and 40%t during germination and 25% during pod formation stages was associated with high temperature. Less rains or seasonal drought at early vegetative stage leads to 32% yield loss because of less tillering and wilting, 42% yield loss because of less pegging at reproductive stage and 35% yield loss due to small/single pods at grain formation stage. Higher insect attack was also common problem reported in case of less rains at vegetative to pod formation stage leading 30 to 40% yield loss in groundnut.

Among other common issues in different cropping systems, high weed infestation from heavy rains during early vegetative stage caused 10 to 25% yield loss in wheat, maize and groundnut. The winds (with rain) caused lodging leading to yield loss due to disturbance in flowering, less grain formation, difficulty in harvesting and threshing ranging from 10 to 30% of the normal season yield across in different crops from low to high altitude.

In MV and HM, low temperature during early and late stages was common hazard affecting germination or ripening of crops. The delay in winter (decrease in temperature) result in delay in sowing due to two reasons, i) lower temperature affects germination, ii) shortage of water (delay in snowmelt). The pre-sowing season of wheat is dormant period in both of the mountainous sites. The sowing starts with water availability from snowmelt at end of January. Low temperature (non-availability of water) was the main factor causing delay in wheat sowing and 20 to 30% yield loss while at germination stage it caused 20 to 40% yield loss due to wilting of early seedlings. Higher frequency of water shortage in HM (4 times per decade) as compared to MV (2 times per decade) during wheat sowing was reported. Less water supply leads to late sowing with partial fallowing. Farmers also reported 2 to 3 events of decrease in temperature per decade during wheat germination stage.

Heavy or continuous rains caused higher weed infestation at early vegetative stage of maize resulting in 14% yield loss. Flash floods from a heavy rain shower disrupting water supply was also common problem in the mountainous agriculture. It mainly affected the maize crop while few incidences during wheat growing season were also reported in MV. The yield loss varied from 20 to 45% due to wilting of crop but in severe cases a harvest loss, once in five years was also reported. Among other common hazards, hot-humid weather conditions “lome” cause 30 to 50% yield decline in wheat, maize and potato in these systems. Winds especially a wind with rain caused severe lodging in wheat and maize after vegetative growth stages. Yield loss from 20 to 40% was reported from lodging in maize and wheat in MV an HM. Wetting of harvested crop from rains was another common issue for wheat in mountainous agriculture as well.

In HM, potato crop was affected by decrease in temperature starting from delay in potato sowing causing 14% yield loss. A sudden decrease in temperature after sowing of potato makes potato seed fluffy that does not germinate resulting in yield loss upto 50%. The temperature fluctuations during potato germination (freezing at night or high during day) cause wilting and 11 to 28% yield loss. A sudden decrease in temperature at maturity before harvesting caused higher losses in potatoes especially a sudden cold spike near maturity caused freezing of tubers (quality deteriorates leaving potatoes unmarketable) leading 30 to 40% losses in potato. Heavy or continuous rains caused root water logging in potato that led to wilting and yellowing of potato plants resulting in yield decline upto 27%. The impact of individual hazards by considering the pathways for each cropping system is summarized for individual crops in Table B.1.

Table B.1
Impact on crop yield by pathways and crop stage (% yield loss).

Cropping systems	IP		MH		MV		HM		Overall
Row labels	Rice	Wheat	G.nut	Wheat	Maize	Wheat	Potato	Wheat	
Pre-sowing		**11.65**	**47.00**	**48.65**					**38.11**
Heavy rain		**17.54**							**17.54**
Delay sowing (PF)		17.54							17.54
Less rain (w. supply)		**8.70**	**47.00**	**48.65**					**40.16**
Delay sowing (PF)		8.70	20.50	35.81					25.21
No sowing			100.00	100.00					100.00
Sowing	**20.44**	**17.88**	**16.75**	**4.29**		**53.32**	**14.35**	**32.42**	**22.86**
Heavy rain	**30.98**								**30.98**
Up-rooting	30.98								30.98
High temperature	**26.79**		**13.88**	**8.57**					**16.41**
Delay sowing (PF)				8.57					8.57
Less germination	26.79		13.88						20.34
Less rain (w.supply)	**14.81**					**61.05**		**32.42**	**33.16**
Delay sowing (PF)	14.81					22.09		32.42	19.79
No sowing						100.00			100.00
Low temperature						**37.86**	**14.35**		**26.11**
Delay sowing (PF)						37.86			37.86
Less germination							14.35		14.35
Un-seasonal rain		**17.88**	**18.18**	**4.29**[a]					**15.72**
Delay sowing (PF)		17.88	18.18	4.29[a]					15.37
Weeds			18.18						18.18
Germination	**39.99**	**35.12**	**45.30**	**34.67**		**45.71**	**21.08**	**33.78**	**35.12**

(*continued on next page*)

Table B.1 (*continued*)

Cropping systems	IP		MH		MV		HM		Overall
Row labels	Rice	Wheat	G.nut	Wheat	Maize	Wheat	Potato	Wheat	
Heavy rain	**48.59**								**48.59**
Submergence	48.59								48.59
High temperature	**20.32**		**39.79**	**12.37**			**10.99**		**21.86**
Less germination	20.32		39.79	12.37			10.99		21.86
Less rain (w.supply)	**60.91**					**45.71**	**20.58**	**48.08**	**43.55**
Less germination	21.82					45.71	20.58	48.08	34.14
Wilting	100.00								100.00
Low temperature							**28.15**	**19.47**	**24.68**
Less germination							28.15	19.47	24.68
Un-seasonal rain		**35.12**	**48.05**	**40.25**					**40.68**
Less germination		35.12	48.05	40.25					40.68
Vegetative	**46.89**	**29.86**	**22.72**	**18.85**	**50.25**	**68.75**	**54.03**	**33.93**	**36.56**
Flooding	**78.78**				**81.36**	**68.75**	**81.78**	**45.36**	**74.74**
Wilting	78.78				81.36	68.75	81.78	45.36	74.74
Heavy rain			**15.63**	**14.66**	**13.89**		**26.28**		**17.39**
Insect attack			2.65						2.65
Weeds			24.28	14.66	13.89				19.34
Wilting							26.28		26.28
Less rain (w.supply)	**15.00**	**10.12**	**40.46**	**27.22**					**22.62**
Insect attack			31.87						31.87
Less tillering	15.00	10.12	49.05	27.22					21.08
Un-seasonal rain		**39.73**							**39.73**
Weeds		10.61							10.61
Wilting		68.85							68.85
Winds (rain)					**24.41**			**28.22**	**26.95**
Lodging					24.41			28.22	26.95
Reproductive	**21.01**	**33.33**	**36.42**	**23.52**	**45.18**	**27.09**	**23.35**	**55.54**	**31.07**
Flooding					**45.44**	**25.00**	**40.43**	**84.36**	**54.17**
Wilting					45.44	25.00	40.43	84.36	54.17
Hails	**39.94**	**18.09**		**32.53**					**30.19**
Spike damage	39.94	18.09		32.53					30.19
Heavy rain	**17.07**	**40.28**					**15.42**		**26.78**
Disease	15.13								15.13
Disturb rep	20.95	20.13							20.54
Wilting		50.35					15.42		38.71
High temperature	**19.14**	**28.57**		**18.94**					**20.68**
Disease	17.50								17.50
Disturb rep	20.77	28.57		18.94					22.26
Hot-humid					**56.04**	**29.76**	**12.52**	**20.38**	**26.83**
Disease								20.38	20.38
Insect attack					56.04	29.76	12.52		28.12
Less rain (w.supply)			**36.42**						**36.42**
Insect attack			30.69						30.69
Less pegging			42.14						42.14
Low temperature							**35.86**		**35.86**
Wilting							35.86		35.86
Un-seasonal rain				**21.59**		**24.26**			**22.93**
Disturb rep				21.59					21.59
Lodging						24.26			24.26
Winds (rain)	**21.22**	**32.51**		**21.02**	**33.80**	**26.69**		**33.08**	**27.08**
Disturb rep	18.85								18.85
Lodging	23.58	32.51		21.02	33.80	26.69		33.08	28.45
Grain formation	**26.41**	**31.77**	**33.74**	**21.37**	**34.93**	**29.20**	**34.79**	**33.82**	**30.81**
Flooding					**38.44**	**30.00**	**46.39**	**29.40**	**35.98**
Wilting					38.44		46.39	31.60	38.81
Grain shrivel						30.00		25.00	27.50
Hails	**38.33**	**31.23**		**22.73**					**30.76**
Spike damage	38.33	31.23		22.73					30.76
Heat stress		**19.69**		**17.75**					**19.04**
Grain shrivel		19.69		17.75					19.04
Heavy rain		**41.93**							**41.93**
Lodging		30.26							30.26
Wilting		47.76							47.76
High temperature	**20.39**		**24.79**						**21.49**
Insect attack	23.06								23.06
Grain shrivel	19.05		24.79						20.96
Hot-humid					**33.35**	**31.52**	**31.78**	**43.49**	**33.95**
Disease						31.52		43.49	37.51
Insect attack					33.35		31.78		32.17
Less rain (w.supply)			**38.22**	**22.64**					**33.02**
Insect attack			41.43						41.43
Grain shrivel			35.00	22.64					28.82
Low temperature								**33.15**	**33.15**

(*continued on next page*)

Table B.1 (*continued*)

Cropping systems	IP		MH		MV		HM		Overall
Row labels	Rice	Wheat	G.nut	Wheat	Maize	Wheat	Potato	Wheat	
Delay ripening								33.15	33.15
Thunderstorm							**20.59**		**20.59**
Wilting							20.59		20.59
Winds (rain)	**32.57**	**25.98**		**21.88**	**29.48**	**26.07**		**38.06**	**27.99**
Lodging	32.57	25.98		21.87	29.48	26.07		38.06	29.01
Grain shrivel				21.88					21.88
Harvesting	**8.86**	**7.07**	**7.01**	**5.81**		**14.22**	**35.31**	**13.41**	**13.14**
Low temperature							**35.31**		**35.31**
Freezing of tubers							35.31		35.31
Un-seasonal rain	**8.86**	**7.07**	**7.01**	**5.81**		**14.22**		**13.41**	**9.97**
Wetting of crop	8.86	7.07	7.01	5.81		14.22		13.41	9.97
Grand Total	**28.77**	**27.53**	**32.44**	**27.54**	**43.45**	**36.55**	**30.78**	**36.06**	**31.48**

PF = Partial Fallow.

[a] Increase in yield due to additional moisture from rain compensates for delay in sowing in rainfed ecology.

Appendix C. Possibility of coping and adoption level

Coping/cropping system	**IP**	**MH**	**MV**	**HM**	**Overall**
Coping possibility	**Responses to cope by hazards' pathway (# of responses)**				
Yes	445	436	141	262	1,284
No	125	217	116	92	550
Total	**570**	**653**	**257**	**354**	**1,834**
Adoption of coping strategy	**Current level of adoption of coping practices (# of responses)**				
Yes	383	370	85	181	1,019
No	62	68	56	81	267
Total	445	438	141	262	1,286
	Coping possibility and adoption level from available choices (%)				
Coping possibility	78.07	66.77	54.86	74.01	70.01
Adoption	86.07	84.86	60.28	69.08	79.36
No-adoption	13.93	15.60	39.72	30.92	20.79

Appendix D. Cost (% of the value of recovered yield) and effectiveness of coping (% of yield recovered)

Study sites	**IP**		**MH**		**MV**		**HM**		**Total**	
Row labels	**Cost**	**Effectiveness**	**Cost**	**Effectiveness**	**Cost**	**Effectiveness**	**Cost**	**Effectiveness**	**Cost**	**Effectiveness**
Flooding	**8.89**	**85.00**			**18.51**	**80.40**	**17.83**	**56.17**	**17.37**	**68.67**
Repair w. channel					18.51	80.40	17.83	56.17	18.14	67.18
Drained water	8.89	85.00							8.89	85.00
Heat stress	**17.59**	**74.00**							**17.59**	**74.00**
Supplemental irrigation	17.59	74.00							17.59	74.00
Heavy rain	**13.76**	**81.40**	**17.82**	**73.75**			**5.64**	**64.00**	**13.76**	**75.95**
Stop irrigation							0.00	38.00	0.00	38.00
Pesticide use	28.69	75.00	16.30	71.67					19.40	72.50
Drained water	3.72	73.67							3.72	73.67
Hoeing			22.37	80.00					22.37	80.00
Add fertilizer							11.28	90.00	11.28	90.00
Partial re-sowing	21.35	96.20							21.35	96.20
High temperature	**21.38**	**73.24**	**24.45**	**88.00**			**12.93**	**79.50**	**20.40**	**77.06**
Pesticide use	30.72	71.00							30.72	71.00
Supplemental irrigation	15.03	76.67					0.89	74.00	12.21	76.13
Partial re-sowing	28.06	64.00	24.45	88.00			24.96	85.00	25.48	81.25
Hot-humid					**21.55**	**92.00**	**13.99**	**78.33**	**15.88**	**81.75**
Supplemental irrigation							0.28	80.00	0.28	80.00
Pesticide use					21.55	92.00	20.85	77.50	21.09	82.33
Less rain (w.supply)	**34.22**	**79.21**	**9.26**	**69.17**			**32.33**	**75.00**	**23.99**	**74.63**
Hoeing			11.18	65.00					11.18	65.00
High seed rate	29.70	60.00	4.17	70.00					16.93	65.00
Add fertilizer			9.66	65.00					9.66	65.00
Changed variety			9.19	70.00					9.19	70.00
Partial re-sowing							32.33	75.00	32.33	75.00
Additional seed fertilizer	59.19	78.00							59.19	78.00
Pesticide use			11.68	80.00					11.68	80.00
Supplemental irrigation	30.13	83.30							30.13	83.30
Low temperature							**5.22**	**74.88**	**5.22**	**74.88**
Supplemental irrigation							2.18	66.00	2.18	66.00

Partial re-sowing							16.53	80.00	16.53	80.00
Early harvesting							0.00	87.50	0.00	87.50
Un-seasonal rain	**23.56**	**77.94**	**16.17**	**88.64**	**24.50**	**70.00**	**18.18**	**90.00**	**20.13**	**82.81**
Drained water	21.65	62.50							21.65	62.50
High seed rate	9.04	73.00							9.04	73.00
Pesticide use	31.53	73.00							31.53	73.00
Bar harrow	6.45	81.00	5.24	75.00					5.65	77.00
Bar harrow +Fertilizer			16.66	87.00					16.66	87.00
Drying	29.38	78.50	19.43	80.00	24.50	70.00	18.18	90.00	23.39	79.50
Supplemental irrigation	8.76	84.00							8.76	84.00
Partial re-sowing	14.23	84.00	11.91	89.50					12.68	87.67
Additional seed fertilizer	56.02	92.00							56.02	92.00
Re-sowing	27.59	90.00	22.51	94.50					24.21	93.00
Add. cultivator + fertilizer	27.04	76.25	21.51	105.00					23.35	95.42
Winds (rain)							**0.00**	**40.00**	**0.00**	**40.00**
Stop irrigation							0.00	40.00	0.00	40.00
Grand Total	**23.64**	**77.94**	**15.35**	**80.91**	**19.30**	**80.57**	**13.73**	**68.50**	**18.81**	**76.63**

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