The Prospects of Agricultural Adaptation to Climate Change:
Climate-Technology Interaction in Rice -Wheat Cropping System in Nepal

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Abstract

We use panel data from Nepal to examine the effect of climate in inducing technology to understand potential agricultural adaptation to climate change in rice and wheat crops. We find different degree of climate-technology interaction in the productivity of two crops.

Introduction

One of the challenges in estimating the potential consequences of climate change for agricultural production anywhere in the world is the understanding of the capacity of agricultural systems to adapt. Using Nepal's district level panel data for a period of 11 years (1991-2001), we examine the extent to which technological innovations has provided farmers with options for adaptation to potential climatic risks in rice-wheat based cropping systems of the country. Specifically, we examine whether or not the productivity of rice and wheat are attributed to climatic variations. We also assess if the effects of technologies such as fertilizer and irrigation on the productivity of rice and wheat are contingent on the spatial variability of climate. The need for understanding potential impact of climate change on Nepalese agriculture is justified for two reasons. First, the existing system of food production is highly climate sensitive because of its low level of capital and technology. Second, agriculture is the main source of livelihood for the majority of the population.

We base our investigation on the induced innovation hypothesis proposed by Hayami and Ruttan (1985), which states that the direction of technological change in agriculture is induced by differences in relative resource endowments and factor prices. In this study, we have considered climate, measured as average monsoon rainfall and the gradient of agricultural land, as key resources that drives technological innovation in rice and wheat based cropping systems of Nepal. The variability in the supply of such climatic resources in the country is expected to induce location specific technological change in these crops.

We begin this paper by reviewing the concerns surrounding climate change and its impact on the food security of developing countries, which also forms the rationale for this study. Then we introduce the hypothesis of induced innovation as a basis for the theoretical argument of climate technology interaction in the context of agricultural adaptation in Nepal. After a brief discussion of the data and methods, we conclude with the results of our analysis.

Climate change and the concerns of food security

Major global studies conducted by the International Food Policy Research Institute (IFPRI) (Mitchell and Ingco, 1993), the Food and Agriculture Organization (FAO) (Alexandratos, 1995), and the World Bank (Agcaoili and Rosengrant; 1995) anticipate aggregate grain yield to increase by 1.5-1.7 percent per year for the foreseeable future, and the real prices of grain to remain constant or to decline. But if we disaggregate global scenarios of food production to the regional level, the picture is bleak. For example, studies from Sub Saharan Africa and South Asia, where agriculture is the key economic sector and accounts for high portion of the national Gross Domestic Product (GDP), show a less sanguine picture of food security in the future. McCalla (1999) reports declining trends of per capita food availability in Sub Saharan Africa due to the combined effect of increasing population and slow or sometimes negative growth in agricultural production. The same trend is reflected in South Asia where the number of under-nourished people has increased significantly in recent decades. Clearly policymakers of these countries are pressed to make continued investment in agricultural technologies and infrastructures in order to meet growing food demand. This has been further compounded by growing concern regarding the abilities of farmers and their supporting institutions in developing countries to cope with and respond to the threats and opportunities of changing climate.

According to the recent review of IPCC (Gitay et al., 2001), global agriculture faces the prospect of changing climate that might adversely affect the goal of meeting global food needs in the coming decades. Sensitivity studies of world agriculture to potential climate change have indicated that global warming may only have a small overall impact on world food security as reduced production in affected areas are offset by increases in others (Reilly 1995; Parry, 1999). This is, however, at a global level. For low-income countries, there is a general agreement that climate change will lead to significant reductions in agricultural productivity (Gitay et al., 2001). For many of these countries in Sub-Saharan Africa and South Asia, that are already struggling to feed their growing population, this is not a favorable prognosis.

The concern with future climate change is heightened because adverse impacts of climate change in agriculture sector will exacerbate the incidence of rural poverty. In Sub-Saharan Africa and South Asia, it is estimated that agricultural sector contributes over 30 percent of GDP, and that nearly 60-70 percent of population is dependent on agriculture for employment (Gilland, 2002). With lower technological and capital stocks, the agricultural sector in these countries is unlikely to withstand additional pressures imposed by climate change without a concerted response strategy.

Role of technology in climatic adaptation:

Impacts of climate change on crop yields depend on both technological considerations and farmers' response to changing environmental conditions. Historically modest investments in agricultural research have enabled societies to achieve relatively rapid growth in agricultural production (Easterling, 1996; Ruttan, 1996). Moreover, the issues of technological innovation have increasingly permeated discussions about the impact of climate change on agriculture (Rosenberg, 1992; Ausubel, 1995; Ruttan, 1996; Reilley and Fuglie, 1998). Yet, despite the importance of technologies accorded to agriculture development few researchers have investigated how spatial climate variability induces technological change (Smithers and Blay-Palmer, 2001). Much of the attention on the effects of climate change on agriculture in developing countries has focused its impact on crop yield and provided little agreement on the current and future adaptability of agriculture to a changing climate.

Although not explicitly used in climate change impact studies, innovation of technologies have received increasing publicity as possible means to understanding the impact of climate on agriculture with particular focus on adaptation to climate change in developing countries (Gitay et al., 2001). The innovation of technology as a means for adapting to climate change is associated with the hypothesis of induced innovation by Hayami and Ruttan (1985). The hypothesis posits that the development of new technologies in agriculture is a continuing process induced by differences in the relative scarcity of resources, and signaled by change in relative price of the resources. Based on the historical evidences of technological responses to changing economic conditions and resource availabilities, scholars have put enormous faith in the ability of technology to continue to provide farmers with the needed strategic and tactical options for handling uncertainties related to future climate change (Rosenberg 1992; Ausubel, 1995). They strongly believe that technologies could be designed to substitute for future climate as societies have done in the past. This optimism is warranted given many well-documented examples of successful innovations in agriculture (e.g. Hayami & Ruttan, 1985; Thirtle and Ruttan, 1987).

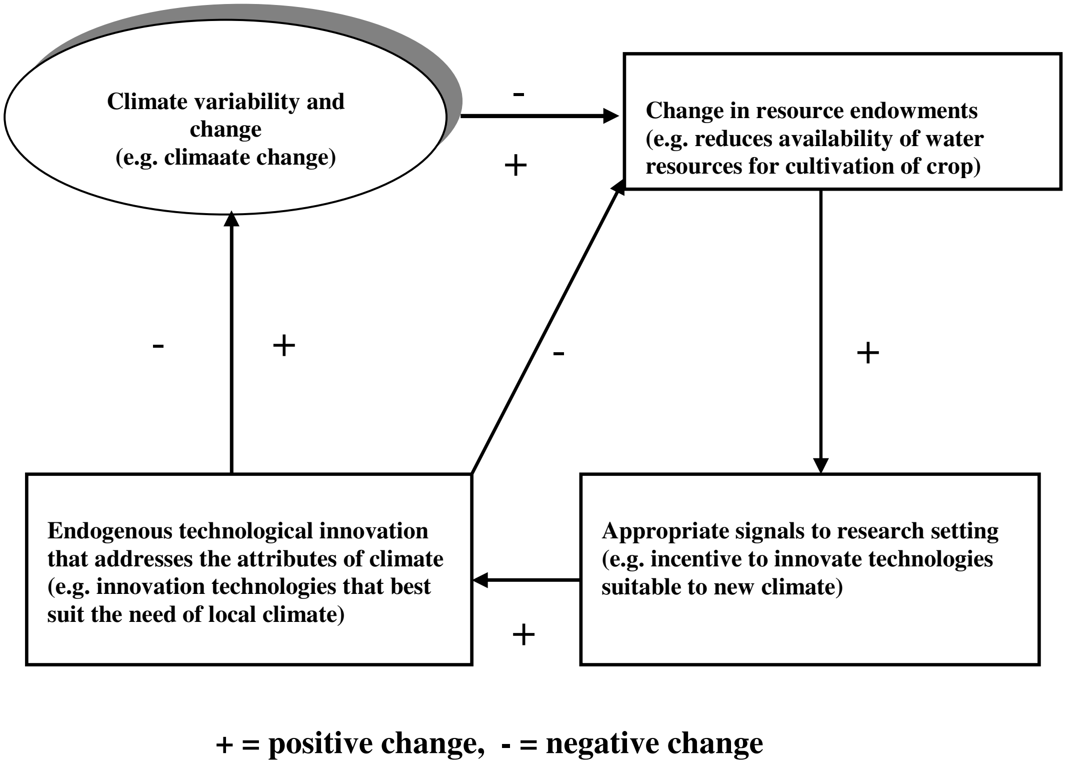
As the role of technology continues to become more ingrained in strategic thinking of agricultural adaptation to climate change (Smithers and Blay-Palmer (2001), there is a need to understand better the role that climate has played in innovation of technologies as fundamental to understanding potential agricultural adaptations to climate change. Unfortunately, as yet, researchers engaged in climate change impact assessments have neglected to include the significance of technologies as adaptation to climate change. Empirical analysis of the interaction between climate and technology, the thrust of this study, is needed to understand the role of technology in future climate change.

Theoretical Framework

As stated earlier this study utilizes the hypothesis of induced innovation to examine the interaction between climate and technology as a foundation for understanding potential agricultural adaptation to climate change and variability in Nepal. Induced innovation refers to the process by which societies develop technologies that facilitates the substitution of relatively abundant (hence cheap) factors of production for relatively scarce (hence expensive) factors in the economy (Hayami and Ruttan, 1985). The fundamental insight of this hypothesis is that investment in innovation of new technology is the function of change (or difference) in resource endowment and the price of the resources that enters into the agricultural production function.

Technological innovation in agriculture does not evolve with respect to climatic condition alone, and that non-climatic forces such as economic and political environment have significant implications for innovation and adaptation of new technologies. However, in this study, we argue that, with other non-climatic factors, technological innovations in the rice-wheat based cropping systems of Nepal are made routinely in response to variable climatic conditions. Hence we assume that *variability in climate prompt the development of appropriate technologies that substitute for and ameliorate the negative impacts of future climate change in rice and wheat production in Nepal.* We hypothesize that, in Nepal, climate variations do not pose serious constraint on the productive capacity of rice and wheat cropping systems. Specifically, the location-specific technological innovation that are devised by the agricultural research establishment of Nepal have been an increasingly important source for reducing climatic risks and remains sensitive to institute technologies to ameliorate the consequences of future climate change. We also hypothesize that technological change in rice and wheat based cropping systems in Nepal is induced by climatic regime.

Figure 1: Conceptual framework: climate-technological interaction



Climate is one of the important resources for crop growth and development. While specific climatic requirements for agricultural production vary between geographic regions, the most important ones are the soil moisture, heat, and sunlight. As shown in Figure 1, climate change may alter these climatic resources by changing growing season length, soil moisture regimes, and adding heat stress to the plant. Such changes will, according to the hypothesis of induced innovation, provide appropriate signals to farmers and public institutions to induce technologies suitable for the new environment. Attempting to translate this idea, the hypothesis of induced innovation offers a pathway for understanding agricultural adaptation to climate change. The strength of this simple framework lies in its ability to highlight the central role of climate as a motivator of technological innovation and ultimately as a source of adaptation. Within this conceptual framework, we examine the role of climate variability as an incentive to innovation in the Nepalese agricultural system. Our argument will detail expected technological responses of Nepalese agriculture to future climate change.

One of the assumptions made by the induced innovation hypothesis is that when agents of production (e.g., farmers, public institutions) experience problems with change in resource endowments such as that brought about by climate change, they are likely to seek new knowledge that will help to overcome these constraints. The change in resource endowment therefore, may solicit an adaptive response whereby farmers and their supportive institutions may adjust management techniques and the allocation of resources to offset the adverse effect of climate change. In Nepal land is already a scarce commodity due to the combined effect of population growth and unfavorable climate for crop growth and development. As pressure to grow more food from climatically stressed area increases, marginal cost of production will rises relative to the marginal cost of production via the application of technologies. Eventually society reaches a stage where land augmentation becomes the appropriate means of increasing production. This will then lead to development of technologies that substitute for climate. This may be through adoption of location specific crop varieties, and/or through a combination of management strategies such as use of efficient irrigation and application of chemical fertilizers. The critical question with regards to agricultural adaptation to climate change, therefore, is *whether substitution of technologies for climate would be employed in the future?* Redirecting research effort along the path induced by climatic stress is an essential step if meaningful insights are to be obtained with regard to agricultural adaptation to climate change.

The Setting

This research focuses on Nepal, a country that faces the challenge of feeding its 23.2 million people. Understanding the potential impact of climate change on Nepalese agriculture is critical for two reasons. First, the existing system of food production is highly climate sensitive because of its low level of capital and technology. Second, agriculture is the main source of livelihood for the majority of the population**.** Over 88 percent of the population lives in rural area of which 80 percent of labor force is engaged in agriculture (HMG/N and ADB, 1995). About two-thirds of rural household income is derived from agriculture, and 8 out of 10 are self employed farmers. Agriculture is the only activity where 90 percent of the poor can earn some cash (ACI, 2003). The consequences of an adverse climate change would have profound effect on the well-being of the Nepalese people, where the average per capita calorie intake is among the lowest in the world (Agrawala et al., 2003).

Nepal has a distinct rainfall gradient. The eastern part of the country is generally wetter than the western part. The diverse ecological setting associated with the topography of the country provides three distinct agro-climatic zones – the mountains, the hills, and the flat terai. The prevailing patterns of monsoon rainfall produces a range of field water regimes, which cause major differences in the rice production potential in Nepal. For example, region with low monsoon rainfall not only demand crop varieties that are tolerant to drought but also requires different production practices. If Nepal's research establishment is sensitive in allocating resources for technological alternatives to substitute for climate in regions with inadequate monsoon rainfall, it is logical to expect increase in crop yields, in this case rice and wheat and be on par with the regions having favorable monsoon climate. Similarly in the hills, low water temperature demands different crop varieties, production practices, and cropping systems than those prevalent in the plains of the warmer terai. The climatic conditions of Nepal provide a natural platform for the study of the relationship between climate change and agriculture adaptation, and by extension the testing of the induced innovation hypothesis in the context of physical climate in the inducement of technologies.

Why Rice and Wheat?

Rice and wheat based cropping pattern is the most predominant agricultural systems of Nepal. Rice and wheat based contributes about 20 percent to the agricultural GDP and provides more than 50 percent of the total caloric requirement (MoAC, 2001). The productivity of rice has increased from 1.76 to 2.46 tons per hectare in the span of 25 years. Rice and wheat are grown on 1.51 million ha, and 660 thousand ha, respectively. In the 1990s, rice and yields grew at an average rate of 1.33 and 3.23 percent in wheat. Although the yield of rice and wheat is very low by most Asian standards, their production has improved over time. The second half of the 1990s registered the highest growth rate of 2.4 percent in rice and 4.7 percent in wheat (Goletti et al. 2001), a factor attributed to the shift in the use of high yielding varieties (HYVs). Moreover, adoption of HYVs has induced farmers to apply other technological packages such as fertilizers and pesticides, practices not followed when local varieties are grown. Since the inception of wheat research program in 1972, the performance of wheat has been impressive and considered a success in the agricultural sector of Nepal (Morris et al., 1994).

In the last 30 years, the agricultural research establishment of Nepal has released 44 new HYVs of rice and 27 varieties of wheat (MoAC, 2002). Some of these HYVs are targeted to specific ecological niches (e.g., drought prone areas and high altitude regions) as well as different ecological regions of the country. This reveals that agricultural research do respond to the climatic needs of specific regions within the country. If this process continues then we could make a reassuring prognosis that in the face of climate change, countries with an agricultural economy like Nepal may be able to cope with and adapt to new climate.

Description of Data

The district is the lowest level for which data on the use of agricultural technologies are available and hence has been adopted as the unit of analysis for this study. We use the district level panel data for a period of 11 years from 1991/92 through 2001/02. In Nepal there are a total of 75 districts: Mountain (16); Hill (39) and Terai (20). All the districts of the Hills and the Terai, with the exception of Kathmandu, Lalitpur, and Bhaktapur, have been included. These three districts are not considered to be average rice and wheat growing districts of the country. The Mountain districts do not produce significant amount of rice and wheat and therefore being excluded from this study.

The lack of data on agro-technologies at the district level prior to 1991 is a major constraint in limiting the study period to 11 years, and is considered to be a short period to observe technological changes in agriculture. Never-the-less, the study period covering the decade of 1990s still comprises a time of significant changes in agricultural sector of Nepal. Along with the restoration of democracy, it brought with it a substantial shift in agricultural policy. The development of Agricultural Master Plan, privatization of fertilizer policy, and the establishment of NARC, an apex agricultural research body in the country were some of the major developments that had considerable influence in the agricultural sector.

We have classified the data as 1) agro-technologies, 2) bio-physical, and 3) socio-index of development. These data have been acquired from three different sources. The data on agro-technologies have been obtained from the Ministry of Agriculture. The MOA has recently released the Nepal Agricultural Database (NAD) that contains a vast quantity of data, collected and computerized as part of His Majesty's Government of Nepal (HMG/N) and the Asian Development Bank's Agricultural Sector Performance Review. For the first time, the MOA has made its data available in a simple and accessible computerized format needed to undertake comprehensive analysis of Nepal's economy, particularly those interested in its rural and agricultural sectors. The bio-physical and index of development data have been obtained from the Department of Hydrology and Meteorology (DoHM) and Integrated Center for International Mountain Development (ICIMOD) respectively.

The dependent variable is the yield (rice and wheat) measured in kilograms (kg) per hectare. The six major independent variables representing climate, technology and control variables are:1) average monsoon rainfall, which is categorized into three climatic regions 2) use of chemical fertilizers, 3) irrigated area under rice or wheat crop 4) gradient of land, 5) development index, and 6) ecological zones.

The amount, timing, and duration of monsoon rainfall significantly affect crop production and have been identified as the most important climatic variable. In this analysis, the monsoon rainfall is computed from the monthly average of 30 years from1968 to 1997[1]. Since the unit of

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[1] It is preferred to have an average of 30 years or more as normal climate, in the absence of such data average of less than 30 years can be used. In the case of Nepal's rainfall data, only 89 meteorological stations have precipitation records for 30 years or more. Therefore, to have spatially normal climate, many other stations having records for less than 30 years are included.

analysis is district the average rainfall data recorded at point location were transformed to district average through interpolation using Geographic Information Systems (GIS).

The average monsoon rainfall of the selected districts is 1427 mm, with the minimum and maximum being 820 mm 2642 mm respectively. In this study, average monsoon rainfall of the district in question has been used to construct climatic regions. The districts having monsoon rainfall less than 1200 mm are categorized as the “unfavorable” climatic region for rice and wheat cropping and are identified as DRY in the variable list. Similarly, the districts with monsoon rainfall more than 1600 mm are categorized as “favorable” climatic region and are identified as WET in the variable list. Finally the districts in between are categorized as “average” climatic region and have been identified as NORMAL in the variable list. These three climatic regions form the basis of the analysis of climate-technology interaction in rice based farming systems of Nepal. Although the climate categories are derived from long term average, for the purpose of this study it has no time series variation.

While the main objective of this study is to test the sensitivity of Nepal’s agricultural research establishment to climate as defined by average monsoon rainfall, historically the agricultural development have been determined by topography – mountain, hill, and terai. For this reason, we also consider topography, commonly used ecological domain in technological development.

Technology is a difficult variable to measure. In agriculture, empirical works are based on indirect measure such as the use of HYVs, chemical fertilizers, irrigation, pesticides, and human capital to represent technologies (Mundlak, 2000). In this study, we use the data on application of chemical fertilizers and irrigation as technology variables in rice and wheat farming in Nepal. The chemical fertilizers are measured in NPK (N_2O, P_2O_5, and K_2O) kilogram per hectare, and the irrigation represents the percentage of irrigated land of the total rice and wheat cropping systems.

Another equally important variable that determines rice and wheat production is the gradient (slope) of the land. This is especially important in the hills. The higher the gradient of the agricultural land the lower the retention of moisture in the soil. The gradient of land is measured as percentage of mapped area of sloping terraces (with slope of 4 – 30^0) in total mapped cultivated area. Data for the gradient in each district is derived from the index of Development Indicators of Nepal – compiled by Integrated Center for Mountain and Development, ICIMOD (1997)

Similarly infrastructure plays a crucial role in the adoption of improved agricultural practices. Rural infrastructure, such as credit, roads and communication, markets, electrification, and agricultural research and extension are essential prerequisites for modernization and growth of agriculture in developing countries. Aggregate measures of socio-economic and infrastructure development index are used for each district as reported by ICIMOD (ICIMOD, 1997).

Analytical Framework

As mentioned above this study uses district level panel data from 56 terai and hill districts of Nepal. We run two sets of models, one for rice and another for wheat with exactly same number of observations. As panel data combines both cross section and time series components the econometric model we specify is different from usual OLS.

A simple model for a panel data analysis can be expressed as,

$$Y_{it} = \alpha_{it} + \beta x_{it} + a_i + u_{it} \qquad \text{for } i = 1,2,\ldots N; \text{ and } t = 1,2, \ldots T \qquad (1)$$

where, N (=56 districts) and T(11 years) are the cross section and time series dimensions respectively. x_{it} is a vector of explanatory variables. The variable a_i captures all unobserved factors and u_{it} is the idiosyncratic error which is assumed to be uncorrelated with the x_{it} (i.e. Cov(x, u)=0). The effect of a_i on Y_{it} may be time invariant but can vary across N. If this holds, a pooled regression using the OLS can be performed. Generally in panel data the Cov(x, u)≠0, therefore pooled OLS is both biased and inconsistent (Woodridge, 2000).

The assumption made about a_i in *(1)* above will have implications for the consistency and efficiency of the estimators in the model. If a_i is assumed to be time invariant and heterogeneous across the unit in model *(1)* then it is called a fixed effect model. This implies that the effect of all omitted variables is the same for a given cross sectional unit through time yet varies across cross-sectional units for a given point in time. On the other hand, if a_i is treated as random then it would be a part of the error term and the model would then be called a random effect model. This implies that the large number of factors that affect the value of the dependent variables, but are not explicitly accounted for in the model, is summarized by random disturbance.

The empirical model for this study involves three different specifications for both rice and wheat. These three specifications are constructed to see the 1) effect of agricultural technology on rice and wheat productivity disregarding the effect of climatic resources, 2) effect of climatic resources on rice and wheat productivity, and 3) effect of agricultural technologies on rice and wheat productivity under different climatic regimes. Consider the equation 2,

Model I:

$$Y_{it} = \alpha_{it} + \beta_1 NPK_{it} + \beta_2 NPK_{it}^2 + \beta_3 IRRI_{it} + \beta_4 DI_i + \beta_5 SLP_i + \beta_6 HILL_i + a_i + u_{it} \qquad (2)$$

In equation to Y_{it} is the rice or wheat yield per hectare in i^{th} district in year *t*. NPK_{it} is the amount of chemical fertilizer applied in specific crop in i^{th} district in year *t*. $IRRI_{it}$ measures percentage of irrigated land of the total area planted with specific crops in i^{th} district in year *t*. DI_i is the index development infrastructure of i^{th} district, and SLP_i indicates the status of agricultural land in i^{th} district, measured as percent of slopping terrace area. The variables *DI* and *SLP* do not have t subscript, implying that their values do not change across time. The variable *HILL* is the dummy variable representing ecological zone. It is specified as 1 if district in question is situated in the hill and 0 if the district is suited in the terai.

In order to determine an appropriate model between the fixed and random models for the given data set, we ran Hausman's specification test. The test result (χ^2=91.68, p<0.001) for rice show that fixed effect model is appropriate so we chose the fixed effect model for the empirical estimations.

The effect of spatial climate variability on innovation of technologies is a crucial factor in our estimation of the impact of climate change on crop productivity. To assess the effect of spatial differences in climate on rice and wheat productivity we specify the Model II as follows.

Model II:

$$Y_{it} = \alpha_{it} + \beta_1 NPK_{it} + \beta_2 NPK_{it}^2 + \beta_3 IRRI_{it} + \beta_4 DI_i + \beta_5 SLP_i + \beta_6 HILL_i + \beta_7 DRY_i + \beta_8 NORMAL_i + a_i + u_{it} \qquad (3)$$

In this model, we treat the climatically defined WET districts as the reference category and consider DRY and NORMAL districts as two separate dummy variables. In Model II, *NORMAL* is defined as the districts with monsoon rainfall considered as specified earlier, and *DRY* indicates those districts with monsoon precipitation lower than normal. The β_7 and β_8 coefficients estimate the relative responses of crop productivity in districts with DRY and NORMAL climate with reference to districts having WET climate.

The effects of agricultural technologies such as fertilizer and irrigation on the productivity of rice and wheat may vary under different climatic regimes. To tease out such effect we specify Model III by introducing interaction terms between climate and technology.

Model III:

$$Y_{it} = \alpha_{it} + \beta_1 NPK_{it} + \beta_2 NPK_{it}^2 + \beta_3 IRRI_{it} + \beta_4 DI_i + \beta_5 SLP_i + \beta_6 HILL_i + \beta_7 DRY_i + \beta_8 NORMAL_i + \beta_9 DRY_i * NPK_{it} + \beta_{10} DRY_i * IRRI_{it} + \beta_{11} NORMAL_i * NPK_{it} + \beta_{12} NORMAL_i * IRRI_{it} + a_i + u_{it} \qquad (4)$$

In Model III, β_9 *and* β_{10} Coefficients represent the effects of fertilizer on rice and wheat productivity in districts with dry climate over the districts with wet climate. Similarly, β_{10} *and* β_{12} coefficients represent the effect of percentage of lane under irrigation on the rice and wheat yield with reference to yield in districts with wet climate.

Results and Discussion

Productivity trend in rice and wheat

Figure 2 compares the overall trend of rice productivity among the three climatic regions of Nepal. The productivity of rice during the study period of 11 years shows an upward trend across all the climatic regions. Average rice yields in districts with WET climate are consistently higher than that in the districts with DRY and NORMAL climate. The rice yield began to converge after 1993. The convergence of rice yields among the climatic regions of Nepal, for example, indicates that technological changes were deliberately targeted towards relatively less favorable climatic regions. This may be explained by the development of location specific cropping technologies, such as development of crop varieties or enhancement of land development activities (e.g. irrigation) or a combination of both.

Figure 2: Rice productivity trends by climatic regime in Nepal, 1991-2001

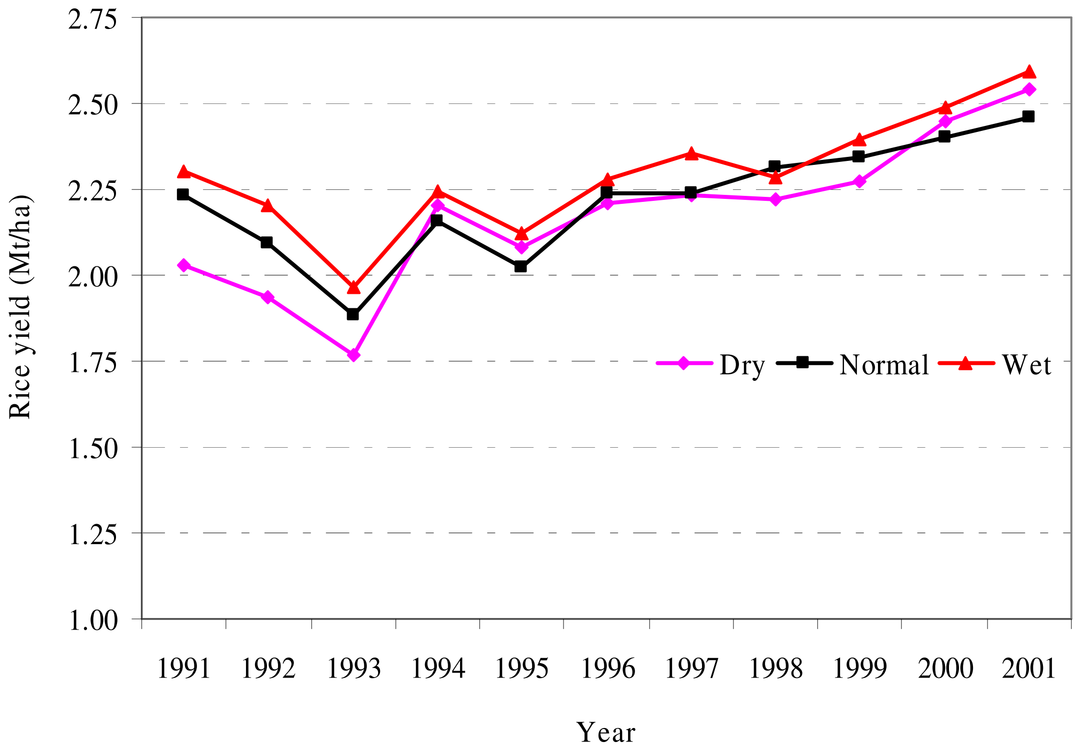
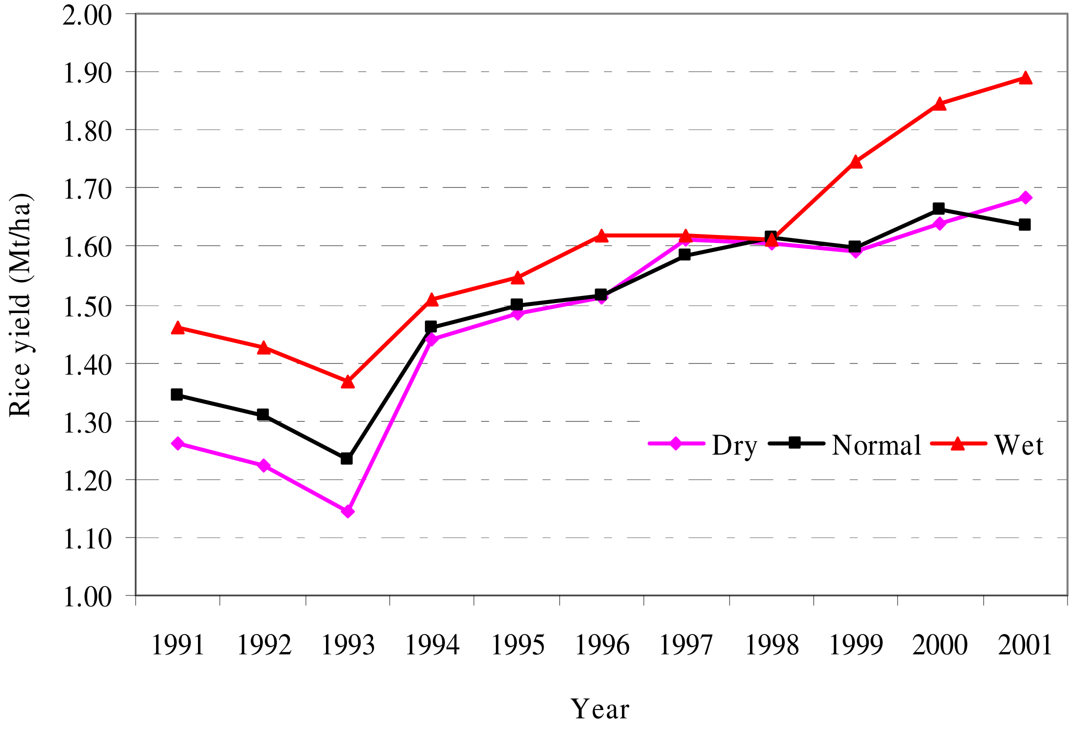


Figure 3 illustrates the overall trend of wheat productivity among the climatic regions. The general trend of wheat productivity during the period is similar to that of rice. With the exception of 1998, the average wheat yields in districts with WET climate are consistently higher than the districts with DRY and NORMAL climate. The gap in the productivity of wheat among districts with different climate gradually converges to a common mean till 1998. After 1998, however, wheat yield in the districts with WET region made substantial gains in comparison to other two regions.

Figure 3: Wheat productivity trends by climatic regime in Nepal, 1991-2001



Effect of technology on rice yield

Table 1 shows the results of fixed effect model on rice yield with and without the consideration of climate. Model I presents the results of the effects of agricultural technologies (fertilizer and irrigation) on rice productivity. The goodness of fit of the model is presented by R^2 (between) which explain 51 percent of the variation in rice productivity among the districts. The overall model is highly significant ($F = 40.81$, $p<.001$). The signs of the coefficients in the model are in tandem with the overall expectation. The coefficients of fertilizer input are significant. The relationship between fertilizer application and the rice productivity is concave. Irrigation also appears to be a significant predictor of rice productivity in Nepal. For example, one percent increase in the irrigation area increases rice yield, on average, by 2.3 kilogram per hectare.

Table 1: Fixed effect model estimates predicting the rice yield (Kg/ha) with and without climate-technology interaction

Parameters	Mode I	Model II	Model III
NPK (Kg/ha)	0.0716***	0.0749***	0.0721***
NPK (Kg/ha) ^2	-3.7e-06*	-4.1e-06*	-5.6e-06**
% of irrigated area	2.3322*	2.4882*	2.2578
Index of development	4.1625***	4.4142***	4.0931***
% of slopping terrace	-0.5866	-0.6988	-0.4396
Hill District (Yes = 1)	-67.4127	-55.2895	-44.8217
Climate regime (WET=Ref.):			
DRY(Yes=1)		23.5251	-38.5939
NORMAL (Yes=1)		35.4829	-35.6958
DRY*NPK			0.0014
DRY*% of irrigated area			0.0479
NORMAL*NPK			0.0479***
NORMAL*% of irrigated area			-1.1387
Constant	1948.412***	1906.278***	1939.878***
F ratio	40.81***	30.70***	22.48***
R^2 (Between)	0.51	0.46	0.51

*=p <0.05 **=p<0.01 ***=p<0.001

Effect of climate on rice yield

Model II in Table 1 presents the effects of climate on the rice productivity. As shown in the table the effects of fertilizers and irrigation technologies are consistent as in Model I. As compared to Model I, the explanatory power of Model II (46%) is not as strong. However, the overall model is the best fit (*F* = 30.70, *p*<0.001). Specific to effects of climatic regimes, with reference to WET climate, the coefficients for DRY and NORMAL climatic regimes are not significant. The result shows that Nepal's agricultural research establishment is sensitive to the climatic resources of the country. Based on the findings of this study it can be said that the spatial variation in climate do not pose a serious constraint on the capacity of rice growers to remain productive. This is attributed to the technological innovations in consideration of climatic resources of the country.

Effect climate-technology interaction on rice yield

Model III in Table 1 presents the effects of agricultural technologies on rice productivity under different climatic regimes. Consistent with Model I and II, the effect of fertilizer on rice yield is significant. In the case of irrigation, however, the coefficient is not significant although it is positive. The explanatory power of the model is similar to that of Model I and F ratio is also highly significant ($p<0.001$). With specific to climate technology interaction the results are interesting. Considering the districts with WET climate as reference, the effect of fertilizer on rice productivity in districts with DRY climate is greater, but remains statistically insignificant. In the case of NORMAL climate, however, it is positive and highly significant. The effect of irrigation on rice yield in districts with DRY and NORMAL climate is not significant. In other words, the districts with DRY and NORMAL climates do not yet recognize the significance of irrigation. This may be associated with the way by which the irrigation variable is defined. It is not clear whether the irrigated area that was reported was actually devoted to rice cultivation or allotted to other high value crops such as vegetables. With the same token, rice may have been cultivated in the area with no assured irrigation facilities.

Effect of technology on wheat yield

Table 2 shows the results of fixed effect model for wheat yield with and without the climate. Model I presents the results of the effects of agro-technologies on wheat productivity. The goodness of fit of the model is presented by R^2 (between) which explain 57% of the variation. The overall model is highly significant (F =50.31, p<001) and the signs of the coefficients are as expected. Net of other factors in the model, the relationship between fertilizer application and wheat productivity is concave, and coefficients are highly significant. One unit increase in NPK, on average, increases wheat yield by about 0.7 units. Surprisingly, the effect of irrigation on wheat productivity turned out to be negative but insignificant. This may be attributed to limited access to irrigation for winter crops, e.g. wheat. In this data set, we cannot specifically calculate the exact acreage of wheat under irrigation out of the total irrigated land.

Table 1: Fixed effect model estimates predicting wheat yield ((Kg/ha) with and without climate-technology interaction

Parameters	Mode I	Model II	Model III
NPK (Kg/ha)	0.0699***	0.0659***	0.0602***
NPK (Kg/ha) ^2	-5.6e-06***	-5.2e-06***	-6.8e-06***
% of irrigated area	-0.0881	-0.3664	1.0651
Index of development	3.4299***	3.1084***	2.6322***
% of slopping terrace	-0.2127	-0.1069	0.0065
Hill districts (Yes = 1)	-87.7418**	-101.1430**	-72.4382*
Climate regime (WET=Ref.):			
DRY(Yes=1)		-44.3714*	16.1927
NORMAL (Yes=1)		-37.1893+	-94.8218*
DRY*NPK			0.0226**
DRY*% of irrigated area			-4.1049**
NORMAL*NPK			0.0418***
NORMAL*% of irrigated area			-0.8681
Constant	1369.734***	1427.457***	1410.076***
F ratio	50.31***	38.50***	30.02***
R^2 (Between)	0.57	0.66	0.63

*=p <0.05 **=p<0.01 ***=p<0.001 +=p<0.1

Effect of climate on wheat yield

Model II in the Table 1 presents the effects of climate on wheat productivity. As shown in the table the effects of fertilizers and irrigation technologies are consistent as in Model I. Compared to Model I, the explanatory power of Model II (66%) is stronger. The overall model is the best fit. With reference to districts having WET climate, the wheat yield in districts with DER climate and NORMAL climate are negative and significant, (p<0.05 to p<0.1). Net of other factors, compared to the referenced climate, on average, the wheat yield in districts with DER and NORMAL climate decreases by 44 and 37 kilogram respectively. Unlike rice, wheat yield is statistically significantly different by climatic regimes. As yet, Nepal's agricultural research establishment seems to be relatively in favor of favorable climate. It seems that climatic resource is not a significant factor to induce technological change in wheat cropping in Nepal.

Effect of climate-technology interaction on wheat yield

Model III in Table 2 presents the effects of climate-technology interaction on wheat productivity. The effect of fertilizer on wheat yield continues to be consistent with the results in Model I and II. While the coefficient for irrigation is insignificant, it is positive. The explanatory power of the model (63%) is stronger than Model I but is slightly weaker than Model II. F ratio is also highly significant ($p<0.001$). With reference to districts with WET climate, wheat yield in districts with NORMAL climate is negative and significant. Interestingly, with the introduction of climate technology interaction terms, wheat yield in districts with DRY climate appears positive but not significant. Considering the districts with WET climate as reference, the effects of fertilizer on wheat productivity in districts with DRY and districts with NORMAL climate are positive and highly significant. The effect of irrigation on wheat yield in districts with DRY climate, however, is negatively significant. In the case of districts with NORMAL climate, it is still negative but not significant. Consistent with Model II, Model III also shows that the effect of climate on inducement of technology is not in line with the assumption of induced innovation hypothesis.

The effects of other variables

In both the rice and wheat models, the effect of infrastructural development is highly significant across the models (Table 1 and 2). As shown in Model III, net of other factors, a district with an increase in one unit of development index increases rice and wheat yields by 4.1 and 2.6 kgs per hectare respectively. Compared to districts in the terai region the yields of rice and wheat in the hill districts are negative across the models. The coefficients are insignificant in rice model but significant in wheat model. On average, the wheat yield in the hill districts is about 72 kg/ha compared to that of the Terai districts. The gradient of the topography of Nepal's arable land is an important factor determining crop productivity. In both rice and wheat models, the percentage of slopping terrace has negative effect on crop productivity. But it is not a significant factor.

Conclusions

The interaction between climate and technology depends on whether technological innovations substitute for climate. If the technological innovation in agriculture is geared towards substituting climatic resources (e.g. soil moisture) we can corroborate that technological change is in effect induced by the differences in climatic resources. In this study we examined the interaction of climate-technology on rice and wheat cropping systems of Nepal. We specifically compared crop productivity among the climatic regions to reaffirm the assertion made by hypothesis of induced innovation.

We found that there is no significant difference in rice yield due to spatial difference in climatic resources. Regardless of the differences in climate, on average, each district is theoretically capable of producing the about the same quantity of rice per unit area. Over the period of time the technological innovation in rice seems to have reduced the constraint imposed by climatic resources. Results also show that technological variables such as the use of chemical fertilizers and irrigation do appear to be adopted by farmers to offset the adverse effect of climate. Specifically, the effect of fertilizer on rice productivity appears to be positively significant in districts with NORMAL climate compared to districts with WET climate.

Compared to rice, the story of wheat productivity is different. Unlike in rice, wheat productivity in Nepal is more affected by climate. Technological innovation in wheat still seems to be geared towards relatively more favorable climatic regions. With reference to climatic resources, in wheat model, the findings from this study do not substantiate the assertion of induced innovation hypothesis. The effect of technology such as fertilizer and irrigation on wheat productivity is different among the climatic regions, and is distinctly different from that of rice crop.

On the whole agricultural adaptation to climate change in rice in Nepal seems to be in the right direction. Technological innovation in wheat seems to be still biased towards favorable climates, hence its adaptation to future climate change with the current technological foundation is not clear. This effort is, however, contingent upon the active engagement of public institutions responsible for developing and disseminating appropriate technologies for farmers operating in specific climatic regions.

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