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Agricultural Diversification and Rural Incomes in the Presence of Climate Change in Central-Western Bhutan

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Abstract

This study draws on prior literature to investigate the risks that climate change poses to Bhutan and how agricultural diversification may alleviate many of these potential detriments. A broad understanding of crop diversification is found to be crucial to the future of Bhutanese agriculture. Using cross-sectional data gathered from a sample of 163 farmers located in the Punakha and Wangdue Phodrang Dzongkhags of central-western Bhutan, this study aimed to understand current crop selection and farmers' perceptions pertaining to crop choice and climate change. Additionally, four measures of inter- and intra-crop diversification are employed to gain an understanding of richness and relative abundance for both crop species and rice varieties. It was found that there is a clear misalignment between what vegetable, fruit, and rice varieties are most prevalent and what generates the most income based on land use. Crop richness is found to be high, but relative abundance is quite low. Combined with farmers' recognition that climate change, water scarcity, and income generation potential are major factors influencing crop choice, opportunities to promote certain high-value and less water-intensive crops are identified. Encouraging land reallocation for such crops will act to increase diversification, rural incomes, and climate resilience.

Keywords: Bhutan, crop choice, crop profitability, farm diversification, rural incomes

Introduction

The scientific community now widely accepts that anthropogenic activities are changing the climate in ways that will become ever more detrimental to many aspects of human life (IPCC, 2014). Throughout the remainder of the 21st century, it is projected that surface temperatures will continue to rise, heat waves and extreme precipitation events will increase in frequency and intensity, and precipitation patterns will shift. Climate change poses a major threat to human health as it will disrupt agricultural systems and exacerbate food insecurity (Costello *et al*., 2009; Wheeler and von Braun, 2013; World Bank Group, 2015). The effects of climate change on agriculture, some of which are already being experienced, will likely unfold in a non-linear progression: as environmental indicators cross critical thresholds, the associated damage will increase appreciably (Schlenker and Roberts, 2009; Hatfield *et al*., 2011).

In South Asia, climate change will profoundly affect both water supply and temperature; this will likely have a large negative effect on crop productivity (World Bank, 2013). As temperatures continue climbing, record temperatures are expected to be frequently observed across the

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region (World Bank, 2013; IPCC, 2014). The Indian summer monsoon will become increasingly intense and variable, and South Asian countries will see a rise in the frequency of extreme precipitation events (World Bank, 2013; IPCC, 2014). Additionally, Himalayan glacial retreat, rapid snow-cover melt, and decreased snowfall will threaten dry-season agricultural irrigation (Kehrwald *et al*., 2008; World Bank, 2013). Combined with the amplification of present precipitation patterns, these trends will continue to raise the risk of drought and flooding in the region (World Bank, 2013). Such irrigation disruptions and temperature changes will severely disrupt food production: a meta-analysis on the productivity of eight major crops projected a 7.7% net yield loss in South Asia by 2050 (Knox *et al*., 2012). Additionally, the protein and mineral nutrient content of grains and other crops will decline in the presence of climate stresses (DaMatta *et al*., 2010; World Bank, 2013).

The South Asian country of Bhutan is particularly vulnerable to the risks associated with the changing climate. Following the global and regional trends, the temperature in Bhutan will continue to increase, and by the end of the century the country is "projected to experience unprecedented heat during more than half of the summer months" (World Bank, 2013, p.106). The prevailing climate models show a net increase of precipitation in Bhutan, and as a result of the amplification of current rainfall patterns, the climate will be characterised by extreme precipitation events increasing in frequency (World Bank, 2013).

These climatic changes pose a major threat to human life, economic activity, and agricultural productivity within Bhutan. The country is home to nearly 1,000 glaciers, and the increasing threat of glacial lake outburst floods (GLOFs) has loomed large since the Lugge Tsho GLOF claimed 21 lives in 1994 (Nayar, 2009; Veettil *et al*., 2016). Bhutan's economy is also facing an acute risk as two of the three largest contributors to its Gross Domestic Product (GDP) are highly sensitive to climate disruptions: Agriculture, Livestock, and Forestry (17.37%) and Electricity and Water Supply (13.22%) (NSB, 2018b). As one of the most important contributors to GDP, agriculture is also essential to those 62.7% of the employed, the rural population who are engaged in subsistence farming (NSB, 2018a). The climate-induced risks to the agricultural sector (and consequently food security) are not trivial in a country where 8.1% of rural households already experience food insufficiency and nearly half of the nation's food demand is met through imports (Dem and Minot, 2010; NSB, 2018a). These concerns are further elevated by a substantial gap in the literature on the effects of climate change on agriculture and related issues in Bhutan. Using a theoretical framework premised on the benefits of inter- and intra-crop diversification in the face of climate change, this study aims to begin to fill this research gap and while providing suggestions for climate resilience and increasing rural incomes.

This article is organised as follows. The Theoretical Framework explores the ways in which agricultural diversification benefits farmers within the context of climate change. Based on this framework, the research objectives are then clearly outlined. The Methodology section describes the study site, sampling technique, interview procedure, and the measures of diversification used for analysis. The Results and Discussion section begins with descriptive statistics which include the demographic and socio-economic profile of the sample. Crop rankings by incidence, average plot size, and income generation per acre are also described here. Next, participants' responses to Likert-scale questions regarding crop choice and climate change are explored. This section concludes with metrics of inter- and intra-crop diversification and explores the most notable findings and the potential implications for Bhutan's agricultural future. A final Conclusions section recapitulates the most relevant methodology, results, and implications while suggesting potential fields for further study.

Theoretical framework

The existing body of literature has proven that the benefits of agricultural diversification are numerous and far-reaching. These advantages become especially consequential when placed within the context of the environmental risks and stresses associated with climate change (Baumgärtner and Quaas, 2010; Lin, 2011; Asfaw *et al*., 2018). Pest and disease outbreaks will increase in their geographic distribution, frequency, and severity due to climate change (Garrett *et al*., 2006; Sutherst *et al*., 2011; Pautasso *et al*., 2012). Diverse farming operations have been shown to improve resistance to both diseases and pests (Zhu *et al*., 2000; Keesing et *al*., 2010; Kremen and Miles, 2012). As temperature and precipitation patterns shift, more diverse agroecosystems will demonstrate less yield variability and greater resilience (Smale *et al*., 1998; Widawsky and Rozelle, 1998; Di Falco *et al*., 2007). The mean production of diversified farming operations is also greater than that of those which are more specialised (Smale *et al*., 1998; Zhu *et al*., 2000; Di Falco *et al*., 2007). Greater profitability and a reduction in income variability are also positive effects of farm diversification and may be ancillary benefits of an increase in production and reduction in yield variability (Schläpfer *et al*., 2002; Di Falco and Perrings, 2003; Di Falco *et al*., 2010).

Diversified farms have redundancies built in which may act as natural insurance and increase their climate resilience (Perrings, 1995; Yachi and Loreau, 1999; Oliver *et al*., 2015). The effect of this natural insurance is so profound that it may act as a substitute for financial insurance in certain instances (Ehrlich and Becker, 1972; Baumgärtner, 2008; Quaas and Baumgärtner, 2008). In the event that the stresses of climate change cause one facet of the farm to fail, a diversified operation will be more likely to have a built-in redundancy to fill the role of the lost ecological service whereas a specialised operation would be prone to higher levels of production variability (Yachi and Loreau, 1999; Oliver *et al*., 2015). The varied responses to climatic stresses exhibited by different species and mixed varieties of the same species provide this 'buffering effect' which increases climate resilience (Loreau *et al*., 2001).

Having firmly established the threats of climate change and the alleviation that agricultural diversification can provide, researchers should place an emphasis on formally understanding such diversification in Bhutan. To this end, the objectives of this study are to: 1) analyse current crop selection by incidence, plot size, and income generation, 2) understand farmers' perceptions regarding crop choice and climate change, and 3) to make quantitative assessments of both inter- and intra-crop diversification. These objectives are met using cross-sectional data gathered from two of the country's central-western Dzongkhags (districts): Punakha and Wangdue Phodrang. Understanding agricultural diversification in Bhutan has imperative implications for policymakers, extension agents, and non-profit organisations, which can help stabilise, and even improve the country's agricultural sector in the presence of a changing climate.

Materials and Methods

The methods that this study employed for both the data collection process and the empirical analysis are detailed throughout the following sections.

Study site and sample

A sample of 163 households was drawn from two of Bhutan's 20 dzongkhags—Punakha and Wangdue Phodrang. Located in central-western Bhutan, these dzongkhags were chosen because of their ease of access and the relative ubiquity of rice production. Punakha and Wangdue Phodrang are responsible for 26.9% of Bhutan's rice production by weight and contain 24.2% of the country's rice cultivation area (NSB, 2018b). The presence of a single, dominant crop allowed for robust intra-crop diversification metrics to be generated.

Punakha and Wangdue Phodrang are comprised of eleven and fifteen Gewogs (blocks) respectively. Seven gewogs were selected at random from each dzongkhag for sampling. The sample to be drawn from each gewog was determined using the probability proportional to size technique in combination with the agricultural census data that the dzongkhag administrations provided. In total, 163 households from 41 villages throughout 14 gewogs were interviewed.

Interview procedure

This study employed an orally administered, closed-ended questionnaire. The interviews were carried out in-person and individually throughout April and May of 2018. The interviews took place at the respondent's home which allowed for observational authentication of the gathered data. Before the interview, it was confirmed that the respondent is the head of the household meaning that they are either the household's primary agricultural decision maker or that they are an equal member in a joint decision-making process. This ensured that the participant had intimate knowledge of the household's agricultural practice.

The data gathered included the household's demographic, socio-economic, and agricultural information. Participants were asked to detail their crop production for 2017. This included the plot size, quantity harvested, quantity sold, and the selling value of each individual cereal, vegetable, and fruit. In addition, special attention was paid to the varieties of rice which were cultivated and the aforementioned data were obtained for each variety. Additionally, the head of the household's perceptions on topics such as crop choice, climate change, and water scarcity were obtained using Likert-scale questions.

Measures of diversification

Four measures of inter- and intra-crop diversification were utilised for the data analysis. The inter-crop diversification metrics do not make a distinction between different species of the same crop; this is measured with the intra-crop diversification metrics (i.e., all varieties of rice richness or a combination of both richness and relative abundance. The first is a product count (Count). For inter-crop diversification, this measures the number of unique crop species present. It also measures the number of unique rice varieties cultivated for intra-crop diversification. Count is a quantification of species richness.

The second farm diversification metrics is a Berry index (BI) (Berry, 1971). The BI is synonymous with economics' Herfindahl–Hirschman index and ecology's Simpson index. It is a measure of both richness and relative abundance, and it is frequently employed to quantify land use diversification (e.g., McNamara and Weiss, 2005; Hellerstein *et al*., 2013; Tung, 2017). A farm's BI is defined as:

$$\boldsymbol{1 - \Sigma P_i^2} \qquad (1)$$

where P_i is the proportion of land allocated to cultivating the i^{th} crop for inter-crop diversification or the i^{th} rice variety for intra-crop diversification.

The third measure of farm diversification is the Shannon-Wiener entropy measure (SWEM) (Shannon, 1948; Wiener, 1948). Originally developed for information theory, the SWEM is frequently found in ecological population studies and increasingly in the agricultural context (e.g., Torres *et al*., 2018). A farm's SWEM is defined as:

$$\boldsymbol{- \Sigma P_i \ln (P_i)} \qquad (2)$$

where P_i denotes the same proportions as the BI employs. Similar to the BI, the SWEM measures both species richness and relative abundance with the distinction that the SWEM employs a logarithmic measure which makes it more responsive to subtle shifts in land use (Campbell and Mínguez-Vera, 2007).

The final measure of diversification is a derivation of the SWEM. From the SWEM, it is possible to calculate the effective number of species (ENS). The ENS measures richness and relative abundance. Most importantly, it reveals how many equally-common species a farm's diversity is equivalent to having present (Jost, 2006).

$$\mathbf{exp} \, [\boldsymbol{- \Sigma P_i \ln (P_i)}] \qquad (3)$$

where P_i represents the same proportions as when determining the BI and the SWEM. When combined with the Count metrice, the ENS is invaluable for understanding the function of relative abundance in determining a farm's true level of diversification.

Results and Discussion

The results of this study are described in the following three sections. These include summary statistics of the sample population and the major crops in the study area by incidence, plot size, and income generation. Farmers' perceptions of crop choice, climate change, and diversification are also explored. Finally, both inter- and intra-crop diversification metrics are shown.

Table 1: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.
Age	49.42	14.22	20	80
Sex [a]	0.60	0.49	0	1
Education [b]	1.40	3.10	0	15
Income [c]	159.26	198.83	0	1608.21
Agricultural Income Pct.	47.40	37.38	0	100
Farm size	2.30	1.72	0.05	10.87
Labour	2.48	1.03	1	6
Labour deficit [d]	1.29	1.05	0	5
Subsistence level [e]	4.42	0.82	0	5

[a] 1= Female. [b] Years of formal education. [c] Nu. 1,000. [d] Number of full time, adult workers needed minus the number present. [e] Categorical variable describing the percent of household food demand met from on-farm production (1: 0-20%, 2: 21-40%, 3: 41-60%, 4: 61-80%, 5: 81-100%)

Descriptive statistics

The summary statistics of the sample population are presented in Table 1. It is shown that the head of the household is, on average, 49 years old and has virtually no formal education. The average household earns Ngultrum (Nu.) 159,260 annually, of which 47% is derived from agricultural sources. Additionally, the mean farm size is 2.30 acres and has 2.48 full time, adult workers present to work on it although an additional 1.29 are required to achieve optimal performance. Finally, the households surveyed are primarily subsistence and report meeting nearly all their food demand from on-farm production.

The five most prevalent vegetables and fruits are presented by incidence and average plot size in Tables 2 and 3 respectively. Chillies were found on almost every farm sampled and they tend to be grown on larger plots than other vegetables. Potatoes, green beans, and spinach were also found to be extremely popular based on both incidence and plot size. Oranges were the most common fruit by both measures. Additionally, tamarillos and pears appear on both lists indicating their popularity.

Tables 2 and 3 also show incidence and average plot size for the most popular rice varieties. These two lists resemble each other closely with the only difference being Bajo Kaap and Ngapja switching between the fourth and fifth position. Bajo Kaap is the only improved variety to make an appearance on either list, and its frequency of cultivation was quite low. Farmers seem to heavily favour local Maap as it was present on nearly three-quarters of farms and the average plot size was over three-quarters of an acre.

The five vegetables, fruits, and rice varieties which were found to generate the most income per acre are shown in Table 4. In addition to being extremely prevalent, chillies produced relatively large returns. Cucumbers were also found to have a high incidence and income generation. In the fruit category, peaches, pears, and guavas showed overlap between incidence or plot size and income generation. While not common, the 'local other' category of rice varieties proved to be the most profitable. This category acted as a catch-all for varieties that did not have sufficient observations to generate unique, robust variables for. Local Other is foll-

Table 2: Top five vegetables, fruits, and rice varieties by incidence

Vegetable	Percentage	Fruit	Percentage	Rice Variety	Percentage
Chilli	96%	Orange	53%	Maap	72%
Green Bean	88%	Tamarillo [b]	45%	Kaap	31%
Spinach	86%	Peach	39%	Tantshering	31%
Cucumber	75%	Pear	36%	Nagapja	10%
Potato	63%	Sugarcane	36%	Bajo Kaap [a]	9%
…	…	Walnut	36%	…	…

The given values are indicative of the percent of farms which were found to be growing each crop.
[a] Improved rice variety (others are local). [b] Locally referred to as tree-tomato.

Table 3: Top five vegetables, fruits, and rice varieties by plot size

Vegetable	Area	Fruit	Area	Rice Variety	Area
Potato	0.18	Orange	0.03	Maap	0.76
Chilli	0.08	Hazelnut	0.02	Kaap	0.22
Green Bean	0.05	Guava	0.01	Tantshering	0.17
Cabbage	0.03	Tamarillo	0.01	Bajo Kaap [a]	0.06
Spinach	0.02	Pear	0.01	Nagapja	0.06

Areas given are in acres. [a] Improved rice variety (others are local)

Table 4: Top five vegetables, fruits, and rice varieties by income per acre

Vegetable	Ngultrum	Fruit	Ngultrum	Rice Variety	Ngultrum
Chilli	602,178	Peach	374,429	Local Other	137,165
Cauliflower	546,013	Pear	271,154	Bajo Kaap [a]	125,198
Broccoli	466,737	Plum	257,142	Tantshering	120,020
Cucumber	415,718	Guava	254,035	Ngapja	112,905
Asparagus	342,424	Banana	159,630	Kaap	112,236

[a] Improved rice variety (others are local)

owed by the improved variety of Bajo Kaap. Local varieties – Tantshering, Ngapja, and Kaap were all found to be prevalent and they produced comparatively large returns.

Individual perceptions

Farmers' responses to Likert-scale questions are presented in Table 5. Most farmers reported potential selling value, climate change, and water scarcity as being major considerations for their crop and seed choice. Additionally, most farmers agreed that water scarcity has been worsening for their farm throughout the past decade. Over 40% of farmers acknowledged that their farming operations are not very diversified since they do not grow many types of crops and raise many types of livestock. Virtually an equal proportion believed that they are diversified. Finally, nearly half of the farmers stated that they do not like to alter their farming practices and only a quarter reported that they do.

Table 5: Farmers' perceptions on crop choice, climate change, and diversification

Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Potential selling value is a major consideration [a].	3.21	12.82	10.90	50.00	23.08
Climate change is a major consideration [a].	2.58	6.45	21.29	50.97	18.71
Water scarcity is a major consideration [a].	14.38	13.75	0.62	31.88	39.38
Over the past ten years, water shortages have been becoming more of a problem for my farm.	4.52	24.52	5.16	38.06	27.74
I grow many different crops and raise many types of livestock.	8.44	35.71	11.69	41.56	2.60
I do not like to change my farming	3.25	23.38	24.03	48.05	1.30

All values presented are in the form of percentages
[a] When choosing which crops and seed varieties to cultivate

Diversification metrics
The four inter- and four intra-crop diversification metrics are reported in Table 6. The first, a species richness Count, reveals that the average farm had between 15 and 16 crop species present. Those with the greatest richness were found to have over double that amount of unique species. Additionally, the minimum reveals that mono-crop operations exist. Figure 1 visualises the Count distribution and shows such operations as being extremely rare.

The BI, SWEM, and ENS are also presented in Table 6. The mean of the ENS is approximately one-third of that of the Count which confirms that farmers tend to highly favour certain crops in terms of land use. Additionally, the BI, SWEM, and ENS metrics demonstrate that while farms may have relatively high species richness, they perform poorly in terms of relative abundance and species distribution. The disparity between the inter-crop measures of Count and ENS is made apparent in Figure 1.

Table 6: Diversification metrics

	Inter-crop diversification				Intra-crop diversification (rice)			
	Mean	Std. Dev.	Min.	Max.	Mean	Std. Dev.	Min.	Max.
Count	15.53	6.34	1.00	34.00	1.93	0.91	0.00	5.00
BI	0.65	0.18	0.00	0.92	0.30	0.26	0.00	0.75
SWEM	1.50	0.46	0.00	2.78	0.47	0.42	0.00	1.39
ENS	4.97	2.30	1.00	16.20	1.74	0.77	1.00	4.00

The results of the intra-crop diversification analysis revealed that the average farm has two unique rice varieties present. The maximum number of varieties found on a single farm was five. The ENS showed a modest decrease in the mean when compared to that of the Count. This is indicative of slightly uneven land allocation for different species. The richness Count, BI, SWEM, and ENS measures confirmed low rice diversification in terms of both species richness and relative abundance.

When taken as a whole, the results of this study revealed that, in the presence of the changing climate and increasing water scarcity

Bhutanese farmers have the potential to improve their agricultural income and their level of farm diversification. In terms of income, a clear misalignment is present when the crops and rice varieties that generate the most income per acre are compared with what is most prevalent. Two clear exceptions to this are chillies and cucumbers which are both popular among farmers and yield relatively large returns. Efforts to increase the cultivation and selling of high-value vegetables and fruits have the potential to raise farm income efficiently. This study identified cauliflower, broccoli, asparagus, peaches, plums, guavas, and bananas as being the most high-value in terms of land use efficacy for Punakha and Wangdue Phodrang. For rice cultivation, Maap seems to be most preferred by farmers, but it does not perform well in terms of income generation per acre. The reasons for this are unknown although the authors speculate that it is preferred for home consumption based on its high prevalence and low income generation per acre. Further research is needed to determine the specific reasons, as to why each rice variety is grown as it was beyond the scope of this study. Encouraging the cultivation of Bajo Kaap, Tantshering, Ngapja, Kaap, and other local varieties may increase farmers' income derived from rice. It is notable that returns from rice are low in comparison with the top performing vegetables and fruits. Considering these findings and increasing water scarcity, shifting cultivation away from rice and towards more profitable and less water-intensive crops seems advisable as a long-term strategy for increasing rural incomes in the face of climate change.

The inter-crop diversification analysis demonstrated that although species richness appears to be high for farms, the relative abundance and ENS are quite low. This is indicative of farms having large plots of single crops (predominantly rice) and small portions of land devoted to others. Encouraging more even land allocation for high-value fruit and vegetable varieties has the potential to increase diversification scores and climate resilience. Based on prior literature, it is also probable that increasing such diversification will act to stabilise, if not actually raise, rural incomes (Schläpfer *et al.*, 2002; Di Falco and Perrings, 2003; Di Falco *et al.*, 2010). The intra-crop diversification metrics show very low species richness for rice. This has the potential to become problematic in the event of pest and disease outbreaks (Zhu *et al.*, 2000). If farmers insist on growing rice, encouraging genetic diversity will help stabilise yields and incomes through combating such outbreaks as they increase with clima-

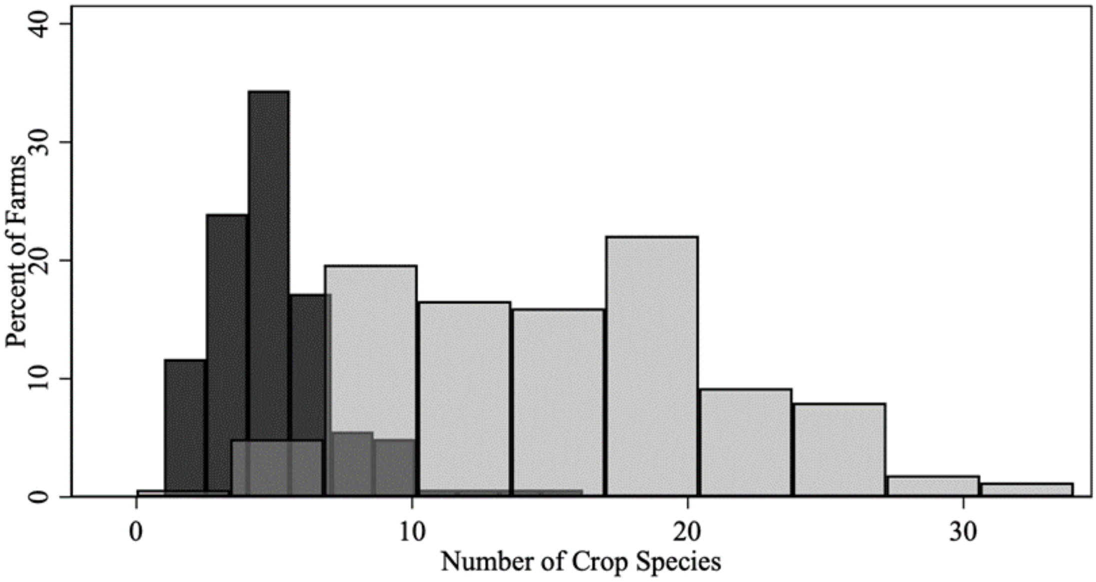

Figure 1: Ten bin histogram comparing crop count with effective number of species

te change (Zhu *et al*., 2000; Keesing *et al*., 2010; Pautasso *et al*., 2012).

The Likert-scale questions revealed that half of the farmers do not like to change their practices. This may be overcome since nearly three quarters reported that potential selling value is a major consideration. Additionally, the majority recognise both climate change as being a factor influencing crop choice and water shortages as becoming increasingly worse. As such, more concerted efforts to educate farmers on the potential increases in income through diversifying with less water-intensive and more profitable crops may be sufficient motivation for them to alter their agricultural practices.

Conclusions

This study took a crucial step in recognising the role that inter- and intra-crop diversification can play in the future of Bhutanese agriculture. Using cross-sectional data gathered from the Punakha and Wangdue Phodrang in 2018, this study was able to rank crops in terms of incidence, average plot size, and revenue per acre. An understanding was gained on what influences farmers' crop selection, and their perceptions on climate change and water scarcity were quantified. Finally, using four measures of diversification, this study established that while species richness is reasonably high, relative abundance is comparatively poor.

Prior literature has firmly established that the advantages of agricultural diversification have become especially consequential in the context of climate change.

This study is the first to explore these topics using data from farms in Bhutan. Further research is needed to determine the best crop mixes and land allocation systems for climate resilience and profitability. Based on this study, it is preliminarily advisable to work in assisting farmers to diversify in terms of relative abundance. Taking such action with high-value vegetables and fruits can act to raise rural incomes while mitigating many of the negative effects that climate change is expected to have on Bhutan's agricultural sector. Additionally, future regional studies across the country can assist stakeholders in identifying which crops should be promoted based on how they fare in local markets and climates. With the threats of climate change looming, pre-emptive action is necessary to help ensure a future of constantly improving economic, health, and agricultural outcomes for Bhutan.

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