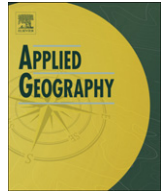


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Institutional and technological innovation: Understanding agricultural adaptation to climate change in Nepal

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History shows that farmers and their supporting institutions have been successful in introducing technological innovations to respond and adapt to environmental and socioeconomic challenges. Innovation itself is a mechanism by which society adapt to changing resource endowments, and which is in turn driven by social and cultural values. In the future, as resource conditions changes, the role of institutions in the process of technological innovations would be crucial to avoid deleterious consequences of climate change in agriculture. Using Nepal as a case, this paper illustrates how farmers and their supporting institutions are evolving and co-producing climate sensitive technologies on demand. Drawing upon the hypothesis of induced innovation, we examine the extent to which resource endowments have influenced the evolution of technological and institutional innovations in Nepal's agricultural research and development. This study reveals that Nepal has developed a novel multilevel institutional partnership, including collaboration with farmers and other non-governmental organizations in recent years. More importantly, by combining conventional technological innovation process with the tacit knowledge of farmers, this new alliance has been instrumental in the innovation of location-specific technologies thereby facilitating the adoption of technologies in a more efficient manner. This alliance has improved knowledge network among institutions, scientists and farmers and enabled them to seek technologies that are responsive to likely changes in climate.

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Introduction

Farmers have practiced agriculture virtually in almost all climatic zones on earth and have developed a rich tapestry of human–environment relations. History shows that farmers and their supporting institutions have been successful in introducing technological measures to respond and adapt to environmental and socioeconomic challenges. Variation in climatic resources, across space and time, has also spurred innovations in agricultural technologies and has been an integral part of agricultural development (Brush & Turner, 1987). However, the numerous factors that drives innovation makes it extremely difficult to detect and attribute the impacts that climate has on agricultural technology. Yet understanding the interaction between farmers and their supporting

institutions is a useful precursor to understanding the importance of technology in the process of adaptation to climate change. In the future innovation and deployment of agricultural technologies will largely shape how well farmers adapt to climate change. The role of technology in adaptation to climate change is even more crucial in developing countries where food security remain a struggle for significant portion of the population and impending climate change is expected to make it even worse.

A large body of literature establishes that capacity to respond to changing climate depends on knowledge flow through a broad range of institutions including farmers' interactions among themselves and with vulnerable communities (Agrawal, 2008) and the ability of private, public, and civil society institutions to act collectively at multiple scales (Adger, Huq, Brown, Conway and Hulme, 2003; Lasco, Cruz, Pulhin, & Pulhin, 2006). Innovation of technologies at the local level is crucial for enhancing adaptive capacity of farmers. Some of this knowledge is tacit, demanding interaction between farmers, operating at a specific climatic

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conditions, and their supporting institutions, while the others are scientific knowledge embedded in the institutions that are designed to minimize uncertainties at the decision level. Yet, much of what is known about the process of technological innovations in agriculture and the role of institutions in it has yet to be captured in the discussions of climate change adaptation. This is partly because appropriate methodologies to study these issues are limited in scope. The role of climate as a driver of technological innovations and the part that institutions play in integrating it into these innovations has been poorly understood (Rosenberg, 1992).

Easterling (1996) suggests retrospective analysis as a way to understand how earlier technological innovations have been targeted to address climatic constraints in specific locations. Utilizing such analytical framework and drawing upon the theoretical premise of 'induced innovation' – which is understood to be technological innovations in agriculture that is induced by variations in relative resource endowments – we investigate if existing differences and limitations in climatic resources have spurred development of location-specific technologies to enhance agricultural productivity. We also examine the evolution of institutions in developing such technologies and discuss the potential role of innovations in responding to future climate. The core organizing questions thus include: (a) how, and in what ways, have existing variations in climatic resources induced technological innovations? (b) in what ways have farmers and their supporting institutions been evolving in response to constraints posed by existing climatic resources?; and (c) can national agricultural research and development systems respond to the needs of a rapidly changing climate?

We begin with the review of salient research that supports the central argument of this paper that farmers and their supporting institutions have evolved proactively to respond to challenges posed by changing resource endowments so as to maintain agricultural productivity. Specifically we discuss the role of technology in modern agriculture to illustrate the means through which society may respond to minimize the impacts of climate change in agriculture. Then, we introduce the hypothesis of induced innovation as the theoretical basis for climate-induced technological innovation in agriculture and is followed by a discussion of Nepal as a case for this study. The methodological approach is laid out in section four. It is followed by a discussion on the demand for institutional innovation as prompted by the need for development of location-specific technologies in Nepal's agricultural system. We conclude with a discussion of the role of technological and institutional innovations in future climate adaptation.

Technology, climate and modern agriculture

Around the world, climate and its effect on agriculture have continued to stimulate technological innovations that best suit specific climatic conditions. The development of cowpea cultivars in the African Sahel illustrates the examples of technological substitutions in response to existing variability in climatic resources. To escape the effects of drought, scientists in the African Sahel developed early maturing cowpea cultivars with different phenological traits. For example, to avoid the effects of late season drought, they developed cowpea varieties (*Ein El Gazal* and *Melakh*) that mature between 55 and 64 days after planting (Elawad & Hall, 2002). Similarly, to avoid midseason drought, scientists also developed a cowpea variety (*Mouride*) that matures between 70 and 75 days after planting (Cisse, Ndiaye, Thiaw, & Hall, 1997). Unlike *Ein El Gazal* and *Melakh*, that begin flowering between 30 and 35 days from sowing and have synchronous flowering characteristics, the *Mouride* variety starts flowering in about 38 days

after planting and spreads out over an extended period of time, thereby escaping the midseason drought.

Complementing the development of newer varieties, the smallholder agrarian communities have been aided by better agronomic practices, a critical aspect of managing climatic risk. For example, to enhance the chances of significant production gain, farmers and their supporting institutions of the African Sahel have developed cropping techniques where both types of cowpea varieties (short and medium maturing) are planted together so that variable climatic input is optimized (Hall, 2004). Among small farmers, who make up the majority of the rural population in developing countries, traditional practices of water harvesting, switching crops, conserving soil and water, have been the main technological adjustments to both short and long-term climate changes. For instance, in Zimbabwe farmers have switched to more drought-tolerant crops in areas where frequent recurrence of droughts has made agricultural production difficult when traditional crop varieties are grown (Matarira, Kamukondiwa, Mwamuka, Makadho, & Unganai, 1996). In the highlands of Ethiopia, farmers have improvised the traditional *zai* pits (i.e. small water harvesting pits), common in dryland region of Sahel, to arrest runoff and sediments during the rainy season. The *zai* pits alone, and in combination with nitrogen (N) inputs, have increased potato and bean yields by 250% and 500% respectively (Amede, Menza, & Awlchew, 2011). In another study, *zai* pits were found to increase the diversity of useful plants, increase production of both cereal grain and straw yield by over tenfold, and significantly increase biomass production after two years, all without significantly altering the properties of the soil (Roose, Kabore, & Guenat, 1999).

Agronomic practices that are applied by farmers in less climatically favorable regions of the world offer insights as to how adjustments can be made in the face of climate change. There are reports of water productivity improvements using conservation tillage farming in low-rainfall areas of Asia. The introduction of zero-tillage rice-wheat cultivation techniques in the Gangetic plains that provided benefit to some 620,000 farmers illustrates another success story in global agriculture (Erenstein, 2009). In this no-tillage practice, seeds are sown in unplowed fields in order to conserve soil fertility, economize on scarce water, reduce land degradation, and lower production costs. There have been significant developments as a result of such practice. For example, zero tillage of wheat in Pakistan using drill planting shows water savings of 15–20% (on average an estimated 100 mm per ha) through reduced evaporation and runoff and through deep percolation, while increasing yields (Hobbs et al., 2000). While most of the traditional approaches of managing climatic risks are autonomous, i.e., spontaneous responses to climatic extremes, they have evolved over centuries and have been widely implemented across the world (Ribot, 1996). So the insights for agricultural adaptation that confront us today may well be found in the experience of handling climatic challenges across various regions.

Additionally, agricultural practices commonly observed in many traditional farming systems in Nepal and India are also pivotal in achieving yield stability, maintaining soil fertility, and attaining a constant supply of human and animal food (Jodha, 1981; Subedi et al., 2004; Sthapit, Rana, Eyzaguirre, & Jarvis, 2008). Nepalese farmers with limited disposable income grow a wide range of perennial and annual plants in their home gardens, defined here as subset of a larger and diverse farming system. According to Sunwar (2003) in a drier part of western Nepal a single household could have as many as 123–131 species of plants in their home gardens. Home gardens are not only seen as sources of food and nutrients for the family, they are also an important reserve of on-farm plant genetic resources. By growing multiple species in their home

gardens farmers also reduce the risks of absolute crop failure due to climate variability and other stresses (Rana, Garforth, Jarvis, & Sthapit, 2007).

The practice of cultivating multiple varieties of rice crop is also apparent in Nepal. For example, in the Hills of Nepal, which is characterized by its highly diverse terrain and climatic niches, it is common for farmers to cultivate as many as eight to ten cultivars of rice in order to optimize the climatic niches and soil conditions. Local rice varieties are valued especially in areas where climatic factors (water and temperature) are a limiting factor. For example, a rice variety (*Mansara*) is well adapted to land with 'poor' soil quality where no other rice variety does well (Sthapit et al., 2008). Public institutions responsible for innovating technologies need to understand the extent to which such local varieties can be developed to reduce vulnerability (an adaptive capacity). Therefore the goals underlying adaptive capacity are also closely connected to agricultural development issues, including development of location-specific technologies, and building it involves complex partnerships and alliances between farmers and their supporting institutions (Perez-Aleman, 2011), operating at multiple scales.

Yet, notwithstanding this recognition, there is a dearth of research that explores the role of climate in fostering institutional alliance for innovation of technologies (NRC, 1999; Ruttan, 1996; Smithers & Blay-Palmer, 2001). A clear understanding of the process that climate plays in technology and institutional development is necessary for developing strategies to adapt to future climate. In the case of Nepal it is an important area of investigation for at least three reasons. First, this country of 28 million inhabitants is now a net importer of food, and so it has become imperative that a productive and sustainable agricultural system is implemented to ensure food security for an ever-growing population. Second, although agriculture is a very significant contributor to the economy, the national agricultural research services lack sufficient capacity for timely delivery of location-specific agricultural technologies on a large scale. Finally, the country's agricultural system is vulnerable to climate change, especially given the growing uncertainty of monsoon circulation juxtaposed within the nation's complex and diverse geographic terrain. New and carefully designed technologies may enable society to increase their robustness to tackle the emerging challenges emanating from climate and other ongoing changes.

Induced technological and institutional innovations: a conceptual perspective

Technological innovations in agriculture have been extremely rich and diverse. Experience shows that these innovations have enabled farmers to cope with various environmental and biological challenges and have been fundamental to the growth and development of agriculture around the world. Although agricultural development in Europe begun in the 19th century, critical technological breakthrough in developing countries began only in the mid 20th century. One of the first such major successes came from an effort to combat wheat rust – a plague known to humanity for thousands of years but one which had never been effectively controlled (Dubin & Brennon, 2009). By breeding rust-resistant wheat varieties, it is estimated about 117 million hectares of land under wheat cultivation became protected against wheat rusts, thereby directly ensuring food security for 60–120 million rural households. Similarly success in maize production in Sub-Saharan Africa was no less important in addressing the persistent threat of hunger in the region. In East and Southern Africa, technological innovation in maize led to the development of high-quality crop needed to provide smallholder farmers with high-yielding varieties (Smale & Jayne, 2003). Implicit in these successes are the part

played by public institutions. Climate change may exert pressure on institutions by aggravating current problems or by creating new opportunities (Tol et al., 2005).

Institutions are defined as “formal rules and arrangements that govern behavior among and within organization” (Ruttan, 2006:250) and normalize the practices of society (Giddens, 1979). Institutions vary in formality, power, contestation, and ambiguity, making them dynamic and subject to reshaping (Scoones, 1998). In the case of climate adaptation, institutions may help society to interpret scientific knowledge and devise adaptation strategies (O’Riordan and Jordan, 1999) and adaptation may not occur in institutional vacuum (Agrawal, 2010). Technological innovations in agriculture may come from multiple sources: public institutions, private firms, and farmers. Hayami and Ruttan (1985:87) reveal that countries that have been successful in developing location-specific technologies were able to “socialize” the process of technological innovation, i.e. increase interactions between farmers and their supporting institutions. For institutions to operate effectively, there is a need for dialog among entities that are public (administrative units, government organizations), private (business organizations), and civic (NGOs, service and community based organizations) (Agrawal, 2008) while ensuring a meaningful collective action among them (Adger et al., 2003).

Cultural endowments, such as social norms and values, may exert influence on the process of institutional innovation (Hayami & Ruttan, 1985:506pp; Koppel, 1995). For example, traditional farmer-managed irrigation systems (also referred to as community-based irrigation systems) of Nepal represent an important form of social capital with traditional norms, values and governance structure (Ostrom, 1990). Depending on socioeconomic and institutional contexts they perform a range of activities, including pooling of resources for maintenance of irrigation waterways, regulating of water distribution and allocation, monitoring of violation of rules, and easing of conflict arbitration and negotiation (Pradhan, 1989). These local institutions have historically been instrumental in safeguarding resources, including the protection of forest and watersheds (Agrawal, 2010). In recent decades they have played important role in bridging the gap between scientists, development workers and community at large (Gyawali et al., 2007) and such local institutions can be vital in facilitating the process of climate adaptation.

The relationship between climate change, institutional and technological innovations and cultural endowments is apparent (see Fig. 1). Climate change may alter crop-growing environment by changing growing season length and soil moisture regimes, and by exerting heat stress to the plant. Such changes, as we argue, will provide appropriate signals to farmers and their supporting institutions to induce technologies suitable for the new environment. So change in resource endowments due to climate change can become a trigger for institutional innovation whereby institutions may reinforce agricultural adaptation through a) innovating location-specific technologies in anticipation of future need (Chhetri and Easterling, 2010), b) linking local, national and international institutions to transfer technologies (O’Riordan & Jordan, 1999), c) integrating local institutions with markets to enhance economic returns (Agrawal, 2008), and d) helping farmers organize and manage local resources through collective action (Adger et al., 2003; Agrawal, 2010).

As climate adaptation is essentially a local process, there is an increasing realization by scientific community and policy makers to include local social and cultural factors in the calculus of adaptation (Hulme, 2009). Consequently, a broad based coalition of farmers and their supporting institutions is likely to exert influence on policies that are driven by local adaptation needs. In this context cultural endowments may add an important

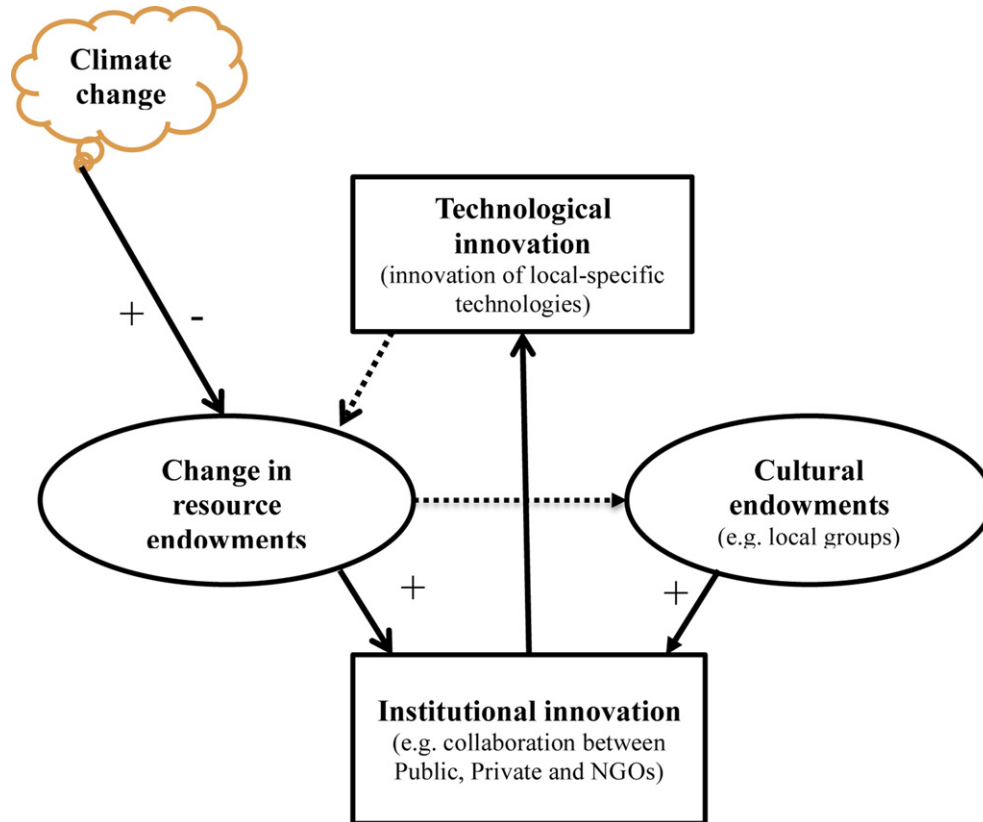


Fig. 1. Conceptual model illustrating interaction between institutional, cultural and technological innovation in agriculture.

dimension to the effectiveness of institutions in the innovation of technologies. Therefore, the interaction between farmers and their supporting institutions will likely to be most effective in areas where traditional cultural groups such as mothers' groups, community forestry groups, and traditional irrigation management groups are active. Likewise, institutions that represent the values and norms of farmers are likely garner strong support from society. However, farmers and community groups representing narrower interests may fail to garner long-term support needed to adapt. Hayami and Ruttan (1985:111) argue that our capacity to understand the link between institutions and technological innovation is reasonably clear but our capacity to see the link between cultural endowments, institutions and technological is poorly understood. Recognizing this shortcoming, the conceptual model introduces cultural endowments as an entity in the process of technological and institutional innovations (see Fig. 1). The hypothesis of induced innovation, therefore, suggests an important pathway for understanding the human–environment relationship, and by extension, the study of the agricultural adaptation to climate change. While there is a general agreement that institutional change has and will continue to evolve in response to change in resource endowment, overcoming the possible negative consequences of climate change in agriculture may demand a different form of institutional innovation. This may involve co-production of knowledge, engagement with stakeholders from local to global level, and leveraging of expert knowledge in the local context. More importantly, it demands harnessing the richness of contextual knowledge to innovate technologies on demand. Consequently, the societal capacity to respond to emerging challenges of climate change in agriculture in itself becomes a product of institutional innovation.

Nepal as a case

Nepal presents a compelling case for studying technological and institutional innovations in agriculture and predicting their future potential for adapting to consequences of climate change for two reasons. First, Nepal's diverse terrain is comprised of distinct belts of ecological zones from the flat plains, or *the Terai*, in the southern part of the country, rising to higher altitudes, or *the Hills*, and eventually culminating in the highly elevated *Mountains* in the north (see Fig. 2). Each of these regions represents a well-defined geographic area with distinct biophysical and socioeconomic characteristics that are significantly different from each other, demanding location-specific technological innovations. Associated with these characteristics are the emergence of distinct human–environment relations between communities and their resources. Meanwhile, during the last six decades, Nepal has made substantial progress in agricultural research and technology development, and has transformed a top-down bureaucratic approach to a more participatory, collaborative, and people-centric one. This transition fostered the development of technology in climate-stress conditions that may have contributed to a new and pragmatic institutional mechanism.

Methodological approach

We analyze varietal traits (specific distinguishing characteristics) of 62 high-yielding varieties (HYVs) of rice released by the National Agricultural Research Council (NARC) of Nepal since the country began formal crop breeding program in the mid 1960s. Data were obtained from two sources: a) official publications in the form of monthly bulletins and research articles from the National

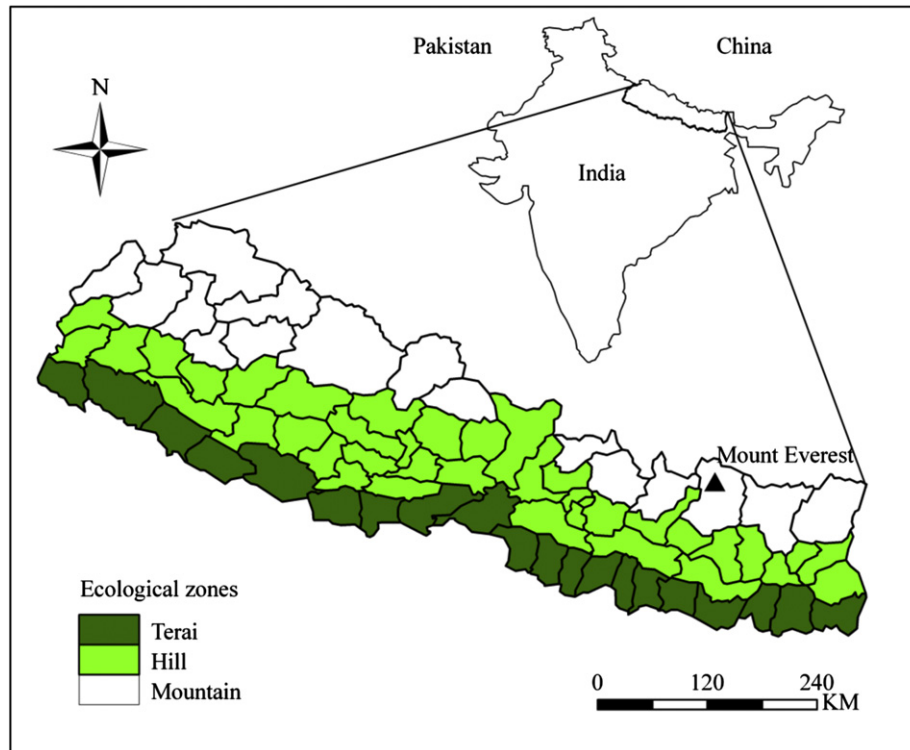


Fig. 2. Map of Nepal showing three ecological zones (Mountains, Hills, and Terai) in the region.

Rice Research Program (NRRP) of Nepal; and b) policy documents of two major governmental institutions - NARC and the Ministry of Agriculture and Cooperatives (MoAC). By reviewing NRRP publications we first developed a list of all released and pre-released varieties of rice in Nepal including the year of release, recommended climatic and ecological domains and geographic region(s). To understand whether the research endeavors in Nepal consider climatic factors as one of the traits during the process of technological innovation, we then compiled the list of specific varietal traits (e.g. drought resistant, disease and insect resistant, maturity, grain yield, quality, biomass yield) associated with each variety of rice.

We employed a two-step process to analyze climate–technology interaction in rice. First we categorized all of the released rice varieties according to three timeframes (1965–1980, 1980–1995, and 1995–2010) that coincided with the development of Nepal's agricultural research institutions that have been described below. Then, we analyzed the emergence of climate sensitivity by investigating the traits of all rice varieties from both technological and institutional perspectives.

Findings and discussion

While it is difficult to make definitive conclusions with respect to the claim of climate-induced innovation, this study reveals that farmers and their supporting institutions in Nepal are increasingly sensitive of location-specific technology on demand. This is not only important for reducing climatic risks, and hence adaptation to future climate, but equally important for the overall growth of agricultural system in the country. We present the findings of this paper in the context of two interrelated but separate frameworks of induced innovation: a) induced technological innovation, and b) institutional innovation.

Induced technological innovation

We found two major considerations to support the assertion of climate-induced technological innovation: i) innovation of location-specific rice varieties in diverse rice growing region of Nepal, and ii) development of climatically appropriate agronomic practices.

Innovation of location-specific rice varieties

Agricultural research establishment in Nepal has been developing and delivering improved cultivars since the mid 1960s. Between 1965 and 1980 the institutional focus was on testing of technologies borrowed from neighboring countries (Yadav, 1987). It was a period of centralized decision-making where farmers were treated as passive recipients whose participation was limited to adoption of released and pre-released advanced varietal lines, and included Farmer Field Trial (FFT), Farmer Varietal Trial (FVT), Training and Visit (T&V), Informal Research and Development (IRD), and Diversity test.

Between 1981 and 1995, the country reformed its agricultural research institutions and began focusing on the innovation of location-specific technology. Consequently, climate sensitivity traits (e.g. drought resistance) began to emerge as an important consideration (see Table 1). During this period the country established a number of regional agricultural research centers across geographic regions and also began to pursue a more integrated, on-farm research approach such as cropping/farming system research program. Despite all these positive transformations, social needs and marginal environments were still not adequately considered, nor were local knowledge and skills taken into account during the varietal development process.

Since 1995, with their focus on client-oriented technological innovation, farmers and their supporting institutions began to show greater sensitivity to location-specific climatic conditions

Table 1
Targeted major crop traits and institutional evolution in Nepal's agricultural research and development approach, 1966–2011.

Period	Targeted crop trait	Evolution of R&D approach
1966–80	High yielding Taste and aromatics Disease resistant Suitable for irrigated condition Focus on Terai and valleys	Establishment of agricultural research stations and farms across the country; top-down approach to technological innovation; government institution as the only source of research and development of technologies, minimal level of collaboration with other institutions; development of commodity-specific research programs in major cereal crops.
1980–95	High yielding Taste and aromatics Disease resistant Suitable for irrigated condition Short duration Drought resistant Biomass yield (straw) Focus shifts to mid hills also	Establishment of farming systems research sites in various part of the country; farmers' participation was limited to adoption of released and pre-released advanced varieties; establishment of Nepal Agriculture Research Council (NARC); government institution as the only source of research and development of technologies; extensive focus on training and visit systems of agricultural extension; farmers as passive partners.
1996– to date	High yielding Taste and aromatics Disease and insect resistant Suitable for irrigated condition Short duration Drought resistant Biomass yield (straw) Focus on mid hills Focus on rainfed areas Focus on marginal areas Focus shifts to Mountains region also	Emergence of new institutional structure; involvement of new actors such as NGOs, private sectors and civic groups in innovation of technologies; decentralization of research program to local level; focus on PTD and PPB; client-oriented technology development; NGOs and private sectors as active partners; regular interaction with farmers and their supporting institutions; expansion of collaboration with international research institutions and universities (multi-institutional collaboration)

Bold in 2nd column indicate additional traits for the given time period.

(see Table 1). Prompted by a disappointingly low performance of improved varieties in marginal climatic conditions of the hills, in the early 1990s, agricultural scientists at the nation's highly reputed crop breeding center, Lumle Agriculture Research Center (LARC) began to work directly with farmers to develop technologies that the latter desired. Farmers were engaged in crop improvement activities such as Participatory Variety Selection (PVS) which provided a 'basket of choice' of most-preferred varieties (Joshi, Sthapit, & Witcombe, 2000; Joshi & Witcombe, 1996) and Participatory Plant Breeding (PPB) which allowed farmers to set breeding goals so that the most desirable traits of crops being selected could be maintained (Joshi, Sthapit, & Witcombe, 2001; Sthapit & Jarvis, 1999; Sthapit, Joshi, & Witcombe, 1996).

During this period the public research institutions began to engage a greater number of stakeholders including NGOs and community based organizations in research and development of technologies. The focus of technological innovation shifted from a top-down to a more participatory approach where emphasis was on the co-production of knowledge. The outcomes of this new institutional arrangement has been the release of 13 rice varieties: four of which have cold tolerant traits targeted for high altitude regions of the Mountains; and nine of which have drought resistant traits developed for the marginal rice growing areas of mid and far-western region of the Terai and the Hills. Such innovation is an example of climate-interaction that has potential for improving yield in changing climatic conditions. With recent focus on Participatory Plant Breeding (PPB), important genetic traits found in local landraces, rare varieties, and their wild relatives have become a significant part of crop improvement program in Nepal.

Adoption of climatic appropriate agronomic practices

Varietal improvement alone will have limited impact on agricultural productivity, especially in marginal climatic areas. Low soil fertility and lack of water are other major constraints that are difficult to overcome. Nepalese researchers have been engaged in devising improved agronomic practices that alleviate the constraints posed by climatic factors. For example, to address the constant dilemma associated with uncertainty of the onset of the

summer monsoons, researchers have improvised traditional methods of "direct seeding" of rice often practiced in risk prone environments as an alternate to the conventional mode of seedling transplantation (Pandey & Velasco, 2002). This method of direct seeding has not only reduced the demand on labor but has thrived in areas of erratic rainfall especially during the early stages of crop development. According to Tripathi, Bhatta, Justice, and Shakya (2004), economic analysis of direct seeding yielded an additional net return of 33 percent compared to the conventional method of transplanting. It became mutually beneficial for both researchers and farmers to understand and implement agronomic practices that resulted in higher production. Evidence also suggests that farmers are quite capable of adopting complex technological interventions as long as there is reciprocal relationship between them and the researchers (Joshi et al., 2001; Witcombe, Joshi, Joshi, & Sthapit, 1996).

Institutional innovation

Although the beginning of agricultural research activities in Nepal can be traced back to the establishment of the Department of Agriculture (DOA) in 1924, concerted effort in research and technology development in the country began after the overthrow of the century old Rana oligarchy in 1951. A small number of agricultural research stations and farms were established in mid 1960s to test technologies that were borrowed from other countries (Yadav, 1987). The release of five rice varieties in the late 1960s, for the first time, was an important breakthrough in Nepal's agricultural development. A more integrated perspective on research and development of agriculture in Nepal began to emerge in the early 1970s (Pokhrel, 1997). In the mid 1970s, with financial support of multilateral organizations such as the United Nations and the World Bank, the country formalized its first Ten-Year (1975–85) Agricultural Development Plan (HMG/NPC, 1970: 328) in which higher cropping intensity was emphasized in the warmer Terai, an integrated crop and horticultural production in the more temperate Hills, and livestock production was emphasized in the cooler Mountains (Yadav, 1987). However, at the time farmers' concerns as

well as location-specific climatic constraints were not part of the feedback process of technology development. Although this typical top down approach remained a big part of agricultural R&D and is credited with developing and deploying a large number of crop varieties, it provided no benefit to a significant majority of small farmers operating in marginal and variable agro-ecological and socio-economical conditions. Rigid conditions required to grow the newly released varieties were only remotely addressing the concerns of small farmers leading to a widening disconnect between what was offered by the R&D system and what was desired by farmers (Galt, 1989; Joshi & Sthapit, 1990; Maurya, Bottrall, & Farrington, 1988; Sperling, Loevinsohn, & Ntabomvura, 1993; Sthapit, Joshi, & Subedi, 1994). Not surprisingly, farmers often rejected most of the varieties released from the standard R&D system.

In 1987, a separate organization, the National Agricultural Research and Service Centre (NARSC) was created to undertake all agricultural R&D. In 1991, NARSC was dissolved and Nepal Agricultural Research Council (NARC) was formed. NARC's goal was to develop location-specific technologies with explicit consideration of indigenous knowledge, traditional practices, and local resources under the overarching consideration of the country's agro-ecological diversity. Located under the MoAC, the greater vision of NARC was to tap institutional, human and financial resources from government and a wider spectrum of stakeholders with focus on food security and sustainability of agricultural systems (Gauchan, Joshi, & Biggs, 2003). Although agricultural research in Nepal has been a public sector activity, frequent changes in organizational structure has been seen as a significant source of uncertainty, contributing to the lag in growth of agricultural development (MoAC, 2009).

NARC's goal in developing technologies that are sensitive to the needs of Nepalese farmers has come about through 18 Regional Agricultural Research Stations (RARS) located in various agro-climatic regions of the country. The RARS conduct research and outreach activities based on the climatic and socioeconomic needs of the farmers (Gauchan & Yokoyama, 1999; Vaidya, 1998), and their tasks are decentralized to ensure that each one has the flexibility to design and develop climatically appropriate cropping technologies. This structure allows farmers to be part of a RARS's participatory research approach. Promising technologies developed through the NARC systems are first demonstrated in farmers' fields for performance evaluation and then preferred varieties are disseminated to the farmers' fields through the district-level government extension agents located in each of the 75 districts. The district-level extension workers not only provide active supervision of these demonstrations, but also work as liaison between NARC and farmers by relaying farmers' response of the evaluated varieties to the national research system. This feedback mechanism between the farmers and the research institutions allows researchers to incorporate specific needs of the farmers in their process of research and technology development.

During the 1990s, Nepal made significant transformation in agricultural research and development, one of which is the decentralization of its research activities (Biggs & Gauchan, 2001). Along with NARC (the only public research establishment entrusted to devise appropriate technology for farmers of Nepal), many new actors such as non-governmental organizations (NGOs), community based farmers group (CBO), and private enterprises emerged to play active part in Nepal's agricultural research and development. Such policy shift provided the mandate for NARC to play a strategic role in coordinating and supporting all stakeholders involved in the innovation of agricultural technologies. As a result, an alternative institutional model in research and development known as Participatory Technology Development (PTD) emerged. Formal

signing of Memorandum of Understanding and Letter of Agreements by NARC, NGOs and CBOs in 1997 is an example of this collaboration. On a more specific example of such collaboration, NARC is jointly working with the Local Initiative for Biodiversity Research and Development (LI-BIRD), an NGO experienced in participatory approach to innovation of technologies in agriculture. This joint collaboration between these two institutions began in 1997 with a project entitled "Strengthening the Scientific Basis of In-situ Conservation of Agrobiodiversity On-farm." Globally coordinated by the then International Plant Genetic Resources Institute, the project formed an apex body called the National Multi-disciplinary Group (NMDG), and local multi-disciplinary group (LMDG) to implement the project. At all levels of decision-making, representations from NARC, DoA, and LI-BIRD were mandatory. The multi-disciplinary groups constituted experts in socio-economics, PPB, agro-morphology, community mobilization, and gender and policy.

The emergence of such new institutional arrangement to develop location-specific technologies can be interpreted as an institutional innovation designed to improve food production by targeted technology. Unlike previous eras, current farmers and their supporting institutions are actively engaged in co-production of location-specific technologies. For example, at the commencement of the PPB program in mid 1980s scientists began their consultation with farmer groups, including mother groups, from the communities of two high-altitude villages (2000 m) of Chhomrong and Ghandruk in Western Nepal (Sthapit, Rao, & Jarvis, 2002). To the surprise of scientists, members of the mother groups strongly considered breeding white grain rice varieties as their strong goal, along with cold tolerance, high grain yield, and resistance to sheath brown rot disease (Joshi et al., 2000). In addition to white being the preferred color of rice, red-pericarped rice imposed drudgery on women, as they needed to spend considerable time removing red bran with a manually operated rice pounder (Sthapit et al., 1996). The participation of women farmers was crucial in setting goals as they knew what they preferred and had in-depth understanding of their crop-growing environment. According to Sthapit et al. (1996), during the process of varietal development other desired traits also emerged, including preference for higher water absorption capacity during cooking as this trait ensured greater volume of cooked rice, an important trait in food deficit areas. This collaboration resulted in the release of two high altitude rice varieties (*Machhapuchre-3* and *Machhapuchre-9*) in the mid 1990s (Sthapit et al., 1996).

The success of PPB in the development of high-altitude rice varieties led to the emergence of novel partnership between NARC, LI-BIRD, and community based organizations. To date, this formal collaboration resulted in the release of two additional rice varieties (*Sunaulo Sugandha* and *Barkhe 3004*) for marginal climatic regions of Nepal. The variety, *Sunaulo Sugandha* is recommended for rainfed areas rather than irrigated rice growing areas of the Terai and inner valleys. It is expected that this variety has the potential for covering over 0.3 million hectares of land with medium to poor soil conditions. This variety has exceptional combination of high yield potential, e.g. $>4 \text{ t ha}^{-1}$ under farmers' management (which is not very common with high-quality rice varieties), good aroma and excellent taste value. Likewise, *Barkhe 3004* is also a drought-tolerant rice variety and has strong trait to tolerate moisture stress. Three other varieties (*Barkhe 2014*, *Sugandha-1*; *Barkhe 2017*) have already been approved by Nepal's Variety Release and Registration Subcommittee, a government entity that certifies new crop varieties. All are resistant to insects and diseases and are recommended for climatically marginal areas of the country. Additionally a number of rice varieties are in the pipeline, including *Mansara*, *Biramphul*, *Kachorwa* and *Lumle-2*. The first three lines have been

developed for dry areas of the valleys and the Terai and contain preferred trait of high cooking quality, and the fourth variety, *Lumle-2* has been developed for high altitude regions. Likewise two maize varieties developed through PPB are in the pipeline. Both of them have been recommended for low-rainfall regions of the country and are resistant to lodging and insect pests.

One of the remarkable outcomes of this collaborative effort has been the development of “grassroots breeding” approach that enhances institutional and technological skills of farmers and communities in plant breeding, seed production and marketing strategy (Sthapit et al., 2008). Community based organizations have also figured prominently in the effort to supply information to breeders regarding farmers’ demand for specific traits and have also been significant in gaining farmers higher and earlier acceptance of improved varieties. A strong rationale for PTD in a country like Nepal has been the existence of cropping systems in marginal environment where the adoption of modern varieties is low, a situation that is not helped by the fact that the impacts of even a small change in climate is quite severe here. Therefore, it is promising that agricultural technologies developed by engaging farmers have performed well not only in high potential production systems (Witcombe, Joshi, Rana, & Virk, 2001) but in marginal environments as well (Sthapit et al., 1996). An additional dimension of PTD has been the focus on on-farm conservation that encourages farmers to continue to select and manage local crop populations and seed supply systems through informal networks, an approach that has positive implications for better climate adaptation.

In addition to the Outreach Programs through RARS, NARC also collaborates with international research institutions. For example, the International Maize and Wheat Improvement Center (CIMMYT) in Mexico and the NARC are working on developing wheat and maize varieties that meet farmers’ needs. Apart from working with NARC, CIMMYT also directly provides financial support and technical backstopping to NGOs for promoting PPB and PVS in the marginal agro-ecosystems of Nepal. The NARC Soil Science Division manages long-term soil fertility trials in collaboration with Cornell University in rice-wheat cropping patterns to study the impact of intensive cropping in soil quality in the region.

Conclusion

Institutions that facilitate innovation of technologies are central for building the adaptive capacity of farmers. This study reveals that, in the case of Nepal, climatic variations have been constantly stimulating the development of new technologies, including varietal development for climate-stress environments and modifications of agronomical practices. As a result, more than ever, Nepal’s research establishment is becoming more focused on addressing the needs of farmers in climatically marginal regions. As climate change may constantly alter growing environments by changing growing period and soil moisture regimes, and by adding heat stress to the plant, such changes will continuously induce or demand farmers and their supporting institutions to develop technologies suitable for the new environments.

Nepal has developed novel multilevel institutional partnership, including collaboration with farmers and other non-governmental organizations at all stages of technological innovation. Most importantly, farmers are involved in goal setting, sharing of knowledge, and development of varieties suitable to local environments. This mutually beneficial partnership has been enhanced over the last decade through the PTD approach, because participatory research program requires a collegial relationship and multi-disciplinary and multi-institutional collaborations. By bringing formal technological innovation process closer to farmers, and by combining the sub-disciplines of agriculture such as crop

breeding, insect and pest management, agronomy, and traditional farmer’s knowledge, PTD has facilitated the government’s effort to transfer agricultural technologies to farmers in a more efficient manner. This approach has maintained an ongoing dialog among farmers, researchers, and agricultural policy makers and allowed them to develop appropriate research agendas, choose appropriate technologies, and broaden the spectrum of partnerships. This new institutional framework has also enabled researchers to receive feedback from farmers about their preferences and perceptions of the technology more directly and frequently, thereby increasing the chances for successful adoption of new innovations.

The stakeholder participation has grown into strong research, development, and knowledge institutions, an unlikely configuration a decade ago. Once skeptical about farmers’ involvement in participatory research (e.g. during selection of plants from segregating population), NARC scientists have now become more open to collaborating with them. Such collaborative effort suggests that climate plays an inevitable role in motivating farmers and public institutions to jointly invest in research and development to overcome climatic constraints in crop production. In future, as climate keeps altering, we might need different forms of institutions that seek wider partnership among the various stakeholders and institutions that are focused on agricultural development on marginal areas. Such new configuration should be responsible for co-producing knowledge, harnessing richness of cultural knowledge for innovating technology on demand, leveraging expert knowledge in the local context, and cultivating better interactions and learning practices. In brief, a new institutional setting for technological innovation should involve plural systems and multiple sources of innovation and talents so that it will benefit science, farming communities, and the entire food-insecure world.

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