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Adaptation in rice-wheat based sodic agroecosystems: A case study on climate resilient farmers' practices

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Resource-poor farmers, living in marginal environments and more directly dependent on local natural resources, have developed location specific agricultural knowledge systems that help them to adapt to climatic variability. In this research, we documented farmers' perceptions of climatic variability and related adaptive practices in three selected hamlets of Azamgarh district of eastern Uttar Pradesh, India. Data were collected with 60 farmers using participatory rural appraisal (PRA) tools and personal interview methods. We found that the farmers are experiencing climatic variability as reflected by reduced frequency of rains and increased rainfall intensity, and that the farmers' observations were consistent with climate data of the past 100 years (from 1901 to 2000), where at several intervals variations in rainfall were very high. To combat climatic variability among resource-poor community and sodic agroecosystems, farmers have developed, through trial and error, a number of adaptive practices in their subsistence agriculture. These include crop diversification, agronomic manipulations and mixed cropping. Small-scale and marginal farmers practice biodynamic agriculture, where they maintain more than 10 crop species with minimal use of external inputs. Soil type, season, nutrient demand, soil fertility, cost of cultivation and local ecological knowledge are all considerations in these systems. These farmers also use indigenous practices to manage the insect pests in their crops. These adaptations help farmers to reduce environmental risks and minimize crop failures, and thus enhance the livelihoods. Farmers consider their location specific crop systems to be ecologically sustainable, economically viable and culturally acceptable.

Keywords: Informal experimentation, Traditional ecological knowledge, Location specific adaptations, Rice-wheat based agroecosystems

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It is well understood that the best available knowledge is found not only in formal institutions and scientific literature, but also among local communities, especially those directly dependent on natural resources, who intensively interact with local ecosystems day to day[1]. Such 'traditional ecological knowledge' (TEK)[2], is being adapted by local communities to help combat climate variation and related ecological challenges, within the context of particular social-ecological systems[3]. Over the centuries, Indian farmers, particularly those living under fragile and marginal environments, have developed climate resilient farming systems and adaptive management approaches for their natural resources through location specific TEK. They have refined the potential practices available with them through years of deliberate selection, planned exposure to natural conditions and other manipulations[4,5]. Resource conservation practices of local farmers drawn from their TEK have been described from many parts of the world, and these cover different environments and cultures[1-3]. Climatic variability coupled with socioeconomic and institutional factors are the driving forces behind the development of location specific TEK led agricultural adaptations. The culture, local economy, and ecological feasibility for agricultural adaptations have led the processes of natural resource conservation and sustainable management of social-ecological systems[4,6,7].

The advent of the Green Revolution, marked by heavy and indiscriminate use of energy intensive chemical inputs and the overexploitation of natural resources, caused an array of socioeconomic and environmental problems. Further, over the last two decades or so the changing climate has aggravated the vulnerability of agricultural systems in the Indo-Gangetic plains. To combat these problems, researchers and officials from scientific institutions have proposed many solutions. Unfortunately

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however, these measures are more suited to large-scale farmers and macro-climatic scenarios. Most of the problems relating to agricultural sustainability are location specific and need solutions at the micro-climatic scale. The approaches offered by scientific institutions do not comply with the basic tenets of traditional agriculture and or socio-ecological ethos of the marginal, small-scale farmers. The need for focused, local solutions has been a driving force towards developing cost effective, ecologically viable and sustainable adaptive agricultural practices[8,9].

The farmers themselves are the experimenters and innovators of many sustainable adaptations[8,9]. They have become specialists in surviving the vagaries of weather. Yet, their unique knowledge and skills relating to crop management, agronomic manipulations and natural resource management are not fully appreciated and recognized by researchers[7-10]. In this study, an attempt has been made to record these farmers' perceptions of climatic variability and to document their agricultural adaptive practices for combating the climatic, ecological and socioeconomic problems.

The study was carried out with the following objectives: (i) to study the farmers' perceptions of climatic variability and to compare these perceptions with 100 yrs of recorded climate data, and (ii) to explore the suitability and effectiveness of location specific climate resilient farmers' knowledge and adaptive practices, particularly in rice-wheat based sodic agroecosystems.

Research methodology

Study area

The Azamgarh district, lying between 25^0 38" and 26^0 27' North latitude and 82^0 40" and 83^0 52' East longitude, is situated in the eastern plain agro-climatic zone. The district has a humid sub-tropical climate with mean annual temperature ranging from a maximum of 44.6°C (summer) to a minimum of 1.1°C (winter). The average annual rainfall of the district is about 878 mm[11]. Wheat (*Triticum aestivum*) and rice (*Oriza sativa*) constitute the staple food crops and form major cropping systems in the district. The study area comes under the irrigated rice-wheat based cropping system which covers about 32% of the total area and 42% of the total wheat area in the four neighbouring countries of India, Pakistan, Bangladesh and Nepal[7]. Most of the rice-wheat based cropping systems are fully irrigated. Identifying the processes that govern the sustainability of rice-wheat based agro-ecosystems in both irrigated and rainfed conditions with site specific attributes is crucial for developing resource conserving and sustainable production technologies[7]. The soils of this region are sodic (*p*H 8.4 to 10.1) and sandy clay in texture, brown to medium black in colour, with flat topography[11]. The economic condition of the farmers is poor to moderate, making them incapable of bearing the costs of external inputs required for energy-intensive agriculture. The social customs, food habits and family structure of these farmers are also factors contributing to their development and use of location specific indigenous agriculture practices.

Approach of study

A qualitative (explanatory) research design was adopted to explore the information documented in this study. This approach was used to learn from the local people as they use, perceive, and sustainably conserve their environment and natural resources for subsistence agriculture and optimizing livelihoods[12]. The research was undertaken in three randomly selected hamlets-Sonapur, Sewta and Hamirpur (which together constitute the Sonapur village), from the Jahanaganj Developmental Block of Azamgarh district, eastern Uttar Pradesh.

To record the farmers' perceptions, knowledge and practices, a representative group was selected of 60 resource-poor farmers (20 from each of the 3 hamlets) belonging to different (45-80 yrs) age groups and using different resources. This group was interviewed for data on climatic variability and documenting the adaptive practices. Wherever required, a few key knowledge holders of this group participated in Focus Group Discussions (FGD) for describing their key adaptive practices (developed through informal experimentation)[13]. To allow intensive discussions on the adaptive agricultural practices, the key knowledge holders, elders of villages and members of Village *Panchayat* were selected purposively for participation. These leading communicators provided baseline data on the cropping systems and related natural resource management at the village level.

An analysis of the agroecosystem (interaction of agricultural resources with ecosystems and society) was carried out with the help of well-informed and creative farmers (5 from each hamlet) having small-sized land holdings. This PRA (Participatory Rural Apprisal) tool allowed us to determine the present status of natural resource management and use at the village level. The adaptive practices of farmers on cropping systems under changing climate and socio-economic conditions were recorded through personal interviews in combination of FGD (Focus Group Discussion), transect walks and participant observations. The transect walks were carried out with a group of farmers, and allowed us to collect soil samples for analysis of *p*H and electrical conductivity (EC), confirming the sodic nature of the soils. These analyses were undertaken at the Central Soil Salinity Research Institute, Kanral, Haryana. The transect walks further helped to differentiate variation among different soil types, cultural practices adopted for different crops and cropping system diversity.

The status of farmers, as resource-rich (RR) or resource-poor (RP), was determined on the basis of land holding size, type of soil, topography, cropping system, cash crop(s) grown, use of labour, use of purchased inputs, use of agricultural implements and overall problems[8]. An interview schedule with open-ended questions was the major tool applied in exploring the farmers' adaptive practices and their compatibility with social and biophysical factors. While for measuring perception about climatic variability, closed types of questions were used. The interview schedule was first pilot tested with sample questions, and on the basis of farmers' feedback, ambiguous questions were deleted and/or refined to ensure reliability in the dataset. A few selected adaptive practices were compared for documenting the sustainability statistics. Data on sustainability statistics, vulnerability and adaptive capacity of farmers were also compiled from grey literature, secondary sources and field observation. The data were analyzed with descriptive statistics (frequency, mean, percentage, CV and standard error) to draw valid inferences.

Results

Perception of farmers about climate variability

The farmers in this study mostly belonged to the small and marginal agricultural categories (85.0%) and had a moderate to high level of vulnerability with low to moderate levels of adaptive capacity (Table 1). In general, the farmers are experiencing climatic variability (Table 2). For example, a majority (89.3 %) of the farmers in the study agreed that winters have decreased in duration (Table 2). Similarly, the weather in general has become less predictable, with increased frequency of droughts and floods in the recent past. Indigenous biometeorological indicators include the flowering time of trees (*Madhuca latifolia* and *Azadirachta inidica*), flying of insects (dragon fly), baths taken by house sparrows (*Passer domesticus*), different colours of clouds, wind direction (during April and May blowing of *loo*- blowing of wind from West to East is must; during *Shrawan* month, there should not be wind blow from West to East) being used in predicting weather have become relatively less reliable, according to about 40 % of the farmers. Few plant species, such as mango during 2012 had late flowering (last week of March to middle of April), while during 2013 till the 10th February, there was no flowering. Whereas, in nearby district Jaunpur, the flowering in mango appeared from 14th January onwards. Such types of anomalies of pre-ponning and post-poning (normal flowering in mango is considered last week of February to middle of March) behavior in mango indicate climatic variability as perceived by the local farmers.

Table 1—Social-ecological system of study area of Azamgarh district

States and districts	Climate & vulnerability level[1]	Farmers and their resource base[2] & number of farmers studied (total 60)	Farming systems	Types of agroecosystems	Adaptive capacity of system[1]
Uttar Pradesh: Azamgarh	Sub-humid, annual average rainfall is 878 to 1021.3 mm. Medium to high level of vulnerab ility	Farmers in majority are resource-poor and population density is 800 persons /km^2. Male led decision making. Low to moderate level of interventions of formal institutions.	Rice-wheat, sugarcane and potato crops. Diversification through cow and buffalo. Common property resources (aquatic and terrestrial) are integral parts of livelihoods. Low to medium use of formal knowledge	Soil is sodic (pH 8.4 to 10.1) and crops are fully irrigated with canal and tube-well. Low level of use of soil & water. Cropping systems are based on some improved and local crop varieties.	Low to medium

[1]Vulnerablity levels and adaptive capacity (using indicators soil, water, climatic, and socioeconomic and globalization data) of the selected districts are mapped by O'Brien et al. 2004; [2]Here resources includes size of land holdings (small farmers with land < 1.0 ha, marginal farmers with land 1.0 to 2.0 ha) and annual income earned by a household; Adaptive capacity was assessed based on personal work and indicators as suggested by O'Brien et al. 2004

Table 2—Farmers' perceptions about climatic variability and its implications in agriculture

Climatic variability and agriculture related variables	Farmers' agreement*				
	Strongly agree	Agree	Undecided	Disagree	Strongly disagree
Duration of winter is decreased	89.3	10.7	00.0	00.0	00.0
Timing of winter start is postponed	82.3	17.7	00.0	00.0	00.0
Duration of summer is increased	92.7	07.3	00.0	00.0	00.0
Timing of summer start is not shifted early	00.0	00.0	00.0	74.5	25.5
Duration of rainy season is decreased	90.6	09.4	00.0	00.0	00.0
Number of rainy days are decreased	95.6	04.4	00.0	00.0	00.0
Event of drought is increased	64.2	25.7	10.1	00.0	00.0
Occurrence of flood is increased over a period of time	52.5	33.8	13.7	00.0	00.0
Weather in general is predictable	00.0	00.0	00.0	90.5	09.5
Types of bio-metrological indicators (flora and fauna) farmers were using 40 yrs back are relatively less effective in predicting weather	40.2	25.5	00.0	00.0	00.0
Due to climatic variability, farmers do not face any problem in their agricultural practices	00	00	02	28	70.0
The climate variability has caused in declining the ground water, and thereby increased energy and time consumption for uplifting ground water	75.0	25.0	00.0	00.0	00.0
Due to climatic variability, now resource-poor farmers are facing more problem than rich farmers in securing livelihood	35.0	45.0	00.0	10.0	10.0
To combat current climate variability, neither government nor farmers and scientific institutions have sustainable solutions/technologies	30.0	65.0	05.0	00.0	00.0
In current climate variability, revival with refinement of indigenous/local crops varieties could be one of the viable adaptations for small and marginal farmers	15.0	35.0	25.0	15.0	10.0
To combat current climate variability, agricultural diversification is an effective option	45.0	40.0	00	10.0	05.0
Farmers should be made an integral part of vulnerability and adaptive research in agriculture	74.0	26.0	00.0	00.0	00.0

*Perception of farmers was measured using scale of Singh (2013)[14]

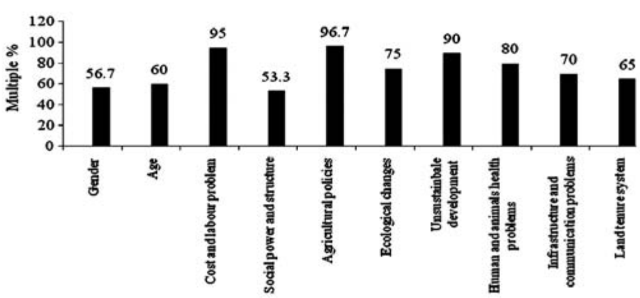


Fig. 1—Factors causing compounded vulnerability with climatic variability in agriculture

The groundwater table has lowered from about 6.10 to 18.30% meter in the last 30 yrs as reported by 75 % farmers. This has resulted in the need for increased energy and more time required for drawing the ground water through tube wells. The farmers' perceptions about climatic variability were consistent with the recorded 100 yrs climate data about 85.0% of the time. Farmers reported that the October 2013 cyclone Phailin, with its heavy torrential rains, affected the matured paddy crop and a vast area under rice became water logged. This event resulted in a considerable reduction of paddy yield, due to delayed harvesting and thereby late sowing of the wheat crop (reducing the period of crop growth). These observations substantiate the view that climate change is now a reality.

Other than the climatic factors, we found different socioeconomic, ecological, institutional and policy factors which make the farmers and their agricultural systems more vulnerable. These variables include gender, age, rising costs of crop cultivation, changes in social structure, inappropriate agricultural policies and the like (Fig. 1). During 2012, erratic rainfall coupled with rising cost of cultivation put the farmers, especially the small and marginal ones, at risk, as revealed by the 85.6% of the respondents. Similarly, a poor response of the state government in the purchase of rice at a minimum support price increased the problems for these farmers, and resulted in an increase of the costs of drying, processing and packaging rice. These observations indicate that even higher input costs could further diminish the marginal returns of farmers and make them even more vulnerable in the changing climatic scenario. The FGD exercise revealed that community managed ponds help to recharge ground water, sustaining indigenous breeds of fish, water for animals and providing life-saving irrigation in places where assured irrigation sources do not exist. As well, forest groves minimize the risks of poor communities by providing multiple benefits (fodder, fuel wood, fruits, grasses, etc.). These natural resources act as micro-ecosystems and give multiple ecosystem services for local communities. However, in the recent past, out of 8 community ponds, only 1 or 2 ponds have been in a functional state. The remaining ponds have deteriorated due to various institutional, socio-political and tenurial problems. A similar situation was observed in the case of community forest groves.

These situations increase the vulnerability and risks especially for marginal and landless people and their related livelihoods. Thus, the farmers' vulnerability assumes a multidimensional aspect. Analysis of historical trends of cropping systems and related practices indicated that a number of cropping systems, along with local crop varieties formerly maintained in sodic environments, are either lost altogether or on the verge of extinction (Table 3). About 72 % of the farmers reported that these cropping systems have deteriorated because of combined impacts of various socioeconomic factors (increased irrigation, dominance of rice-wheat cropping system, improved adaptive capacity of farmers to grow cash crops, etc.) and climatic variability (erratic and high intensity rainfall).

The 5 yrs period mean annual rainfall data revealed that the overall coefficient of variation from 1901 to 2000 (100 yrs) was 9.72%, with a standard error of 30.22 (Fig. 2). During 1920-1925 (1027.6 mm) and 1945-1950 (1157.6 mm), the aberrations in rainfall were very high while for the remaining periods (1901-1919 and 1926-1944), on an average, rainfall was in the range of 900-1000 mm. Again, from 1990 to 1995 and 1996 to 2000, a high aberration was recorded, with mean annual rainfall values of 716.5 mm and 713.4 mm, respectively. At the same time, other than these periods, on an average the annual mean rainfall was in the range of 900-1025 mm. In the 1901-2000 period, on 5 yrs spans, the coefficients of variation for maximum and minimum temperatures were observed to be 0.656 and 1.058 %, respectively with a standard error of 0.0675 (maximum temperature) and 0.0650 (minimum temperature). The overall mean maximum and minimum temperatures were 32.5 ^{O}C and 19.4 ^{O}C, respectively, except the year span 1955-60, when the maximum temperature was 33^{O}C. The lowest annual mean minimum temperature (18.8 ^{O}C) was recorded in the 1970-75 period. When the climate data from 1901 to 2000 were analyzed on decadal basis, more or less the same trend of variations in rainfall and temperature were observed (Fig.3). When comparing this climate data with the farmers' perceptions, we found that, at least on the aspects of reduced period and days of rain, they matched the climate data pattern, particularly over the last 30 yrs.

Adaptation

A. Farmers' adaptive practices for cropping systems

Before the 1980s, farmers generally grew red gram/maize/sorghum/sugarcane and wheat in rice-wheat based cropping systems. Over the years, however, the productivity of this mixed cropping system declined. Erratic rainfall, stray cattle and the menace of blue bulls (*Boselaphus tragocamelus*), drainage blocks caused by infrastructure development, incidence of wilting disease, disintegration of the joint family system and lack of supportive government initiatives acted in unison to suppress this viable cropping systems. Some innovative farmers, endowed with moderate resources, took up the challenge of adjusting to meet these problems and creating new economically viable cropping systems, more feasible and compatible with socio-economic and biophysical conditions. Three major legume crop based models developed by these farmers are described here:

1. Black gram + sorghum (summer) - rice (early) - pea; and sugarcane-wheat for loam (*domat*) soils with gentle slope and facility for irrigation. Black gram and sorghum are sown with only two ploughings. This cropping system not only helps contribute to food security with the pulses, but also provides fodder to cattle, improves soil fertility and promotes crop diversification, reducing environmental risks and ensure higher profits. This model provides a net profit of US$ 160-210 per hectare per year.

Table 3—Combinations of indigenous mixed cropping systems under rice-wheat agroecosystems

Season*	Combination of mixed cropping	Type of agricultural setting	Soil pH and EC	Purpose	Status
Kharif	Maize + red gram + black gram + snap melon	*Bangar jamin* (clay loam soil under rainfed conditions)	8.4 (0.25)	Food during lean period and diversifying food items	Does not exist
	Sorghum + millets (*kodo*, finger millet, *sanwan*, *kutki*)	Upland, soil with gravels and sandy loam without irrigation	9.1 (1.5)	Fodder and food drought or lean period. Foods for meeting out socio-cultural and nutritional demands	
	Sorghum + red gram	Upland, un-irrigated sandy and gravely soils	9.1 (1.5)	Fodder with food and soil fer tility enrichment by legumes	Rare
	Sanwan + sorghum + redgram + snap melon	Upland, loamy clay and gravely soil with un-irrigated condition	9.1 (1.5)	Food during lean period and for meeting out socio-cultural and nutritional demands	Does not exist
	Local paddy (*karhani* variety) + jowar	*Kiyari jamin* (sandy clay soil under rainfed conditions)	9.5 (0.5)	Reducing crop failure	Does not exist
Rabi	Chickpea + coriander + field pea + flax or linseed	*Bangar jamin* (clay loam soil under irrigated conditions)	8.4 (0.23)	Legumes for food, soil fertility improvement and pest control in mixed cropping	Very rare
	Wheat + mustard + barley	*Kiyari jamin* (sandy clay soil with partial to full assurance of water)	9.8 (1.5)	Major food resources and oil	Does not exist
	Chickpea + barley + mustard + field pea	*Kiyari jamin* (sandy clay soil with partial water availability)	9.8 (1.5)	Source of diversified food for human and nutrient rich fodder and feed for animals	Does not exist
	Potato + maize (under zero tillage)	*Bangar jamin* (fertile sandy clay soil with full irrigation facility)	8.5 (0.25)	Cash crop (potato) and food and fodder crop (maize)	Rare
	Potato + raddish + bakla bean (*Vicia faba*)	As above	8.6 (0.30)	Human food and nutrition, soil fertility enrichment by legumes	
	Early variety of rice- lentil	Karail mitti (heavy soil) under water logged conditions	9.5 (0.5)	Lentil is taken as relay crop for pulse and fodder	Rare
Zayad	Sugarcane + urd bean	*Bangar jamin* (fertile sandy clay soil with full irrigation facility)	8.6 (0.35)	Household consumption of sugar and sale to sugarmills for cash. Urd bean as protein source and for enriching soil fertility	Does not exist
	Sugarcane + red gram	As above	8.6 (0.35)	Household consumption of sugar and sale to sugarmills for cash. Red gram as protein source and enriching soil fertility	Few farmers adapt
	Sugarcane + onion + red gram	As above	8.6 (0.35)	Household consumption of sugar and onion and sale in local market for income	Few farmers adapt

*Seasons are defined according to farmers' calendar.
Kharif: Crops of rainy season sown and harvested between first week of June to first week of October.
Rabi: Crops of winter season sown and harvested between second week of October to last week of March.
Zayad: Crops of summer season sown and harvested between first to second weeks of March to last week of June.
Data in parenthesis indicate EC (electrical conductivity)

2. Green gram + sorghum+ *okra* (summer)-paddy (early)-potato for medium textured, gently sloping and irrigated soils. Green gram, sorghum, and okra are sown with only two ploughings. In this cropping system, farmers receive net profits of US$ 175-250 per hectare per year. It offers multiple benefits similar to the first cropping system.
3. *Bodo* (cow pea) + maize + *okra* (summer) - paddy-wheat is taken under irrigated condition in medium textured *domat* soil. Bodo is cultivated with only one tillage, and this cropping system is more remunerative, bringing farmers a net profit of US$ 425-475 per hectare per year.

These three cropping models were tested further for their acceptability and economic viability with the

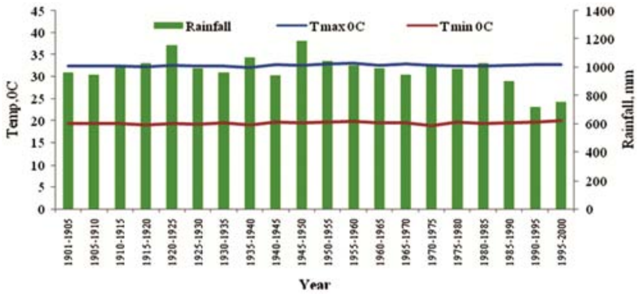


Fig. 2—Five-year mean rainfall, and maximum and minimum temperature of Azamgarh district of last 100 years (1901-2000).

CV: Temp Max.= 0.6562; Temp Min. 1.058; Rainfall= 9.729. Std Err: Temp Max. = 0.0675; Temp Min.= 0.0650; Rainfall= 30.229 Source: IMD data through NICRA project

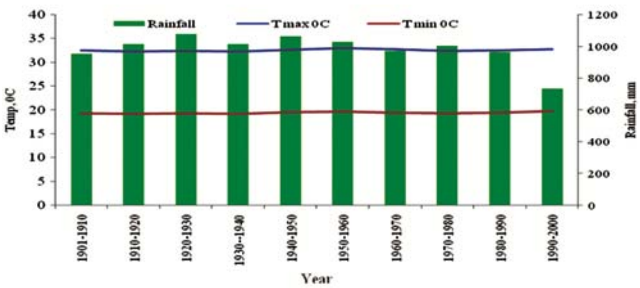


Fig. 3—Decadal mean rainfall, and maximum and minimum temperature of Azamgarh district of last 100 years (1901-2000).

CV: Temp Max.= 0.706; Temp Min. 1.366; Rainfall= 11.058. Std Err: Temp Max.= 0.0514; Temp Min.= 0.0593; Rainfall= 24.29 Source: IMD data through NICRA project

farmers. Their responses showed these models to be of great importance and well appreciated (Table 4).

In recent years, farmers have started sowing a red gram crop on a raised bed system (Fig. 4), particularly in those sodic soils where wilting disease has posed a major threat in conditions of water stagnation. This system has significantly increased red gram productivity. It was initially adopted by only three farmers, but now a considerable number of farmers in the area are applying this method. In considering new cropping systems, farmers are more cautious in weighing the criteria for crop selection in terms of cost of cultivation, soil type and slope, household and animal needs, green manuring, economic viability and ecosystem sustainability. Gradually, through informal institutions and a farmer led extension system, these cropping systems are diffusing to similar agroecosystems elsewhere

B. Adaptive practices in nutrient management and tillage operations

Instead of using complex practice and technologies to overcome a particular problem, farmers try to adjust their crop sowing times and make optimal use of residual soil fertility to achieve good yields and save costs. In rice-based cropping systems, farmers grow potatoes initially. Then, after the potato harvest in the first week of February (planted in October last), many farmers make use of residual soil fertility and save on land preparation by planting sugarcane, which germinates and grows well after potatoes. Sugarcane is generally grown over the next 2-3 yrs. In planting sugarcane, the farmers simply make a furrow with a local implement called a *pahiya* (made of *Acacia nilotica* wood) to insert the cane sets directly into the soil. By adopting this method, the farmers save about US$ 175-250 per hectare and improve cane productivity by about 25-30% in comparison to planting of cane in the field which was not having potato crop earlier. This indigenous practice for sugarcane cropping is low cost and compatible with traditional methods. It is economically viable, conserves natural resources and works well with available local resources.

Table 4—Perceptions of farmers about legume based cropping models

Indicators	Cropping models		
	A	B	C
Economically viable	89.2	96.8	79.81
Ecologically sustainable	77.81	85.90	91.80
Technically feasible	81.92	76.92	69.25
Cost effective	72.62	74.17	89.45
Compatible to be tuned with past experiences	87.12	90.12	79.19
Socially justifiable (equitable)	80.25	70.54	80.60
Culturally acceptable	96.94	92.18	89.65

Data in parenthesis indicate percentage
* Multiple response percentage
Abbreviations
A= Black gram + sorghum (summer)- rice (early)- pea and sugarcane f
B= Green gram + sorghum+ okra (summer)- paddy (early)- potato
C= *Bodo* (cow pea) + maize cobs + okra (summer):

C. Adaptations relating to crop diversification and risk management

Resource-poor farmers in the study area do not usually grow a single crop, due to the risk of crop damage or failure from extreme weather events. Rather, they opt for crop diversification, using either mixed or intercropping systems. In crop diversification, the general intent is to reduce the risks of damage from droughts and floods, and increase net profits per unit of land over time. Prominent cropping systems followed by sugarcane growers in the study area include:

1. Sugarcane + onions: Cane and onions are planted in February. Onion crop is harvested in May last. Mulching of rice stalk is done in the sugarcane crop during the first week of June. Farmers earn about US$ 800-1100 per hectare besides reduced reducing insect pest infestations in sugarcane.
2. Sugarcane with *urd* bean (black gram): Cane and *urd* bean are planted together in February. The bean pods are harvested during April-May, and the *urd* bean plant and root biomass is incorporated into soil at this time. Mulching with rice stalks is applied to the sugarcane crop during the first week of June, helping to retain moisture and reduce insect pests.
3. Sugarcane + *okra*: This combination is practiced by only a few farmers, who take advantage of the spaces available between two rows of sugarcane to plant okra, which they maintain has a higher yield when intercropped with sugarcane.
4. Sugarcane + red gram and sugarcane with cucurbits: these combinations are used to produce vegetables for home consumption. Mulching with rice stalks, again, is applied to the sugarcane crop during the first week of June. A few small-holding farmers were observed to grow *urd* bean with *okra* and pearl millet (for fodder) for sale. The practice is more popular in the areas where early paddy (e.g. *Saryu-52*) is to be grown and where farmers are not able to apply more fertilizers. The farmers consider these cropping systems to be biophysically and socio-economically sustainable (Table 5).

Table 5—Perception of farmers about sugarcane based cropping models

Indicators	% of farmers perception on their cropping systems			
	A	B	C	D
Economically viable	68.12	59.25	63.42	70.10
Ecologically sustainable	60.17	67.82	69.41	72.40
Technically feasible	70.19	74.91	70.40	81.42
Cost effective	60.20	57.19	71.60	76.50
Compatible with existing climate and past experiences	71.65	67.10	64.90	70.50
Socially justifiable (equitable)	79.40	61.50	65.30	63.21
Culturally acceptable	76.60	60.25	58.19	60.25

Data in parenthesis indicate percentage
*Multiple response percentage
Abbreviations: A. Sugarcane+ onion, cane and onion;
B. Sugarcane + urd bean (black gram
C. Sugarcane + okra; D. Sugarcane +red gram and sugarcane with cucurbits

5. *Sanda* method (double transplanting) ofrice transplanting:

Over the years farmers have learned incrementally to devise location specific methods of raising rice nursery and planting. In the study area, about 85% of the farmers (large, and small and marginal farmers also) have adapted the *sanda* method (double transplanting) of raising rice nursery and cultivating the crop. From May 8-20th, they prepare nursery fields and sow the seeds of desired rice varieties. After about 20-25 days, the rice seedlings are transplanted into a second nursery field and left there for about 20-22 days. Then, when every seedling has about 4-5 tillers, the plants are re-transplanted into the main field. Certain varieties, such as *Sambha, Mahasru, Moti gold* and *Saryu-52* are preferred for this adaptive practice. This method is seen by farmers to be very useful under conditions of variable climate (erratic rainfall), disease and pest infestations. It also helps in meeting labour demands and contributes about 25-30 % more yield than the conventional method of single transplanting of seedlings in a more simple nursery technique. One of the knowledgeable farmers, Mr Sheshnath Singh (village Sonapur), explained (translated from Bhojpuri to English):

> "This adaptive practice has tremendous potential to manage the rice crop against variable and uncertain climates. This technique requires only about 8-10 kg of seeds/ha as compared to conventional method which requires about 30-32 kg seeds/ha. The *sanda* method helps in the management of labour demands during the increased load of rice transplanting, plants are better adapted to erratic rainfall, reduces disease and pest infestations, and results in a better yield by reducing the *paiya* (choppy grains) in comparison to conventional method" (24th January 2013 and 8th February 2014).

Earlier, this adaptive practice was done by farmers whose lands were located near to canal and low lying areas. This adaptive practice was useful for them to sustain transplanted rice under flood condition in low lying areas. Later on, this practice has been adapted by other farmers after by farmer-led extension and trial and error. These farmers found that *sanda* method is better suited for labour problems, climatic variability and saving of seeds and plant protection and weedicide chemicals. With this practice, farmers can harvest their paddy crop in second week of October, and the same plot they can take potato (high value crop) or early wheat (sowing in first fortnight of November).

D. Collective water management for dispersing risks of erratic rainfall

The farmers in our study reported that most of their paddy fields are located near a small canal which acts as the outlet of Lake *Badaila*. This lake supports a great diversity of plant species and aquatic animals, and the water from this lake is considered rich in organic material and is good for rice (especially *Saryu-52* and *Mahsuri* varieties) and wheat. In the months of September and October, when there is no rain, farmers form groups and make a small dam in the canal from which water is diverted out in the rice fields. On the basis of a rotation system, farmers are each allotted days when they are able to use canal water for irrigation. In the last 10 yrs, however, due to the highly erratic rainfall and negligence by the state government in cleaning and maintaining the canal, the farmers' vulnerability has increased as the canal's water carrying capacity has greatly decreased. This situation poses threat on the existence of informal institutions formed during the erratic rainfall period for water management. Since day by day, the water flow in the canal is reducing due to high seepage and blockage caused by silt and weeds. The farmers who form informal institutions are bound to have their individual tube-well (increased cost) for irrigating their crops.

E. Biodynamic agricultural adaptations

In this study, about 18% of the farmers maintained 12-18 species of crops during the winter season, including: wheat, mustard, barley, field pea, red gram, chick pea, sugarcane, potato, coriander, spinach, chilli, tomato, sowa, brinjal, garlic, onion, carrot, turnip, radish and *barseem*. These crops are generally cultivated in a mosaic over the entire field. In a few cases, even a single patch of land may produce more than 12 species (Fig. 5). During the summer, farmers having access to life-saving irrigation facilities maintain about 8-13 crop species on one piece of land. This combination includes summer maize, black gram, green gram, cow-pea, onion, *okra*, ridge gourd, sponge gourd, bottle gourd, pumpkin, bitter gourd, sugarcane, and *bajra*. Most of these crops are self consumed, with the surplus sold in the local market. About 5-8% of farmers grow summer maize, onion and okra as cash crops to make up for the higher production costs incurred in the cultivation of other crops in succeeding season.

In the study area, we observed the practice of informal seed exchange (through local seed networks), seed conservation by individual farmers and local production of high yielding seeds by some innovative farmers/communities. For example, the local *Koiri* community is well known for cultivating and maintaining good varieties of vegetable crops, which are adapted to local conditions, and the small-holding and marginal farmers have easy access to the seeds of these varieties. In some cases, the farmers grow red-gram crops near tree groves (Fig. 6). During the winter season, the farmers told us, trees regulate the micro-climate and help minimize frost damage to the red gram. Similarly, during the winter about 2-3% of farmers cultivate potatoes with field pea (Fig. 7). The pea pods are harvested for self consumption before the potatoe harvest. The farmers claimed that this adaptation helps them at least to get a small amount of peas as a vegetable. Previously, they used to cultivate field pea with chick-pea, but this practice has become almost unproductive due to a shift of the sowing season combined with the impacts of several diseases and insect pest problems. Sowing of field pea alone is considered less productive. Field pea plants, by fixing atmospheric nitrogen, partially meet the nitrogen requirements of the potato crop.

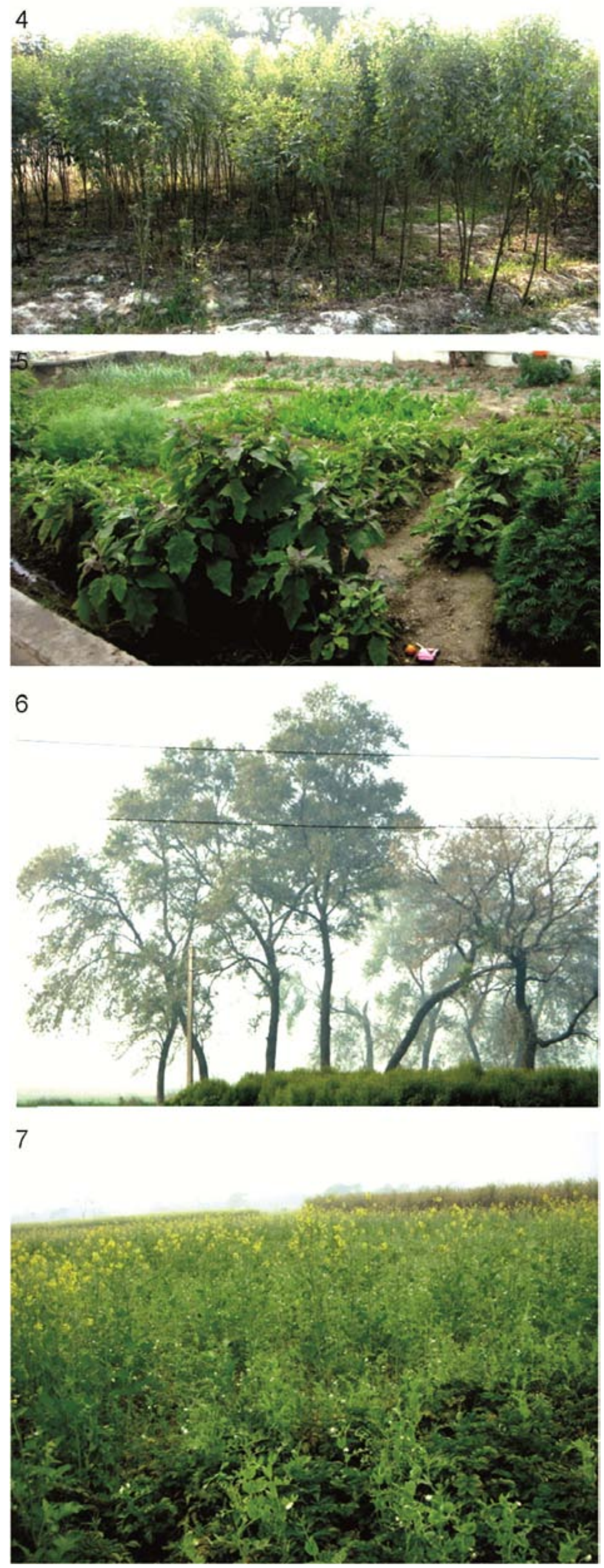
F. Adaptive practices for disease and pest management

To control the tuber moth in the potato crop, farmers apply a basal dose of *neem* cake @ 4.0 q/ha at the time of sowing. This practice is more popular among small-scaleand resource-poor farmers. For controlling the red gram pod borer, seeds of coriander are mixed with the gram crop; the coriander crop acts as a repellent against this pest. To control the shoot borer in sugarcane, farmers sow *patua* (a fibre producing crop of the Malvaceae family in 3-4 rows as a border crop around the sugarcane field. For reducing the wilting problem in red gram, farmers purposely mix in the seeds of *bajra*, which helps to some extent to controlling this problem.

Discussion

We found that the farmers' perceptions relating to climatic variability were consistent with recorded climate data in the region. These data show that the number of rainy days has decreased and the intensity of rainfall has increased over the last 40 yrs. For example, the cyclone Phailin, with its heavy rains, put farmers at risk by heavily damaging the rice crop just as it was ready to harvest[14,15]. Other than this, the untimely heavy rains caused a delay in sowing the wheat crop, decreasing the crop season. In the recent past, changes in socioeconomic and institutional systems, ecological degradation and erosion in policy making have further aggravated the agricultural risk, despite improved input of the supply system and communication networks[11]. Climate change adaptation in resource-poor conditions mostly takes place through a set of social networks, approaches and efforts. Unfortunately, in last 30 yrs the social networks in the study areas have weakened due to changes in the socio-political system, erosion in social principles and ethics, and changes in livelihood patterns. This has resulted in a widening of the social bonds between the different groups of farmers due to the isolation of adaptive practices, thereby reducing opportunities for reciprocal learning and increasing input costs. The compounded impacts of climatic variability and socioeconomic factors have put the small and marginal farmers at higher risk[16]. The productivity of different crops, particularly rice and wheat, has increased with the enhanced adaptive capacity of even small and marginal farmers over the past few decades. However, the increased costs of cultivation, uncertain weather conditions and other abiotic and biotic stressors have reduced the net profits from crop cultivation[11].

The socioeconomic, climatic and ecological compulsions have been instrumental in the development of location specific adaptive practices by a few innovative and knowledgeable farmers in the study area. A few of the adaptations we explored represented a type of co-knowledge (knowledge and practices originating after interactions among scientific institutions, governments and farmers). For example, in the study villages, farmers have reclaimed their sodic lands using the *saat* method [making a trench, putting FYM (farm yard manure), rice stalks and press-mud from sugar mills into this trench, and placing the land under rice cultivation after a fallow during the winter] through a collective management system. Gypsum technology promoted by the State Government appeared much later, and even so it has not been readily available to the farmers. Basically, the farmers were dependent on the *saat* method with minimal application of gypsum. Many other adaptations explored in this study–such as using improved varieties of crops (e.g. in rice *Moti gold, Sambha, Saryu-52, Kala Namak, Mahsuri, Pusa 1509, Jira 32*, etc.) – could be categorized as co-knowledge



Figs. 4-7—Red gram crop cultivated on a raised bed; (5)–Biodynamic agricultural mosaic; (6)–Red gram crop sown near the tree belt; (7)–Potatoes with field pea crop.

led adaptations under local agronomic practices. Some of the adaptations, however, (cropping systems, cropping sequences, relay practices and plant protections measures based on green practices) had been exclusively developed by farmers, with the multiple benefits.

The adaptive practices documented have long-term implications for sustainability of rice-wheat based cropping systems. At times when most of the local cropping systems and sequences have disappeared, or are being practiced by very few farmers (Table 3), great losses have occurred in terms of declining local biodiversity maintained through indigenous cropping systems. It is widely known that to produce 1.0 kg of rice, 3000 liters of water (20-35 irrigation) are required, and to obtain 1.0 kg of wheat, 1000 L of water (1-3 irrigation) are required. With 2-4 irrigation, however, a maize crop needs only 850 L of water per kg[17]. The local cropping systems maintained earlier with maize, however, no longer exist. A few farmers who grow summer maize for the cobs play a crucial role in sustaining natural resources. When we compare the new innovative adaptations by farmers with the traditional systems of food production in terms of minimum tillage, using less NPK in a few crops and using rice stalks as mulch in the sugarcane crop and residue for subsequent wheat crop, we found that these adaptive practices are more sustainable in terms of saving water, farm power and energy (60%)[18,19] than conventional agriculture, improving system productivity, sequestering carbon[20], and resulting in an overall reduction in the carbon foot-print (Table 6). Any crop residue used as mulch material, we found, is effective in weed control[21].

The adaptive practice of incorporating summer black gram and green gram into crop plantings enhances the soil organic carbon (0.835%) and thereby improves its physical properties, increases microbial biomass and suppresses nematode populations[22]. The incorporation of *mung* bean residue into the soil further enhances the sustainability of rice (0.84) and wheat (0.77) cropping systems[23]. The *Kharif* season *mung* bean, black gram and cowpea each contribute 40 kg nitrogen per ha per season to the subsequent crop[24]. Incorporation of vegetable components in the cropping system/sequence is important in enhancing economic adaptation and livelihoods by maximizing the net profit per unit area over time[25]. A few adaptive practices of farmers (for example, mixed cropping, and relay cropping of lentils) have been advocated to adapt to the excess water in low-lying areas of eastern India[23]. Similarly, growing of potatoes with field pea and red gram on raised beds has emerged as a new adaptive practice among the small-scale and marginal farmers in the recent past. This innovation may have resulted from previous experiences of failure of pea and red gram crops due to late sowing, due to variable climate, environmental change and other anthropogenic factors[11].

In rice-wheat cropping systems, zero-tillage technology, introduced very recently in the eastern Gangetic plains by the State Agricultural University together with the Rice-Wheat consortium (CIMMYT), is also becoming very popular. Traditionally, farmers of the study area had been growing directly seeded rice, a practice that was abandoned in favour of puddle/transplanted rice. The practice of directly seeded rice may find new favour with the introduction of zero till drills in the area for direct rice planting. Now, due to the labour shortage caused by the MNREGA (Mahatma Gandhi National Rural Employment Guarantee Act)[26] and out-migration from the region, farmers are experiencing great problems in transplanting of the rice crop, since this method of rice transplanting further increases

Table 6—Statistics of benefits of some sustainable adaptive practices (cropping systems, residue incorporation and minimum tillage) of studied farmers

Particulars	Benefits statistics
Water saving	25-30%
Improving the system productivity	10%
Saving of energy (fuel)	2000-2500 MJ/ha/year
Eliminate residue burning and add nutrients to soil	100 kg/ha/year
Reducing carbon foot prints and green house gas emissions equivalent to	100 kg/ha/year
Zero/minimum tillage/minimum with residue increases carbon efficiency	9.84±0.43*
Zero/ minimum tillage with residue increases sustainability	8.84±0.47*

*Sapkota *et al*[28]

labour demands. Large-scale farmers manage this demand by paying higher wages, but the small and marginal farmers are unable to do so and thus become more vulnerable. However, farmers have widely adapted the *sanda* practice, described previously, to reduce labour pressures during rice transplanting time, and to mitigate the disease and insect infestations caused by climatic variability and extremes. This adaptation is consistent with the ICAR recommended contingency plan for coping with climatic uncertainity[27]. The farmers in our study regarded direct seeded rice cultivation as a better technology, provided they have cost effective availability of suitable varieties and single robust herbicide to control all types of weeds. Therefore, effective policy development is urgently needed to encourage farmers to continue with adaptation, which was already in vogue but diminished due to labour and institutional factors.

Conclusion and policy implications

The study revealed that excessive climatic variability has become a reality in the Azamgarh district of eastern Uttar Pradesh and has made small-scale and marginal farmers more vulnerable. In the recent past, variations in rainfall patterns have increased; the number of rainy days has decreased, with increased rainfall intensity. Farmers and their perceptions about variable climate and weather data are closely linked to the increased aberrations in climate. The climatic variability after combining with socioeconomic and ecological factors put farmers at higher risks. The study showed that farmers generally acquire knowledge of cropping systems and natural resource management through experiential wisdom and incremental learning. Their location specific ecological knowledge and associated adaptations are usually more compatible with their biophysical and socio-economic condition than externally imposed approaches. Some of the adaptations reflected co-knowledge development (e.g. *sanda* practice bridging the recommended method of transplanting rice with short duration nursery), while a few were exclusively based on the farmers' innovations. Most were governed by low investments in energy based inputs, subsistence in nature, using locally produced materials and crops, and enhancing local livelihoods.

Integrating farmers' knowledge together with sustainable adaptations and modern crop management, and production practices can significantly accelerate the adoption of newer agricultural technologies, making agriculture more resilient overall. Further, participatory research and extension approaches may help not only in validating farmers' adaptive practices, but also in the more ready adoption of new technologies such as zero till wheat. Farmers' practices relating to insect and pest management are of interest and may be refined and validated to replicate and use more broadly in similar socio-ecological systems in eastern Uttar Pradesh where farmers are facing increasing problems from insect pests in potato, sugarcane, red gram and chick pea crops, due in part to the erratic rainfall. Since the documented adaptive practices are eco-friendly, working with natural processes, as well as being cost effective and compatible with the socio-economic conditions of farmers, they will undoubtedly be more popular with some other similar social-ecological systems as well. These adaptive practices, with the help of the farmers themselves, could be refined and validated by the Agricultural Universities and Krishi Vigyan Kendra (KVK) through participatory approaches to further scale-up and refine, ultimately providing more sustainable adaptations and increasing the moral of participating farmers through mainstreaming their practices together with science and policy.

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