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Hybrid knowledge and climate-resilient agriculture practices of the Tharu in the western Tarai, Nepal

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Indigenous knowledge can function as a basis of innovation in agriculture because it is not only culturally accepted, but often also environmentally adaptive. The debates and misunderstandings regarding the relations between Indigenous and scientific knowledge are transforming into a trend to integrate all knowledge to deal with complex issues, such as climate change. In this study we explore the understandings of the Tharu people of their farming system in relation to adaptation and mitigation of climate change, based on mixed methods design using both ethnographic analysis of their specific agriculture practices from participant observation and a survey of 229 households in the western Tarai of Nepal. Among our findings is the fit of the traditional agricultural calendar of the Tharu with the labor regimen of agricultural seasons. We found that conservation tillage-oriented agricultural practices, such as relay cropping, including zero-tillage, remain important in the farming system. Although this practice is decreasing, particularly due to the low yield as compared to the conventional tillage system, relay sowing and zero-tillage in the lowlands and uplands remain important for timely crop sowing. Similarly, mixed cropping is prevalent, particularly among small holders, for subsistence-based farming, in part due to higher yield than sole cropping. We conclude that Indigenous knowledge regarding climate and agriculture practices assists making informed decisions for climate-resilient and low emission agriculture. Although some traditional climate-resilient agriculture practices may yield lower profit than those derived from scientific knowledge/methods, the Tharu have therefore embraced “hybrid knowledge”—a combination of Indigenous and scientific knowledge, technology and practice—to balance increased yield and profit maximization with concurrent decreased vulnerability to extreme weather events. We argue that it is not useful to make firm distinctions among traditional, Indigenous and local knowledge in the age of hybridity. This hybridity is evident in the complementarity of the use of improved varieties and scientific agricultural practices for the major grains and the continuing use of landraces for minor crops such as lentils, peas and mustard. However, further research on the sustainable productivity of such practices is required before their widespread dissemination.

KEYWORDS
climate change, adaptation, mitigation, climate-smart agriculture, Indigenous knowledge, Tharu, Nepal

Introduction

The complementarity of different knowledge systems in regard to climate science, biodiversity conservation, and sustainable farming is being realized in the contemporary climate change context (Agrawal, 1995; IPCC, 2007). Indigenous knowledge is increasingly appreciated because scientific knowledge alone is recognized as inadequate to deal with the complex global climate crisis (Ellen, 2007; Sillitoe, 2007; Finucane, 2009). The knowledge of Indigenous people about agriculture and natural resource management, as well as their perceptions of climate change, is important due to their generations of engagement. Indigenous knowledge is often used interchangeably with concepts of traditional and local knowledge despite these having different meanings. According to the Food and Agriculture Organization of the United Nations (FAO, 2004, p. 1), Indigenous knowledge has a close association with "tribal groups" and the "original inhabitants of an area," while traditional knowledge has the connotation of being "rural, isolated, static and not interacting with other knowledge systems," and local knowledge is community knowledge of people who may or may not be Indigenous people and whose knowledge may have various sources. Scientific knowledge, in contrast, is derived from scientific method through the formal academic and research institutions and includes scientific technology, input and information in the subject matter. Traditional farming communities, such as the Tharu of Nepal, continue to use proven traditional agricultural practices, but also adopt knowledge, input and technology from others into a hybrid farming system harnessing all available knowledge. Such hybrid knowledge of agricultural practices is being adopted in local sociocultural and environmental contexts to contribute to climate-smart agriculture. Knowledge hybridity in agriculture occurs because the local land use systems that are dominated by traditional beliefs and Indigenous knowledge in agriculture may not meet future food demands due to increasingly limited land and low productivity of landraces (Van Vliet et al., 2012).

A discussion of knowledge hybridization with due consideration of Indigenous knowledge gained momentum with its integration into development programs by the World Bank (Warren, 1991; Woytek, 1998; World Bank, 2004) and its consideration by the Inter-Governmental Panel on Climate Change (IPCC) in the fourth assessment report (AR4) in 2007 (IPCC, 2007). In the modern world, Indigenous knowledge has proven beneficial when integrated with science. Local practices and Indigenous knowledge have been integrated in climate science and natural resource management in many projects worldwide, such as the use of Inuit knowledge to explore snow routes in Canada (Galloway McLean, 2009) and Australian Aboriginal knowledge for controlled bushfire management in Australia (Kimber, 1983; Andersen et al., 2005). Similar examples involve traditional techniques for field contouring in Mali that reduce water runoff by 20–50% and increase yields by up to 30% (Technology Need Assessment, 2017), and shifting cultivation or swidden farming practices used for such crops as dry rice by Indigenous communities in the tropics (Conklin, 1957, 1980; Sillitoe, 2017). However, debate continues regarding soil degradation and low production under shifting cultivation, which involves keeping land fallow between crop plantings, crop rotations and slope/contour farming, all of which are useful to reduce soil degradation and nutrient losses, especially in forest contexts, and reduce carbon emissions. There are diverse local practices in agriculture, mainly for crop production and soil and insect-disease management that contribute to scientific knowledge (Thurston, 1990; Warren, 1991; Dewalt, 1994). For example, Dewalt (1994) describes how scientific knowledge complements Indigenous knowledge, for example, in managing locusts by identifying specific species and using scientific control measures when Indigenous knowledge does not recognize such species at the time and place of the outbreak. The integration and legitimization of Indigenous knowledge with formal science could help to develop and scale-up Indigenous knowledge using programs of bilateral/multilateral agencies (Briggs, 2013). Similarly, the use of weather forecast systems, integration of flooding early warning mechanisms in the Tharu *barghar* system (village leadership), and adoption of agriculture input (inorganic fertilizer, pesticides, herbicides, and seed) are some of the examples of the contribution of scientific knowledge to Indigenous knowledge to reduce climatic risks to contribute resilient agrarian livelihoods (Chaudhary et al., 2021).

Adaptation to changing climatic conditions and mitigation of the sources of greenhouse gases (GHGs) are necessary to improve the resilience of agriculture among agriculture-dependent communities. A meta-analysis by the IPCC on wheat, maize and rice showed that adaptation will increase the yield equivalent by 15–18% more than without adaptation until the 2080s (Porter et al., 2014). Indigenous knowledge and traditional farming practices, including agrobiodiversity conservation, have been widely described as providing adaptation to climatic variability, mitigation of GHG emissions, and sustainable productivity and income (Sterrett, 2011; Caritas, 2016). Climate-resilient agriculture practices and technology can minimize negative impacts and can also mitigate future risks (Speranza, 2010). Climate-resilient agriculture refers to the robustness of the system that can reduce climatic stresses and impacts, as well as dealing with future risks (Adger, 2006; Folke, 2006; Speranza, 2010; IPCC, 2014). Although resilient agricultural practices often emit low GHGs, their yield and profitability may not be as competitive as climate-smart agriculture that utilizes both traditional and innovative agricultural practices and technology

Abbreviations: FGD, focus group discussion; GHGs, greenhouse gases; ha, hectare; IPCC, intergovernmental panel on climate change (IPCC); t, ton.

to effect productivity enhancement, in addition to adaptation (resilience) and mitigation (Totin et al., 2018).

Traditional agricultural practices may be the basis for innovation in modern agriculture. Mixed cropping, relay sowing and zero-tillage are examples of traditional practices that farmers have used for many years in Asia and other parts of the world. Mixed cropping avoids complete crop failure and increases per unit area productivity of land, as well as reducing weeds, pest incidence and lodging; as well, it provides crop insurance against unstable market prices and extreme weather conditions (Sarker et al., 2004; Lithourgidis et al., 2011; Wang et al., 2012). Relay sowing in the Tarai setting of Nepal includes broadcast sowing of lentil, grasspea, linseed and other crops 2–3 weeks before rice harvesting. The productivity of relay sowing is determined by the genotypes and management practices used (Sarker et al., 2004; Wang et al., 2012; Malik et al., 2016; Wiraguna et al., 2017). Conservation tillage, such as zero-tillage, no-tillage or minimum tillage, in rice–wheat systems produce similar or higher yields, particularly of rice, than conventional tillage, along with having lower production costs (mostly through reduced labor), increased water productivity and reduced GHG emissions, thereby contributing to the mitigation of climate change (Jat et al., 2014; Gathala et al., 2015; Sapkota et al., 2015; Ladha et al., 2016). Such agricultural systems are specifically suited to the local context, resilient to climate change, and also emit low GHG. However, adoption of these practices is, in all likelihood, unrelated to perceived or actual climate change because these strategies have not been employed only after perceiving the impact of climate change. Rather, the practices are embedded in the traditional farming system due to providing a consistent yield, one which is able to respond to climatic variability.

The Tharu of the western Tarai (foothills/southern plains) have been, for generations, dependent on agriculture, with limited engagement in services, business and foreign labor (Bista, 1972; Rajaure, 1981; Guneratne, 2002; Chaudhary, 2008). The Tarai of Nepal, particularly its central and western regions, is comprised of forested land where there has historically been a high risk of malaria infection before its eradication in the late 1950s. The Tharu in the Tarai were the only frontier group who continuously settled in the area and supported Nepali rulers throughout the centuries. As a consequence of long-term settlement in the Tarai, the Tharu adapted and became genetically resistant to malaria (Modiano et al., 1991). After malaria eradication, hill and mountain people were encouraged to migrate and resettle in the Tarai, rendering the Tharu economically, socially and politically marginalized and suffering from an identity crisis (Müller-Böker, 1997, 1999; Guneratne, 1998, 2002).

Previous studies of Tharu knowledge have not focused upon what they know about climate, weather and the contribution of agricultural practices for adapting to and mitigating climate change. Studies touching on their knowledge in regard to climate change and adaptive agricultural practices have mostly been limited to consideration of crop landraces, pest management and adjusting crop sowing/harvesting dates (Devkota et al., 2011; Maharjan et al., 2011). The studies have not explored why such traditional practices are being continued by the farmers despite comparatively lower yield than the modern agriculture technology and practices, as well as how Indigenous and scientific knowledge are blended in local agricultural practice. Therefore, this study addresses two issues, first it contextualizes the knowledge of the Tharu relating to climate and agriculture in the context of a changing climate. Second, the study examines the role of conservation agricultural practices (e.g., relay sowing, zero-tillage, and mixed-cropping) in rendering agriculture resilient in withstanding climate change. The study endeavors not only to provide greater depth on existing Indigenous knowledge and its value, but also to contribute to the theoretical discourse concerning integration of different sources of knowledge for climate-resilient and climate-smart agriculture.

Materials and methods

Fieldwork area

The study was conducted in two rural villages, Thapuwa and Bikri, in Gulariya municipality, Bardiya district, Nepal, as shown in Figure 1. The villages are situated between the latitude of 28° 14′ N and longitude of 81° 18′ E at an altitude of ∼215 m above mean sea level. The district shares its southern border with India. The Bardiya district was selected due to the high percentage of the Tharu in the district (53%, ∼226,089 Tharu) (CBS, 2014), high reliance on agriculture-based livelihoods (DDC Bardiya, 2013; DADO Bardiya, 2015), and its status as one of the least developed districts in the *naya muluk* (new territory—Banke, Bardiya, Kailali and Kanchanpur) in terms of the human development index (HDI, 0.466) (Government of Nepal UNDP, 2014). Within the Bardiya district, Thapuwa and Bikri villages were chosen based on predominance of Tharu ethnicity and vulnerabilities to flooding and drought, respectively (DDC Bardiya, 2013; RKJS/Practical Action, 2013). Thapuwa village is long-settled, whereas Bikri village was settled in 1967 by immigrants from Dang-Deokhuri, which is more than 100 km to the east.

Research methods and data analysis

The research utilized a sequential mixed-methods approach, with collection of quantitatively analyzed data followed by qualitative data elicited through in-depth interviews, focus group discussions (FGDs) and participant observation, conducted across 6 months in two phases in 2018. Table 1

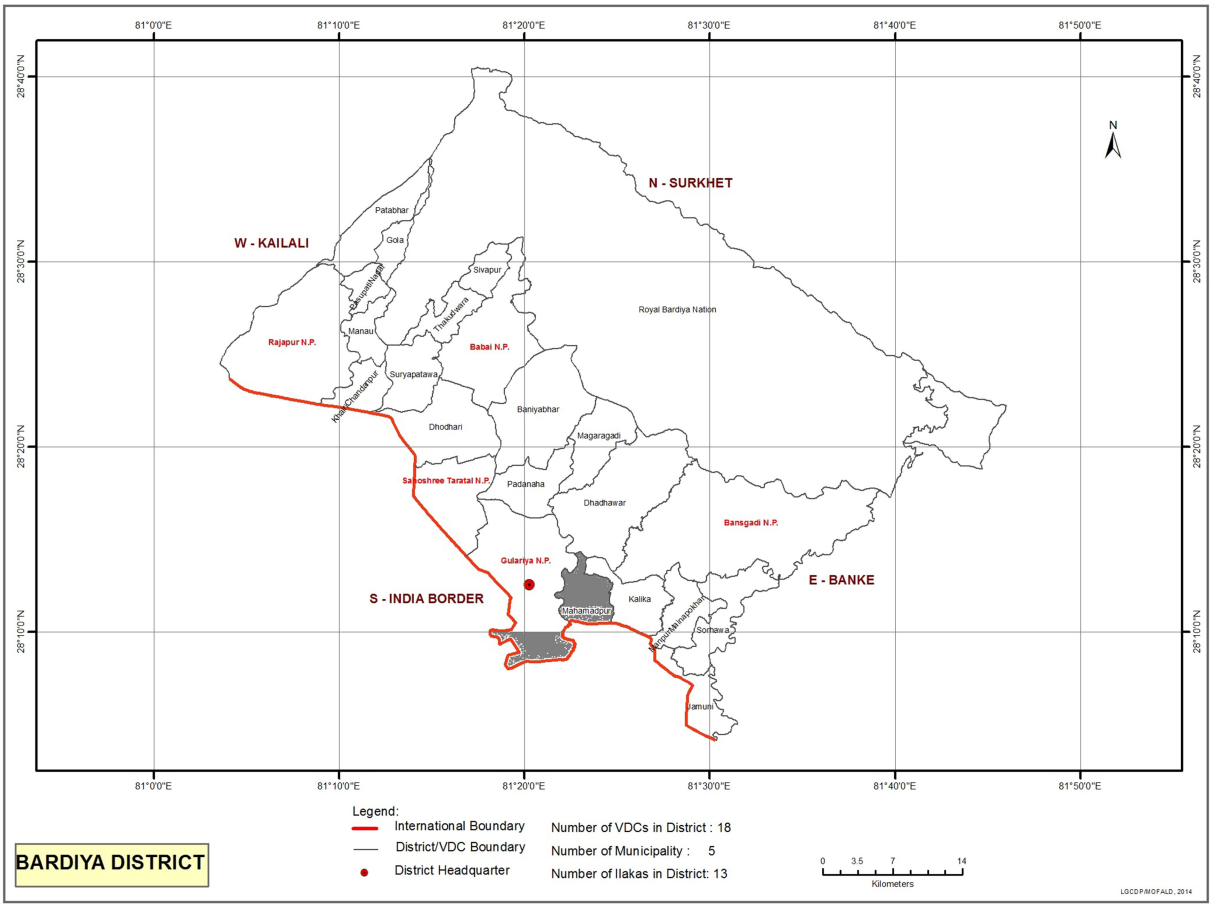

FIGURE 1
Bardiya district map showing the two fieldwork villages, Thapuwa and Bikri. Source: DoFRS (Cartographer) (2019).

gives a summary of the study's research methods and numbers of participants.

The research utilized a mixed-methods approach in order to provide data validation and triangulation. The knowledge, interpretation, and experience of people are guided by their cultural beliefs; therefore, ethnoscience, with its emic focus on local classifications and knowledge, defined one study framework. Complementarily, etic analysis of agricultural production required quantitative analysis. Mixed methods increase the reliability and validity of research from both approaches (Neuman, 2004; Creswell and Plano Clark, 2011). A mixed methods approach includes the use of qualitative methods—participant observation, in-depth interviews, and focus group discussions/FGDs)—to elicit locally grounded data to complement quantitative results and also to facilitate triangulation of data (Creswell and Plano Clark, 2011). In the study, qualitative and quantitative analyses were performed separately, but the findings were mixed for discussion and interpretation.

Quantitative methods

A census was conducted of 229 households (143 in Thapuwa and 86 in Bikri), comprising all village households in the populations under study, using a semi-structured survey questionnaire after 1 month of familiarization and rapport-building with the people to ensure reliable information. The survey questionnaire was in three sections: agriculture, climate change and livelihoods. The survey was conducted with a household head or member engaged in farming, both wife and husband, if possible. Particular consideration in the choice of interviewees was given to people over 30 years old so that they could recall 10–20-year-long scenarios of climate and farming.

The questionnaire covered aspects of conservation agriculture—minimum soil disturbance, soil cover and crop rotation—aspects that are considered for analysis as climate-resilient agricultural practices. Relay sowing and zero-tillage constitute the minimum soil disturbances, rice stubble after harvest serves as a soil cover, and rotation of lentil and wheat in rice field meets the criteria of crop rotation. Relay sowing

10.3389/fpos.2022.969835

TABLE 1 Interviews, focus group discussions (FGD) and household surveys during fieldwork in 2018.

Village	No. of interviews	No. of female interviewees	No. events observed[a]	No. of FGD	No. of participants in FGD	No. of female participants in FGD	No. of households surveyed	No. female respondents in the survey	Female-headed households
Thapuwa	17	3 (18)	3	2	21	5 (24)	143	45 (32)	1 (1)
Bikri	12	6 (50)	3	2	23	11 (48)	86	32 (37)	8 (9)
Totals	29	9 (31)	6	4	44	16 (36)	229	77 (34)	9 (4)

Figures in parentheses represent the percentage of females in the respective category.

[a]In Thapuwa, the field researcher observed a public hearing of the women's group, bore installation to lift underground water, and rice seedling and transplantation. In Bikri, he observed two meetings of the Bhawani community forest user group and one meeting of a women's group for saving and credit.

of lentil is conducted through broadcasting before 2–3 weeks of rice harvesting, which is conducted according to absolute no-tillage. In this study, one minor tillage with bullock or tractor cultivator is considered as zero-tillage. Tillage with mouldboard plow or harrow for two or more than two times is considered as conventional tillage. Mixed cropping (two or more than two crops cultivation) and sole cropping (single crop cultivation) are also considered in lentil cultivation. Lentil is normally mixed cropped with pea, mustard, and wheat. IBM SPSS version 20 was used to calculate frequency, means, standard deviations and t-tests for the productivity analysis.

Qualitative methods

During the first month, several transect walks, bike-rides, and many informal conversations were undertaken with the villagers. Building rapport was facilitated by the field researcher (i.e., the first author) also being Tharu and having been brought up in the region. The *barghar* (traditional village head), *guruwa* (shaman), school teachers and social leaders were approached as key informants and to obtain their support for the study.

Altogether, four focus group discussions/FGDs (2 in Thapuwa and 2 in Bikri) were conducted with farmers to assess the changes in agriculture in the last 10–20 years and possible reasons of change, strategies to manage insects, diseases and performance of ritual practices. The first FGD in each village was conducted with a wider range of participants, comprising household heads, traditional village leaders (*barghar, guruwa, and chaukidar*), farmers, and animal herders to assess the impact of climate change on livelihoods and farming and their coping and adaptation strategies. The second rounds of FGDs were conducted specifically with the farmers to assess the change in agriculture over 10–20 years, its possible reasons and farmers' responses to manage it. The agricultural knowledge and practices gathered from the FGDs were also triangulated with the district agriculture office and private service providers (e.g., agro-vets). For each of the FGDs conducted, 8–10 people representing different ages, genders, educational levels, and landholding sizes were selected. Farmers were asked to recall changes in agriculture and the farming system. The FGDs' format facilitated their memory of visible changes in the major aspects of agriculture and their recall of reasons for these changes. Hence, a maximum 20-year timeframe is considered for this analysis to gather robust information on such topics as changes in cropping patterns, as well as use of improved seeds and inorganic chemicals in agriculture. The FGDs were conducted during the pre-monsoon season (April to May) to reflect the preparation of rice cultivation, as well as preparation for coping with climatic extremes (flooding and drought). The FGDs took place in the community hall used by the entire village, and each lasted for a maximum of 4 h. The questionnaire checklist and framework for each FGD were translated into Tharu to facilitate the researchers leading the discussion with the support of a local facilitator. The research was carried out with the approval of the Human Ethics office (reference number RA/20/4133) of The University of Western Australia, Perth.

The qualitative data were manually categorized into themes and tabulated. NVivo 12 Plus (Qualitative Research Software (QSR) International) was used to analyze qualitative information. Interviews were manually transcribed. The qualitative data files were uploaded into the NVivo 12, categorized into different groups such as FGDs, interviews, and observations. The uploaded files were coded to form the nodes and sub-nodes in the software, where node and sub-node identify a theme and sub-theme. Different facilities of NVivo, such as node comparison, hierarchical chart, and cluster analysis, were used as a foundation for analysis in terms of important words and thematic areas (nodes). The final analysis was conducted by reading and re-reading transcriptions, digesting the information, and reflecting upon the interpretation of interviews to reach conclusions regarding knowledge and practices regarding climate and agriculture of the Tharu.

Ethnoclassification

Local peoples have their own ways of understanding and classifying climate/weather and seasons, agricultural land, weeds and other aspects of agriculture that derive from their Indigenous knowledge and its practical applications in everyday life. The Tharu ethnoclassifications were elicited based on the thematic analysis of various levels of discussions in groups, interviews, and participant observation during the major agricultural operations, such as rice transplantation and winter crop harvesting. Weeds were commonly observed during fieldwork in the winter and monsoon seasons. A series of individual and group interviews were conducted to capture local people's ethnotaxonomy of weeds and their management.

Results

Household and farming characteristics

Landholdings and other essential household characteristics are presented in Table 2. The households are small landholders (normally a household head owns the land), with households in Bikri have smaller landholdings (0.55 ha/household) than Thapuwa (1.17 ha/household). There are 19 *mukta kamaiya* families (former agricultural bondage laborers) in Thapuwa with small plots of land (0.07 ha/family). Despite the small landholdings, particularly in Bikri, the primary occupation of people in both villages is agriculture. The Tharu have been a patriarchal society, but the household leadership role of women is increasing in nuclear families.

Most large farmers cultivate the land themselves, while some of them lease additional land or rent out part of their land for cultivation. When renting land, 50% of the product is usually shared, which is called *adhiya bataiya* (sharecropping). Sharecropping is common among many families, with 64% (n = 91) in Thapuwa and 27% (n = 23) in Bikri participating in the practice. There are a small number of non-cultivators, 6% Thapuwa and 2% in Bikri, who own land, but who do not farm themselves. The members of these families mostly engage in salaried work or are in skilled employment.

TABLE 2 Average household characteristics of the study villages.

Characteristics	Thapuwa (n = 229)	Bikri (n = 86)
Mean landholding (ha)	1.17	0.55
Mean family size	5.8	5.7
Median age of household head (hhh)	42	39
Literacy of hhh	96%	99%
Occupational agriculture of hhh	88%	85%
Female-headed households	4%	5%
Share cropper (*bataiya*) percentage	64%	27%
Local non-cultivators with land	6%	2%

Climate change—Perceptions and data evidences

Local people's perceptions are important for strategies of adaptation and mitigation and their realization. The responses of the participants regarding perception of climate change against four indicators (temperatures, rainfall, insect-diseases, and weeds) revealed consistent perceptions of increased temperatures (except for winter temperatures) by three-quarters of the respondents. Our analysis of 38 years of temperatures and rainfall data of the study area from government sources showed a significant increase in maximum temperature and mean temperatures almost by 1°C and 0.6°C, respectively. However, there has been no clear trend in rainfall due to high variation in the year-to-year rainfall. Therefore, we could not validate local Tharu perceptions of decreasing rainfall with climate data.

The Tharu in the study village prioritized flooding as the number one hazard, in both villages followed by droughts in Bikri and storms in Thapuwa in the 2nd place. The Tharu consider storms and hail as a natural disaster. Flooding has destroyed houses and roads, swept away stored grains, affected livestock, inundated standing crops, and sometimes caused irreversible damage to agricultural land by converting it into sandy riverbed. The local Tharu do practice riverbed farming based on the suitability of crops, including cereals, legumes and vegetables. Droughts have had varying levels of impact on crops, ranging from reduction in yield to complete crop failure. Droughts have still constituted a common threat in crop yield despite introduction of an irrigation technology and improved varieties of crops. Storm before monsoon (March to May) is disastrous to crops, fruit trees and even destruction of roof of houses thereby impacting livelihood of farmers.

Adjustment in agriculture—Changing climate and technology

There are multiple factors inducing change in an agricultural system. Household food security, market demand, technology, as well as climatic factors, have contributed to such change in cropping patterns, the crop calendar, and crop types/varieties. The crop calendar for the study villages is shown in Appendix 1, while possible reasons for changes in the agricultural system are summarized in Supplementary material.

There has been a clear adjustment in cropping pattern and cropping calendar over the last two decades. Rice and wheat are cultivated about 2 weeks earlier than 10–20 years ago. Monsoon-season maize has been almost entirely replaced with rice. An experienced farmer said, "Farmers near my maize field started to cultivate rice, which creates soil waterlogging that makes my field unsuitable for growing maize; then I also started to cultivate rice in that field." Many farmers started to cultivate rice instead of maize in the summer/monsoon season due to the availability of short-duration rice varieties, high rice yields, and preference for eating rice over maize. Also, maize can be grown in winter/spring after harvesting rice, but rice normally grows only during the summer/monsoon season. No changes in lentil and pea cultivation were noted, but mustard cultivation has declined.

Traditional minor crops, such as linseed and sesame, are rarely cultivated due to the changes in land cultivation patterns and possible decline in market demand. Similarly, pigeon pea and pointed gourd cultivation have practically disappeared in Thapuwa due to changes in the river course making the land unsuitable for their cultivation. Local soybean, Tharu *alu* (Tharu potato) and chickpea cultivation have also drastically declined in the study area.

Major changes in the agricultural calendar and related activities have taken place regarding the traditional rice field preparation and threshing of crops. Rice field preparation was traditionally (up until 10–20 years ago) very labor-intensive, with at least three tillage passes before rice transplantation. The first preparatory tillage of the *khetwa* (rice terrace field) is called *ofar/chir*. It is performed after the onset of rain to loosen the soil, exposing it to sunlight, and to accelerate later land preparation for rice and maize cultivation. The first tillage of *dihwa* (flat land traditionally used for maize cultivation) is called *dhuriya* tillage—meaning dusty tillage without soil moisture. The main characteristics of *ofar* and *dhuriya* are one-way tillage (no cross-sectional tillage), shallow depth, and tillage not taking place in a flooded condition. The second tillage is called *gejar*, which is performed during the rice cultivation season in the shallow flooded field. The field is then left for 7–10 days so that weeds can decompose. The final tillage, called *lewa,* is then undertaken, followed by *danta/kilwahi* (raking) and *henga* (leveling) to puddle the field for rice transplantation. However, now the land preparation is much faster and easier than in the past because of use of farm implements (harrows) and mechanized power (tractors and power-trailers). A disc-harrow is used for plowing the *dihwa* as well as *khetwa* for land preparation, and there is no waiting period for crop cultivation. Overall, this process demonstrates the use of hybrid knowledge, combining traditional and modern methods, in land preparation, selection of adaptive and resilient crop varieties, and production and postharvest processing of crops.

Tharu agricultural calendar—Associated knowledge and practices

Tharu farmers perform activities based on the agricultural calendar and a combination of Indigenous and modern weather forecasting systems. Preparatory activities for agriculture are based on the Tharu seasons and crop calendar.

Tharu classify a year into three seasons based on the climate, with each season comprising ∼4 months: *Jar mahina* (winter, November to February), *Gham mahina* (summer, March to June), and *Barkha mahina* (monsoon, July to October). Table 3 represents the months of the agricultural calendar with their associated activities.

Jar represents the winter from mid-October (*Katik*) to mid-February (*Magh*). A thick fog, *kuhira*, is followed by cold waves, *shitlahar,* rendering life harder. The night frost is called *pala*. The area receives winter rainfall, labeled *hewat*, and rain in the peak of winter is called *chamar barha*, which kills cattle and goats due to the cold and lack of green fodder. If there is no rain, then the local people believe the chance of hail is high and vice-versa. *Jar* has positive and negative aspects in relation to agriculture. Farmers declare that the winter frost and dew are important for pulse crops (lentil, pea) and wheat. *Hewat* (winter rainfall) is an indicator of good winter crop production. Local farmers believe *hewat* increases the branching and growth of winter crops. Local people have a strong belief that canal irrigation without *hewat* is insufficient for good winter crops. Extended foggy weather with limited sunlight and high humidity increases the incidence of diseases, such as late blight in potato.

Gham, the summer season (March to June), is characterized by high temperatures and low humidity. Frequent windstorms occur during summer. Villagers believe storms come from the north-west, causing damage to houses, trees and crops. This is the agriculture leisure period before onset of the monsoon.

Barkha (monsoon season) runs from July to October. Most of the annual rain falls during this period. *Barkha* is characterized by high temperatures (lower than summer season) and humid conditions. The monsoon season is one of the busiest seasons because of rice cultivation. The Tharu in Thapuwa and Bikri villages identify rainfall by different names, such as *Bundibunda barkha* (scattered raindrops for a very short time), *Jhimjhim* (drizzling rain for a short period), *Jhammak* (heavy rain), and *Jhari* (continuous rainfall). *Jhammak* and *Jhari* lead to *khet bahiya* (field flooding) and *ghar bahiya* (house flooding) based on the intensity and season of rain. Villagers in Thapuwa prefer *khet bahiya,* as it deposits clay soil on the *khet*, which gives bumper crop yields and improves soil quality.

Hybridity in the sources of weather information

The use of scientific weather forecasts is increasing in the Tharu community despite continuing consideration of their Indigenous knowledge. Some local indicators that Tharu farmers consider the basis of their decision making in daily life are listed in Table 4. The regional weather forecast from local media is not accurate for specific locations; therefore, local knowledge remains important to farmers. The specific indicators of climate variability and local weather allow farmers to take appropriate actions to cope with the incoming changes and challenges in agriculture.

The Tharu in the study villages are increasingly using scientific weather information, particularly during rice cultivation and for preparedness from flooding disasters. Radio is still the most important source of information. Accessibility to radio stations and local FM on mobile phone devices has greatly increased access to weather information (Table 5). Other sources of information are social networks (friends, relatives, neighbors) and television. More than 90% of respondents receive reliable weather information in a timely manner, so they act upon it, especially in the case of flood warnings.

Ethnoclassification—A basis of Indigenous knowledge

Indigenous and local peoples have their own traditional ways of understanding and practicing agriculture. One of the most important aspects is grouping their understanding, knowledge and experience into the thematic categories that forms the basis for traditional classification, as was evident in the classifications of seasons and of weather indicators treated above. As these classifications reveal, the Tharu farmers have a rich knowledge of understanding on weather and agriculture, which is reflected in their classifications of seasons, agricultural land and weeds and which functions to facilitate agriculture.

Classification of agricultural land

Tharu farmers classify agricultural land into three categories—*dihwa/dadwa, khetwa/khet* and *baggarwa*—that are further divided into sub-categories associated with varying agricultural land usage. *Dihwa* is flat land that is not normally divided into smaller units (plots). A bund (low height, 10–15 cm) separates *dihwa* from the plots owned by others. There is no stagnation of rainwater in the field and traditionally no provision for irrigation. Farmers generally cultivate maize in the monsoon and mustard in the winter on such land. Residential land, *gharauri,* also comes under the category *dihwa,* which is comparatively further upland than normal *dihwa* land. *Gharauri* is the safest land and accessible by foot-trails and road.

Khetwa is wet rice land that is divided into square or rectangular-shaped small plots (350–650 m^2) called *oenra*. Bunds are normally higher than the *khetwa* (about 30–50 cm height) to conserve water for rice cultivation. Irrigation is mostly feasible on this type of land, and the soil has good water-holding capacity. *Khetwa* is further divided into *dadai khet* and *jabda*. *Dadai khet* is more upland than *jabda*, sometimes sandy and with low water-holding capacity for 1–2 days. *Jabda* is lowland with blackish-colored soil that has better water-holding capacity than *dadai khet*. Short-duration *ashan* (coarse) rice is grown in *dadai khet*, whereas *jarhan* rice (late maturing, super quality fine rice) is cultivated in *jabda*.

Baggarwa is riverbed land that is affected by rivers and streams flooding and consequent erosion. It usually floods when the water volume increases during the monsoon. *Baggarwa* is further divided based on its suitability for farming. In the initial few years, rice can be grown in lowland riverbed areas, and black/green gram, lentil and linseed in upland areas in the riverbed. *Baggarwa* soil is sandy, so crops such as watermelon, groundnut and gourds can grow during lean periods; this is called *baggar kheti* (riverbed farming). Riverbed farming is one of the Indigenous knowledge-based traditional practices among the Tharu and others in the region (Gurung et al., 2014; Schiller, 2014). Bushes, shrubs and tall grasses in the *baggarwa* that make land not suitable for cultivation are normally called *bhagraiya*.

Classification of weeds and their management

Tharu farmers classify weeds based on the season of growth, crop of prevalence, habitat (herb/shrub), consumption (edible/inedible) and physical characteristics (thorny/non-thorny). The Tharu mostly classify weeds as edible or inedible. Edible weeds are further divided into edible for humans, animals, or both. Inedible weeds are noxious for both humans and animals.

Herbicides are used primarily to reduce agricultural labor due to family labor scarcity and unavailability of workers during periods of peak agricultural activities. Herbicide costs are 8–10 times cheaper than labor costs. Both pre-emergent and post-emergent herbicides are used in rice, but only post-emergent herbicides are used for wheat and maize.

TABLE 3 Tharu agricultural calendar in wet rice and associated activities.

Months	Rainfall (mm)*	Season	Activity	
			Rice–wheat system	Rice–maize system
Magh (Jan to Feb)	22	*Jar*	Fallow	Irrigation, fertilizer
Fagun (Feb to Mar)	18	*Gham*	Fallow	Fallow
Chait (Mar to Apr)	18	*Gham*	Wheat harvesting	Fallow
Baisakh (Apr to May)	37	*Gham*	Fallow	Maize harvesting
Jeth (May to Jun)	138	*Gham*	Fallow	Fallow
Asar (Jun to Jul)	321	*Barkha*	Rice seedling	Rice seedling
Saun (Jul to Aug)	365	*Barkha*	Rice transplantation	Rice transplantation
Bhadau (Aug to Sep)	268	*Barkha*	Rice weed removal	Rice weed removal
Kuwar (Sept to Oct)	142	*Barkha*	Rice irrigation	Rice irrigation
Katik (Oct to Nov)	29	*Jar*	Rice harvesting	Rice harvesting
Aghan (Nov to Dec)	8	*Jar*	Wheat sowing	Maize sowing
Pus (Dec to Jan)	18	*Jar*	Weed removal, herbicide	Weed removal, herbicide

*Based on the mean monthly rainfall data of Gulariya meteorological station calculated from 1973 to 2016 (44 years, 2012 and 2013 not available). Mean rainfall calculated from the two Gregorian months shown in brackets.

TABLE 4 Tharu Indigenous indicators of weather and extreme events.

Indicator	Behavior	Indication
Biological indicators		
Ant	Carrying eggs from the nest to an uphill safe place	Rain
Poultry (a hen)	Spreading feathers under the balcony of the house	Rain
Cattle	Running, jumping and producing sounds with tail straight	Rain
Earthworm	Comes out of the ground and crawls on the mud	Rain
Dhansuhi bird	Cries near villages are an indication of no rain during the summer and monsoon seasons	Drought
Common crane (*Mansi Surwal*—migratory bird)	Groups of birds return south at height, producing the *karlyang kurlung* sound that signals the end of the monsoon	End of the monsoon
Physical indicators		
Wind direction	Easterly wind for 2–3 days followed by westerly wind from March to June	Rain
	Easterly wind from July to September	No rain
Rawaniya wind	Wind blowing from the southeast on rainy days	No rain
Sunlight and wind direction	Bright sunshine during the day, air blowing from the west in winter	Frost
Winter rain	No or less winter rain	Hailstorms during next summer

TABLE 5 Top five sources to obtain weather information.

Source of weather information	Thapuwa ($n = 143$)		Bikri ($n = 86$)		Total ($n = 229$)	
	%	f	%	f	%	f
Radio	72.7	104	96.5	83	81.7	187
Mobile phone	4.9	7	0	0	3.1	7
Social network	4.2	6	0	0	2.6	6
Television	3.5	5	0	0	2.2	5
IK and *Pandit**	6.3	9	2.3	2	4.8	11

IK, Indigenous knowledge; *Pandit is the Hindu priest; f, frequency.
Total per cent is not 100 since only the top five sources of information are presented here.

The Tharu farmers use both Indigenous and scientific knowledge—hybrid knowledge—for weed management. The decision to apply herbicides is based on the crop history of the land and the weed infestation. Farmers use pre-emergence herbicides based on the weed prevalence in preceding years. However, most post-emergent applications are based on direct observations of the weed population. If <25% of the land is covered by weeds, then the weeds are removed by hand. The decision making is also based on weed vigor. If the crop is taller than the weeds and the weeds are scattered, then farmers prefer hand removal or even no weed removal. Hand removal of weeds also loosens the soil, and walking on the soil works as inter-tillage for the rice. Within the village area, anyone can harvest weeds from any field, so manual harvesting of weed grass is common for livestock. If weeds remain in the field, then farmers will use a post-emergence herbicide.

Farmers have not been fully satisfied with the results from herbicide application. Some farmers reported that pre-emergent application of herbicides during rice field preparation reduces rice yield and even affects pulse crops (lentils and peas). Bharose Tharu from Thapuwa declared, "Last year, I did not use herbicides in rice after 5 years of regular use. I had a problem with weeds, then started manual hand removal. It took us 22 days in two *bigha* (about 1.25 ha) of land. I couldn't use post-emergence herbicides because it had become too late to spray by the time weeds matured."

Likewise, Binod Chaudhary from Bikri shared, "A couple of years ago, I had used a pre-emergence herbicide in rice soil that badly affected my succeeding peas and lentils. Crops grew well, but when reaching the flowering stage, they turned yellow and died. I did not get any harvest. After that, I use post-emergence herbicide by spraying mainly in rice and wheat at the early stage."

Apart from traditional classification, there is the Indigenous knowledge system operating in crop protection and grains storage, e.g., *dehari*—earthen wares. *Dehari* is an earthen storage structure prepared at home by Tharu women. *Dehari* is not only used for seed and grain storage, but also as a room separator; it has cultural importance, e.g., as a wall painting, and as a type of holy bag containing a deity and divine tools (cane, swords). Dried grains are stored in air sealed conditions that are unfavorable for insects and fungi. Various traditional methods of crop protection, such as the scarecrow (*jhukka*), deadfall trap (*odra*), watch tower (*atwa*) and botanical pesticides are traditional ways of farming of the Tharu in western Nepal. The Tharu Indigenous ritual practices related to agriculture, such as *hareri* (wishing for green and productive crops along with removal of Gandhi bugs (*Leptocorisa spp.* or the rice ear bug), *darbandhi* (sealing village territory) and various non-lethal traditional techniques for crop protection, reflect and enhance their adaptive capacity. In recent decades, chemical methods have become an integral part of farming, but various non-chemical techniques are still used that support the concept of integrated pest management.

Traditional climate-resilient agricultural practices

Mixed cropping

Mixed cropping is one of the oldest farming techniques of smallholders to maintain food security, reduce the risk of crop failure, and conserve agrobiodiversity. Mixed cropping involves growing more than one crop simultaneously on the same land

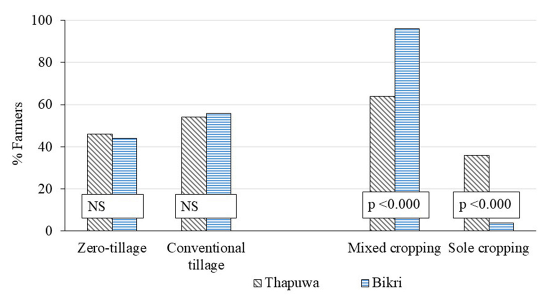

FIGURE 2
Prevalence of zero-tillage and mixed cropping with lentil in the study villages.

TABLE 6 Cropping patterns on *khetwa* and *dihwa* at Thapuwa and Bikri.

Type of agri. land	Thapuwa	Bikri
Khetwa	Rice–wheat–rice	Rice–lentil + mustard–rice
	Rice–maize–rice	
Khetwa	Rice–lentil/pea + mustard–mint/black gram*-rice	Rice–lentil + mustard + pea–rice
Dihwa	Rice–potato–mint/black gram–rice	Maize–lentil + mustard–maize/rice
	Maize–mustard/vegetable crops	Maize–vegetable crops

– followed by, / or, + and (i.e., at the same time).
*Mint and black/green gram are short-duration crops (3 months, March to May), so crop intensity increases from 2 to 3 crops per year.

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TABLE 7 Lentil yields under different tillage and cropping systems.

	ZT ($n = 58$)	CT ($n = 69$)	p-value	Mixed crop ($n = 105$)	Sole crop ($n = 22$)	p-value
Area (ha/hh)	0.29 ± 0.025	0.24 ± 0.026	0.148	0.26 ± 0.021	0.28 ± 0.037	0.578
Yield (t/ha)	0.71 ± 0.055	0.83 ± 0.050	0.020	0.84 ± 0.040	0.61 ± 0.088	0.016

ZT, zero-tillage; CT, conventional tillage.
ZT includes no-tillage (NT) or one minor tillage, and conventional tillage (CT) includes 2 or >2 tillage passes with tractor and/or mouldboard plow.

FIGURE 3
No-tillage garlic at Thapuwa.

without row maintenance (Sekhon et al., 2007). Growing two or more crops in separate rows is known as intercropping, which is a modified version of mixed cropping (Sekhon et al., 2007).

In the study area, various combinations of mixed cropping occur, e.g., the cultivation of lentil with mustard and pea. Cereal crops (rice, wheat and maize) are generally grown as sole crops. Common mixed cropping patterns in Thapuwa and Bikri are listed in Table 6.

Mixed cropping is more prevalent in Bikri (96%) than in Thapuwa (64%) (Figure 2), with an average of 82% of households in two villages cultivating lentil in mixed cropping. A yield analysis of lentil under different tillage and cropping systems is presented in Table 7. Lentil yields are significantly higher in mixed cropping (0.84 t/ha) than sole cropping (0.61 t/ha). Farmers reported that the higher lentil yields from mixed cropping than sole cropping were due to the production of two or more crops from the same piece of land, low weed infestation and few insect/disease problems.

Mixed cropping is a common strategy by farmers that can be used for climate change adaptation, as it reduces the risk of total crop failure and diversifies the household food basket, contributing to food and nutritional security. One drawback of mixed cropping, especially for the medium and large farmers in the study villages, is that machine harvesting is limited to the sole crops—rice and wheat.

Relay sowing

Relay sowing is broadcast sowing of lentil, grass pea, linseed and other crops into the standing rice crop 2–3 weeks before harvest. Relay sowing is a traditional practice in the Tharu community to overcome high and low soil moisture. Broadcasting of lentil into rice is the most dominant practice, followed by grasspea, linseed and faba bean. Relaying extends the period for vegetative growth, uses residual soil moisture and reduces tillage costs compared to sole cropping (Sarker et al., 2004). Relayed crops germinate before or at the time of rice harvest; the relayed crop grows quickly after rice harvest, meeting the appropriate winter length for growth and development. Relay sowing is a no-tillage method that meets the principles of zero-tillage (minimum soil disturbance) and conservation agriculture through crop rotation and soil cover.

Relay cropping varies with soil type and the availability of irrigation. No relay sowing occurs in Thapuwa. In Bikri, about 50% of the fields are under relay crops (lentil, pea and grasspea). In Thapuwa, the soil is sandy, which is easy to till, and farmers have pumps for irrigation, so they cultivate wheat or maize after the rice harvest. In Bikri, relay-sown lentil had more uniform germination and better vegetative growth than conventionally tilled lentil.

The comparative yields of lentil under relay sowing and zero-tillage are shown in Table 7. Yields are significantly lower (0.71 t/ha) in zero-tillage including relay sowing than the conventional tillage system (0.83 t/ha), contradicting the others research findings of higher yields under zero-tillage than conventional tillage. Most zero-tillage lentil comes under relay sowing. Farmers reported that lentil production depends on the weather conditions, as some crops fail due to waterlogging.

Zero-tillage

Zero-tillage is practiced in different crops to varying degrees. In the study villages, farmers practice zero-tillage mainly for lentil and garlic. Although zero-tillage in the rice–wheat system has been widely researched in South Asia (Jat et al., 2014; Bhatta and Aggarwal, 2015; Sapkota et al., 2015), it was not practiced in the study villages. As discussed earlier in the mixed cropping section, slightly fewer households (about 45%) practiced zero-tillage than conventional tillage (55%), with lentil yields significantly lower under zero-tillage (0.71 t/ha) than conventional tillage (0.83 t/ha) (Table 7).

TABLE 8 Landraces cultivated in Thapuwa and Bikri.

Crop	Landrace	Characteristics	Reason of cultivation
Rice	Karangi	Black seeded with awns	Early maturity/short duration, direct seeding in dry or wet bed, early or late sowing possible, suitable in upland
Rice	Sauthyari	Covered in sheath, black and seed with awn (shorter hair than Karangi)	Early maturity, early or late sowing possible, direct seeding in dry or wet bed
Rice	Andi	Tall plant, red seed coat, large seed	Sticky rice, cultural value, *jaar* (sweet rice beer)
Maize	Raksi/Gaiji	Short plant, normally two cobs, short and compact seed	Popcorn, hardy, short growth duration allows timely sowing of mustard in winter, taste
Mustard	Local lahi	Blackish brown seed, dwarf	Productive, oil has strong smell and taste, short crop duration
Lentil	Kariya Masri	Small and blackish seed coat, red cotyledons	Taste, mixes well in cooked rice, locally adapted, drought-resistant
Pea	Local	White and medium-size seed	Taste, withstands drought and cold waves
Potato	Tharu alu	White small tubers, red eyes in tuber	Taste, resistant to late blight, long post-harvest life
Vegetable	Poe sag *(Basella alba)*	Perennial, climber, red vine, berry red upon ripening	Waterlogging tolerant
	Kundhru *(Coccinia grandis)*	Perennial, climber, year-round fruiting	Drought tolerant

In the study area, farmers do not use zero-tillage equipment; instead, they practice shallow tillage with a bullock-pulled plow and tractor-driven cultivators. Many farmers also use modern inputs (seeds, inorganic fertilizers, herbicides) in combination with the traditional practice of wheat broadcast sowing, a method using one plot of land—another example of the Tharu turning to hybrid agriculture.

No-tillage (a type of zero-tillage) of garlic is an innovative practice in rice-based farming systems (Figure 3). After the rice harvest, cloves of garlic (sprouted or non-sprouted) are inserted in the harvested rice stubble and, in some cases, covered with mulch (rice straw). Tharu farmers stated that no-tillage garlic produces few weeds, conserves soil moisture and produces larger bulbs than conventional tillage-based cultivation. It also reduces the costs of tillage, irrigation and weed management, as well as increasing yield. No-tillage garlic cultivation is common in Thapuwa, but rare in Bikri, where farmers cultivate garlic in the *dihwa* (flat upland field) together with potato and other winter vegetable crops.

Garlic is a minor crop cultivated on a small piece of land (<0.07 ha), mostly for household consumption, with excess produce sold. One farmer, Kallu Tharu, said that in the previous year he cultivated garlic on one *kattha* (0.03 ha), consumed much of it, distributed some to relatives, and sold 75 kg for NPR 22 per kg (USD 0.2/kg) before the *Dashya* festival in October.

Crop landraces

Crop biodiversity is the one of the widely used agricultural adaptations to reduce the impact of climate change (Bhatta and Aggarwal, 2015; Totin et al., 2018). Landraces may produce lower yields than improved varieties, but many have characteristics that are preferred by farmers. Some of the crop landraces and reasons for their continued use in the study area are listed in Table 8.

Low yields of landraces are a key challenge faced by farmers to continue their cultivation. Despite this, farmers grow local landraces for their hardiness—tolerance to high temperature, drought and waterlogging—and taste and because they lack access to improved varieties. It is predicted that the frequency of extreme climatic events such as droughts, flooding and high temperature will increase. Consequently their advantages in stress tolerance will become increasingly of value. Total crop failure does not occur for landraces under adverse climatic circumstances (drought, flooding, insect/ disease). However, Tharu farmers were found open to adopting new crop varieties, technologies and practices.

Discussion

To illustrate the links between knowledge systems, climate adaptation and mitigation, and yield/profitability, we developed a framework to compare the various agricultural practices used by Tharu farmers (Figure 4). This discussion sections present a description of components of the model, knowledge and agricultural practices, and their contribution to mitigation/adaptation and yield/profitability.

The framework is presented in the form of a triangle with the sides illustrating inter-relationships among different knowledge-based agricultural practices with adaptation/mitigation and yield/profitability. Agricultural practices that have been adopted in and adapted to the local environment to produce low emissions and competitive yields have led to more

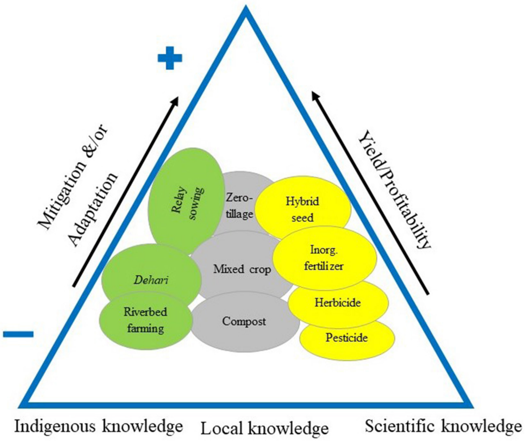

FIGURE 4
Role of knowledge systems in climate change adaptation and mitigation.

climate-resilient agriculture. The axis along the base of the triangle reflects knowledge across a spectrum from scientific knowledge at one end to Indigenous knowledge at the other end, with local knowledge often a synthesis of those two extremes, as the basis of agricultural practices. The left axis of the triangle represents the contribution to adaptation/mitigation, and the right axis represents yield/profitability. Various agricultural practices prevalent in the Tharu community are shown in ellipses with different colors and positions at different distances from the base of the triangle. The relative size of the ellipse represents its prevalence in farming, while color represents the form of knowledge (yellow—scientific, gray—local, and green—Indigenous); the vertical position on each ellipse indicates the level of contribution to adaptation/mitigation and profitability dimensions in agriculture. Complementarily, the horizontal position of practices implies that the practice belongs primarily to or is most related to one of the three knowledge systems along the horizontal axis. The upward direction of the black arrows, along with the signs (+ and –), indicates the direction of contribution to adaptation and mitigation and profit, with a larger contribution signified by a position toward the apex of the triangle.

To the left side of the triangle, the first group of knowledge/practices includes relay sowing, *dehari* (earthen grain storage structure), and riverbed farming, which are considered Tharu Indigenous agricultural practices, as they are largely exclusively practiced by the Tharu in the region. In the middle of the triangle are zero-tillage, mixed cropping, and compost use, all of which are used locally, but integrate scientific knowledge and are used in other Nepalese communities and elsewhere; therefore, these practices are considered as derived from local knowledge. The final group (use of improved seed, inorganic fertilizer, pesticide, and herbicide) on the right side of the triangle, are categorized as scientific knowledge, as their use is mostly derived from science and is widespread as a result of various development programs and interventions.

The Tharu Indigenous knowledge of weather, climate and farming/agriculture is diverse. Ethnoclassification and associated knowledge of seasons, agricultural land, and weeds are some of the key bases for climate-resilient and sustainable farming. Furthermore, Indigenous knowledge-based crop protection and management are embedded in Tharu culture and are reproduced through everyday practice and performance of various rituals. Tharu unanimously follow the traditional agricultural calendar to perform major agricultural activities. The Tharu have their own way of classifying seasons, rain and floods that help them to take appropriate actions to minimize climate-related hazards and risks. For example, when a biological indicator (e.g., behavior of insects, animals and birds) indicates severe rainfall, they prepare for safety. Similarly, wind velocity and direction help to predict frost during the winter, thereby allowing them to take appropriate measures. However, the application of Indigenous knowledge (e.g., old climate rules) for weather predictions and practices (e.g., local pest control) has been decreasing due to access to scientific information and technology. It is not so much that traditional knowledge is declining, but rather that it is evolving and in some cases integrating with scientific knowledge in hybrid forms as the climate changes and other sources of knowledge become accessible. A hybrid knowledge system that includes Indigenous knowledge and scientifically sourced knowledge now shapes Tharu agricultural practices, helping farmers to make informed decisions, thereby making agriculture resilient to climate change.

The application of information and communication technology for digital agriculture is increasing to reduce risks from climatic hazards and insect pests and diseases (Shen et al., 2010; Marvin et al., 2013). Access to information plays an important role in building perceptions and responses to climate adaptation and mitigation. Among information and communication technology tools, radio remains the most common source of information in Nepal, in terms of cost, convenience and frequency coverage. Piya et al. (2012) reported that radio, training and agriculture extension services are important sources of climate information, perception and adaptive measures among the Chepang elsewhere in Nepal. Similarly, Marvin et al. (2013) in a general review described the supportive role of various media in information dissemination during climate extremes and disasters.

The perceptions of the Tharu regarding change in the temperature has validated with the local weather station data covering 38 years. The increased monsoon temperature (June to September) has been reported for Nepal (Shrestha et al., 1999; Practical Action, 2009; DHM, 2017). Inconsistent perceptions of winter temperature (December to February) may be due to the increasing intensity of cold waves, foggy days with extended hours, and sudden drops in night temperatures that have been reported in the Tarai (Manandhar et al., 2011; Shrestha et al., 2018; Budhathoki and Zander, 2020). The perception of decreased rainfall cannot supported by the climatic data of the Bardiya because of very high year-to-year variation in rainfall. Erratic patterns of rainfall have been reported in Nepal (Practical Action, 2009; MoE, 2010; DHM, 2017). However, the perceptions of the Tharu are also in line with other Indigenous and local peoples of Nepal and India (Chaudhary and Bawa, 2011; Chaudhary et al., 2011; Piya et al., 2012). The increased temperature, erratic rainfall and droughts increase risk of crop failure and yield reduction. Hybrid knowledge and practices, such as the adoption of modern agricultural technology (e.g., irrigation, improved varieties) in traditional agricultural practices (relay sowing, mixed cropping), help to increase yield by reducing climatic risks. Knowledge hybridization at the household level is also reflected through continuing traditional practices in minor crops (e.g., lentil, pea and mustard), but adopting improved varieties in a certain percentage of their farming in major cereals (rice, wheat and maize).

The distinction between Indigenous and local agricultural practices is fuzzy in practice. However, specific Indigenous knowledge explicitly relating to the Tharu, such as the making and use of *dehari* (earthen grain storage; for details, see Chaudhary, 2021) and relay sowing, is considered as Tharu Indigenous knowledge. The claim to Indigenous knowledge is made based on the engagement of the Tharu in agriculture in the Tarai region of Nepal over centuries. Some other practices that are not specifically related to the Tharu and are used in the wider community are considered as local as well as traditional knowledge and practices. Local knowledge is shared by the larger local community in a particular geographical area and may also integrate scientific knowledge during the process of knowledge generation. In this sense, local knowledge itself represents a form and process of knowledge hybridization. Thus, agricultural knowledge and the practices associated with the Tharu have developed over time, as the Tharu have sought to improve and consolidate their agricultural livelihoods.

The situation of the Tharu parallels that of other Indigenous peoples in Nepal who are largely dependent on natural resources, such as the Chepang and Bote Majhi. The livelihood of Chepang depend on collection, use and marketing of non-timber forest product (NTFPs) and shifting cultivation (*khoriya*). Collection and selling of non-timber forest products with commercial value cannot improve livelihood of Chepang, as the selling price is currently so low that it does not cover labor cost (Piya et al., 2011). However, Pandit (2001) argues integration of NTFPs in *khoriya* can contribute to income as well as reduce pressure on forest resources. Similarly, traditional fishing of the Bote Majhi is constrained due to the establishment of national parks and protected areas in Nepal (Jana, 2007).

Despite the advantages regarding the adaptation and mitigation provided by Indigenous and local agricultural practices, their application has been decreasing in some contexts mainly due to their low yields and profitability. Indigenous knowledge and traditional agricultural practices are less used for major cereals, such as rice, wheat and maize, but are consistently being used for minor crops, such as lentil and pea. Farmers often practice Indigenous and scientific knowledge and practices together for the crops to cope with local challenges. Thus, different knowledge and practices complement each other for climate adaptation and resilient agriculture. Relay sowing (lentil, grass pea, linseed), zero-tillage/no-tillage (pea, garlic), and mixed cropping (any combination of lentil, pea, wheat and mustard) are some of the traditional and Indigenous crop production methods practiced in the western Tarai, Nepal. The yield and profitability of relay sowing and zero-tillage practices are not consistent, and yields are normally on a par or lower than conventional tillage-based production. This finding contradicts others in Nepal and Bangladesh (Sarker et al., 2004; Malik et al., 2016; Pokhrel and Soni, 2018), but is supported by Jat et al. (2014), who reported competitive yields under conservation agriculture (zero-tillage is a main component of conservation agriculture) in the long-term (>5 years) in a rice–wheat system on the Indo-Gangetic Plain (IGP) in India. Research shows that lentil yields under relay sowing depend on the varieties (genotypes) used, management, and other conditions (Sarker et al., 2004; Wang et al., 2012; Malik et al., 2016). In Bangladesh, lentil (improved varieties: Barimasur−2 and Barimasur−4) relayed into rice crops produced higher yields than conventional tillage of the local cultivar (Sarker et al., 2004). However, Malik et al. (2016) reported that relay-sowing the local lentil cultivar in Bangladesh was more economical (yield, >1 t/ha) than early flowering lines in sole cropping to fill the fallow gap in rice cultivation. Another study reported equal or slightly higher yields under conservation agriculture in a rice–wheat system on the IGP than conventional tillage (Sapkota et al., 2015). Farmers practice conservation agriculture mainly because of the lower production costs in rice–wheat and rice–lentil cropping systems than conventional tillage (Kumar and Ladha, 2011; Sapkota et al., 2015), but this form of agriculture can also potentially offer benefits for climate change mitigation and adaptation. Few studies have related conservation tillage to climate change mitigation, as many believe that zero/no-tillage does not play a significant role in mitigation due to the small amount of soil carbon deposition, which is often emitted during later tillage, and consider that the role of conservation agriculture has been over-emphasized (Powlson et al., 2016; Wolf et al., 2017). Farmers continue traditional agriculture practices in the absence of competitive and compatible technology despite in some cases reasonably lower yield/profitability than the scientific/modern agriculture practices.

The higher yield under mixed cropping than sole cropping is supported by other research findings. The literature indicates that mixed cropping is productive with an appropriate planting density, which is determined by the seeding rates. Mixed cropping avoids complete crop failure and increases per unit area productivity of land, and reduces weeds, pest incidence and lodging, as well as providing crop insurance against unstable market price and extreme weather conditions (Sarker et al., 2004; Lithourgidis et al., 2011; Wang et al., 2012). The relationship between conservation agriculture and climate resilience is multi-dimensional, with various positive effects on soil health, reduction of risks from pests and climatic extremes, as well as reduction of GHG emissions and energy use and higher crop quality. Most of the positive effects of relay and mixed cropping concern soil fertility improvement through integration of legumes, reduction of labor cost and energy use, the latter particularly contributing to adaptation to and mitigation of climate change (Quinn, 2009; Sapkota et al., 2015; Ladha et al., 2016).

The adoption of modern agriculture technologies, inputs and methods is increasing within the Tharu community. Adoption has been limited largely to major staple crops (rice, wheat and maize) in terms of the cultivation of improved seeds and the use of chemical inputs and irrigation technology in order to boost yields. However, the proportion of total farmland cultivated with improved varieties and the application of chemical inputs per unit area of land is negligible. These practices support small farmers to improve food security and household economy, but modern agriculture also increases dependency on production inputs (seeds, inorganic fertilizers, herbicides), as well as decreasing crop diversity. The use of improved crop varieties, agronomic management (e.g., crop rotation, adjusting sowing dates) and technology (irrigation, machinery, and information) are widely discussed strategies for climate adaptation (Nelson et al., 2009; Shen et al., 2010; Speranza, 2010; Bhatta and Aggarwal, 2015). Modern agriculture is comparatively energy-intensive, with higher emissions of GHGs, though the emissions are lower in terms of per tons of crop yield than traditional and local methods (Ladha et al., 2016). Modern agriculture often excludes legume crops (lentil, pea) in the rice system and has been promoted with an almost exclusive focus on cereal production (rice—maize) in the study area. However, the use of crop landraces not only conserves crop biodiversity, but also is a practice that continues and transfers traditional knowledge, thus contributing to its revitalization (Dahlin and Svensson, 2021). Local seeds that are adapted to harsh climatic conditions, such as emmer (*Triticum dicoccon)* and einkorn (*Triticum monococcum*) varieties of wheat that have been used in the high altitude context of Iran (Aksoy and Öz, 2020), have proved useful in modern breeding as part of the gene pool.

Conclusions

In conclusion, neither Indigenous knowledge nor scientific knowledge alone is sufficient to improve the resilience of Tharu farming communities. The Tharu have embraced "hybrid knowledge"—a combination of Indigenous and scientific knowledge, technology and practice to increase yield and maximize profit, as well as decrease vulnerability to extreme weather events. This hybridity is evident in the complementarity between the employment of modern varieties and scientific agricultural practices for the major grains and the continuing use of landraces for minor crops such as lentils, peas and mustard. In addition, the traditional pest management strategies, which often have a ritual component, are used in conjunction with botanical and chemical pesticides. Indigenous knowledge-based agriculture encourages the use of local resources, low-energy intensive practices and the conservation of crop biodiversity, which can provide diverse options within the hybrid knowledge system not only for decision making among local farmers, but also policy options at national and global levels. The integration of scientific weather information in traditional weather forecasting and the early warning system for flooding in the Tharu *barghar* system (village leadership) helps to cope with weather extremes and to reduce climatic risks. Similarly, hybrid agricultural practice, integrating the adoption of technology, inputs and methods in existing traditional agriculture, enhance yield and income in agriculture. The flexibility of options provided by hybrid knowledge and practice offers various choices based on household requirements, local environment and market demand from which farmers can benefit in the face of climate change.

A limitation of this research concerns the justification of local agricultural practices in the mitigation of climate change. The study did not focus on the quantitative calculation of emission reductions and mitigation potentials of local agricultural practices and technologies. Estimation at the local level could be possible, using the mitigation potential provided in similar studies as a reference. However, the figures from two small villages would be too small to generalize for the district and the country. It would be valuable to calculate the mitigation potential at a sub-national and national level using a suitable model that offers a low emissions scenario.

The research has, nevertheless, demonstrated the value of many insights from the perspective of Indigenous peoples in terms of the contribution of Indigenous knowledge and local responses in climate and agriculture for theoretical discourse regarding integration of Indigenous and scientific knowledge in hybrid knowledge systems. The deployment of such knowledge systems in resilient and climate-smart agriculture can contribute to several of the UN Sustainable Development Goals, such as (2) zero-hunger and (13) climate action, and to conservation of agro-biodiversity for future farming. In terms of policy implications, the research has documented and explored some Tharu Indigenous knowledge and practices that can be further studied in agricultural research for use in response to the needs and vulnerability of farmers in the Tarai of Nepal and elsewhere to improve their livelihoods and adaptive capacity. For the Tharu community, the research helps to identify climate-resilient knowledge, methods, technology and practices that will assist their planning for adaptation and mitigation of climate change and reduce vulnerability with support from local authorities.

Four interventions could reduce the anticipated increased vulnerability of the Tharu specifically and farmers in the Tarai in general: first, providing skill enhancement and vocational training, particularly for youth, to diversify the income of smallholders through off-farm related activities; second, continued infrastructure development for improved safety and accessibility; third, strengthening agricultural extension for resilient agriculture; fourth, recognition and promotion by the government of Nepal of the continuing value of traditional practices for at least some crops and thus the incorporation in farming extension of the value of hybrid knowledge-based practices. Local adaptations based on hybrid knowledge can contribute to the improved management of Indigenous knowledge-based traditional agriculture for continuing and future climate-resilient and climate-smart agriculture.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by RA/20/4133. The patients/participants provided their written informed consent to participate in this study.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpos.2022.969835/full#supplementary-material

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Appendix 1

Appendix 1 Comparison of crop calendar (current and 20 years ago) in Bardiya, Nepal.

Crop		Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Rice	Past													*	*	^	^	^	^	^	^	x	x	x	
	Current												*	*	*	^	^	^	^	^	x	x			
Wheat	Past	^	^	^	^	^	^	^	x	x													*	*	^
	Current	^	^	^	^	^	^	x	x													*	*	^	^
Maize	Past										*	*	^	^	^	^	^	^	x	x					
	Current	^	*	*	^	^	^	^	x	x													*	*	^
Lentil/ Pea	Past	^	^	^	^	^	x	x														*	*		^
	Current	^	^	^	^	^	x	x													*	*	^	^	^
Mustard	Past	^	x	x															*	*	^	^	^	^	^
	Current	^		x	x	j	j	j													*	*	^	^	^

* sowing, ^ growing, and x harvesting. j : Brassica juncea harvest.