IMPACTS OF CLIMATE CONDITIONS AND ADAPTATIONS ON AGRICULTURAL OUTPUT AND HOUSEHOLD INCOME IN INNER MONGOLIA, CHINA

A Dissertation

by

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ABSTRACT

Climate change has imposed significant challenges on global dryland systems. In this dissertation, Inner Mongolia, a typical dryland system in the world's largest developing county, China, was selected as an example to study the relationships between rural agricultural production/income generation, climate factors and adaptive activities in the dryland system.

Two respective multiple regression models on grain and livestock production were built with secondary panel data in Inner Mongolia from 2000 to 2008. The research results indicate that temperature and precipitation changes, technical assistance, agricultural diversification and highway density had significant impacts on local agricultural production, though the significance level and direction of the impacts of these variables differed between grain production and livestock production. For adaptation strategies, while the grain production sector might have to act against both the higher temperature and decreased precipitation, the livestock production sector could mainly focus on adapting to the drier weather. But adaptive activities such as irrigation infrastructure building, adoption of water saving technologies, and improvement of technical personnel would serve both the sectors well through increased adaptive capacity.

A multinomial logistic regression model on rural household income was also built with primary survey data collected in 2010 in Xilin Gol, a typical rural setting in Inner Mongolia. The research results also indicated that land degradation hurt the poorest household groups most and that conservation programs benefited the same

groups the most significantly with respect to household income. In addition, diversification of income sources contribute significantly to the income increase of the poorest and middle-level income level households, market access contribute significantly to the income increase of all but the highest two income level households, and high-value agriculture significantly contributed to income increase for the farmer households. Therefore, land conservation programs, high-value agriculture, diversification of income sources, and market access should be given top priorities in policy making in order to increase rural income.

DEDICATION

To my family

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CHAPTER I

INTRODUCTION

Climate change has imposed significant impacts on global natural and human systems (Bernstein et al., 2007; Parmesan & Yohe, 2003; Yohe & Moss, 2000), among which dryland systems are especially vulnerable (Reynolds et al., 2007). Climate change also has significantly impacted the welfare of people (Adger, Huq, Brown, Conway, & Hulme, 2003; Parry et al., 2007), among which people from developing nations are particularly threatened (IPCC, 2001; Parry, 2009).

In this dissertation, the impacts of climate factors and adaptive activities on agricultural production and the rural livelihoods in Inner Mongolia, a typical arid and semi-arid area in the world's largest developing country, China, are examined. In this chapter, the need for this type of research is described, the theoretical framework to address the research challenges is provided, the research goals and objectives are stated, and the dissertation structure is described.

1.1 Statement of needs

1.1.1 Climate change's impacts on global natural and human systems

As the Intergovernmental Panel on Climate Change (Bernstein et al., 2007) defines it, climate change refers to "any change in climate over time, whether due to natural variability or as a result of human activity." Climate change manifests itself in many forms, including (but not limited to) global air temperature changes, changes in precipitation patterns, sea-level rises, and extreme weather events (Bernstein et al., 2007).

Critical changes to a host of terrestrial and marine ecosystems have occurred on all continents and in most oceans as a result of climate change (Hoffman & Vogel, 2008; Parmesan & Yohe, 2003; Parry et al., 2007). For example, using global meta-analyses, researchers detected a shift in ecosystem ranges and an advancement of spring events among more than 1,700 species (Parmesan & Yohe, 2003). Investigations conducted through satellite data indicated a decrease in global Net Primary Production (NPP) (Zhang, Kang, Han, & Sakurai, 2011; Zhao & Running, 2010). Through the examinations of forest ecosystems, researchers found that climate-induced droughts and heat stress increased the mortality rate of trees across the world (Allen et al., 2010). Doney et al. (2012) argued that climate change resulted in changes in the structure and diversity of marine ecosystems, and that it was possible for novel ecosystems to form under the conditions caused by climate change. Based on IPCC projections, the average global surface warming from 2000 to 2100 could range from 1.1 ^{o}C-6.4 ^{o}C (Parry et al., 2007). Foley et al. (2005) predicted that by the year 2050, 11% of the world's natural habitats existing in 2000 could be lost.

Climate change also has imposed tremendous impacts on our various socioeconomic systems. Globally, these changes have increased the variability and risks of world food production, availability, and stability, which in turn have altered the utilization of food, access to food, and food prices (Schmidhuber & Tubiello, 2007).

Since the 1930s, climate change events, such as extreme drought and floods, as well as land degradation and deforestation partially caused by climate change, have induced large scale migration in many countries. Migrations in some of these countries also have led to various levels of violent conflicts (Reuveny, 2007). Due to climate change, technology, management practices, institutions, and even cultures and values have transformed across the world (Howden et al., 2007; Pelling, 2011; Rogers, 1998; Smit & Pilifosova, 2003).

Despite the challenges in predicting the precise impacts of future climate change, estimations were made regarding different aspects of the issue. IPCC projected that by 2080 in the mid-range climate change scenario, 200 million people would be at risk of flood by coastal storm surges (Parry et al., 2007). United Nations Development Programme (UNDP, 2007) predicted that without action, the "poorest 40 percent of the world's population – some 2.6 billion people" would suffer from future negative impacts resulting from climate change. Based on IPCC's A2 emissions scenario (IPCC, 2000) and the exposure and sensitivity to climate change and current adaptive capacity of individual countries, Yohe et al. (2006) mapped the vulnerability of world countries to climate change in 2050 and 2100 (Figure 1.1). The A2 scenario hypothesizes a heterogeneous world where economic development is self-reliant and current local identities are preserved. Moreover, in the A2 emissions scenario, the world's population keeps growing, economic development is regional-oriented, and "per capita economic growth and technological change are more fragmented" (IPCC, 2000). As displayed in Figure 1.1, analysis results based on the A2 emissions scenario predict that more than half of the world's countries would be moderately vulnerable to climate change in 2050; however, in 2100, nearly all the countries in the world would be extremely vulnerable (Yohe et al., 2006).

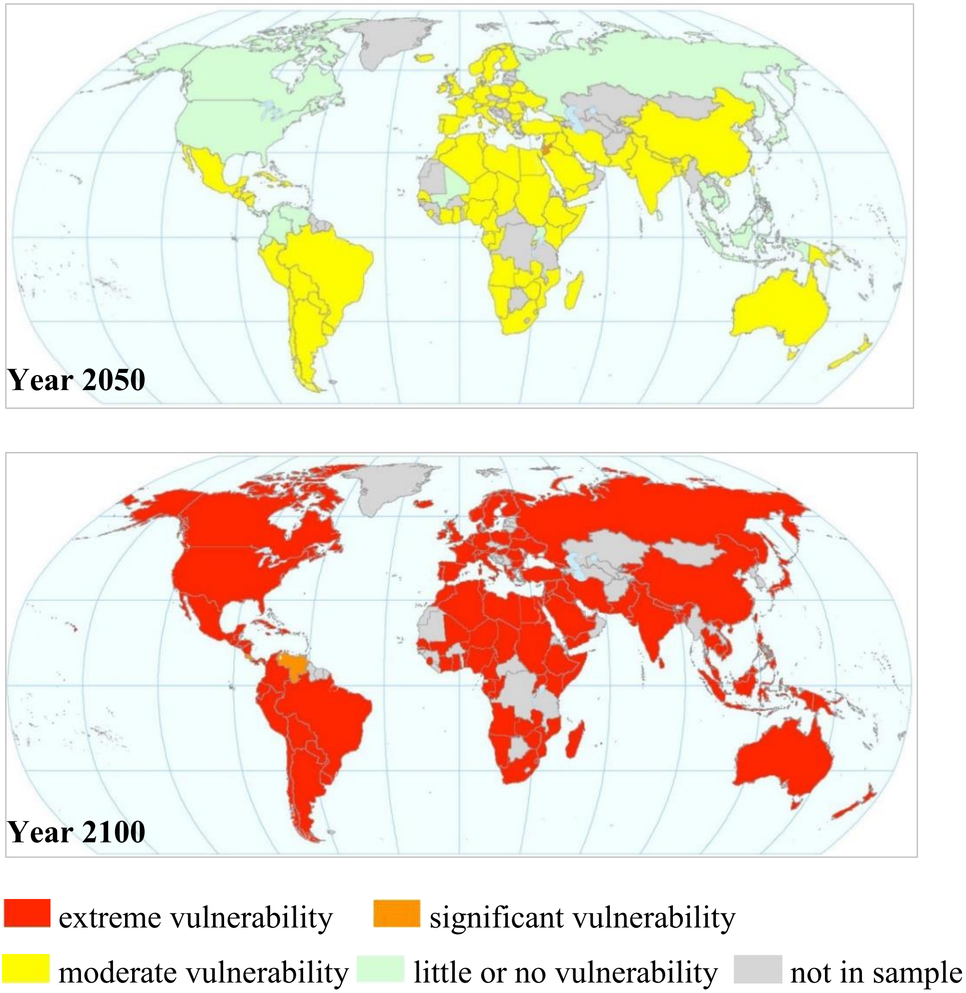

Figure 1.1 Global distribution of vulnerability to climate change in 2050 and 2100 with a static representation of current adaptive capacity under the IPCC A2 emission scenario with a climate sensitivity of 5.5°C.
Source: Yohe et al., 2006

The unprecedented impacts of climate change on the world's natural and human systems and the vulnerability of these systems require all societies to increase their capacity to mitigate and adapt to both the present and future climate change in order to achieve sustainable development. The foci of this dissertation are the impacts of climate change and adaptive activities on agriculture and rural livelihood in Inner Mongolia, a typical arid and semi-arid area in China.

1.1.2 Dryland desertification and climate change

Among the areas suffering from the impacts of climate change, one specific land type is especially vulnerable: drylands (Cowie et al., 2011; Fraser et al., 2011; Hulme, 1996). In dryland systems, a wide range of complex and interconnected environmental, socio-economic, and political factors significantly challenge the livelihoods, especially rural livelihoods, of dryland people (Reynolds et al., 2007). In addition, the looming climate change might exacerbate such challenges (Holmgren et al., 2006; MEA, 2005).

Dryland is defined according to the aridity index (which is the ratio of precipitation to potential evapotranspiration) as an area with an aridity index value less than 0.65 (Middleton & Thomas, 1997). This land type covers more than 40% of the world's land area and covers portions of all of the continents except Antarctica (Figure 1.2). Globally, three major ecosystems exist on this type of land: 65% are rangelands (including deserts), 25% are cultivated land, and 10% are used for other human purposes such as urban areas (Table 1.1).

Figure 1.2 Distribution of the world's drylands
Source: (UNCCD, 2011a)

Table 1.1 Characteristics of the four types of drylands in the world

Dryland type	Aridity index*	% rangeland	% cultivated	% other (including urban)
Hyper-arid	<0.05	97	0.6	2.4
Arid	0.05-0.20	87	7	6
Semi-arid	0.20-0.50	54	35	11
Sub-humid	0.50-0.65	34	47	19
All drylands		65	25	10

*The ratio of precipitation to potential evapotranspiration
Source: Safriel et al. 2005

According to the United Nations Convention to Combat Desertification (UNCCD, 2011a), people living on drylands account for more than 1/3 of the global population, and 90% of these people live in developing countries. Among all the drylands areas, 72% are located within developing countries and 28% are located in industrial countries (MEA, 2005).

One of the primary challenges facing global dryland systems is land degradation and desertification. Forms of dryland degradation include water erosion, wind erosion, salinization, and soil compaction (Dregne, 2002). Once land degradation occurs, a desert-like environment is formed which is characterized by unpredictable precipitation levels, significant differences between daytime and nighttime temperatures, little organic matter in the soil, and plants and animals being forced to adjust to changing climate variables (UNCCD, 2011a).

In the past few decades, global drylands have suffered from land degradation and desertification (Lepers et al., 2005; Middleton & Thomas, 1997; Oldeman et al. 1990), which has led to considerable economic loss. UNCCD (2011b) estimated that in arid and semi-arid regions, especially in Asia, Latin America, and sub-Saharan Africa, the productivity of grasslands might drop by 49% to 90%; and land degradation was costing developing countries 4% to 8% of their annual Gross Domestic Product (GDP). In China alone, desertification-induced problems cost US$6.5 billion each year (UNCCD, 2002).

The looming global climate change can intensify dryland desertification. Increases in extreme climate events such as floods, droughts, and fires lead to soil erosion in dryland systems. Affected by such soil erosion, both the primary production and nutrient cycling in such systems are reduced which eventually leads to desertification (MEA, 2005). For example, in Sahel, Southeast Africa, and the Horn of Africa, a severe drought occurs once every 30 years (on average), putting local dryland systems under enormous stress (Adeel, Safriel, Niemeijer & White, 2005). Solomon et al. (2007) predicted the proportion of arid and semi-arid land in Africa will increase by 5% to 8% by 2080 due to such droughts.

Climate change associated with the El Niño Southern Oscillation (ENSO) may also intensify dryland degradation and desertification. In some dryland areas, during the La Niña phase, fuel load (dry plant materials) accumulates due to ample rainfall; while during the El Niño, massive wildfires can occur due to the dry weather and great amount of fuel load, which put the local ecosystem in danger and cause land degradation (Holmgren et al., 2006). Such extreme events have occurred several times in the Simpson Desert of Australia since the early 20th century (Letnic et al., 2005).

Dryland degradation and desertification, on the other hand, can also contribute to climate change. Hulme (1996) found that in the last century, the global drylands as a whole (0.65^{o}C/century) warmed up greater than all the world land areas (052^{o}C/century). Hulme (1996) cited the research of Balling (1991) and Nasrallah and Balling (1994), and argued that the greater warmer trends in global drylands might be due to the increased albedo caused by land degradation and desertification. Boko et al. (2007) also found that dryland degradation reduced the capacity of carbon sinks in such lands, and contributed to the accumulation of atmospheric carbon dioxide, which in turn led to warming and drier conditions in places such as southern Africa.

As discussed in this section, land degradation and desertification has threatened human wellbeing on global drylands. The threat could be exacerbated by the looming climate change. In addition, desertification also contributes to global warming, which in turn intensify desertification. The threat facing drylands and the complicated relationship between drylands and climate change point to the importance of research into mitigation and adaptation strategies for dryland ecosystems.

1.1.3 Inner Mongolia affected by climate and socioeconomic changes

1.1.3.1 Inner Mongolia as a typical arid and semi-arid area

The levels of vulnerability of dryland systems are not uniform throughout the world. Integrating the five most important vulnerability dimensions (i.e., degradation, poverty, water stress, natural agro-constraints and isolation), Sietz, Lüdeke and Walther (2011) categorized global drylands into seven vulnerability levels, with "1" representing the most vulnerable and "7" representing the least. This categorization is presented in

Figure 1.3. In this evaluation system, the least vulnerable drylands of levels "6" and "7" mainly exist in industrial nations (such as the U.S. and Australia), while levels “1” to “5” drylands mainly exist in the developing nations.

Lands in the Inner Mongolia Autonomous Region (Inner Mongolia) are mostly drylands of levels “2” and “4”. Level “2” drylands face the highest levels of water stress, and the severest land degradation; while level “4” enjoys a favorable water condition, but are also challenged by severe land degradation (Sietz et al., 2011). Located in northern China (see Figure 1.4), the average annual rainfall in Inner Mongolia forms a sharp gradient from the east to the west, ranging from below 100 mm to 600 mm (Yu, Ellis, & Epstein, 2004). The distribution of different dryland types, based on the standards in Table 1.1, is depicted in Figure 1.5 (FAO, 2009a). As shown in this figure, except for a small area of meadow steppe and forests in the northeastern part of the area, most of Inner Mongolia is hyper-arid, arid, or semi-arid (Kang et al., 2007).

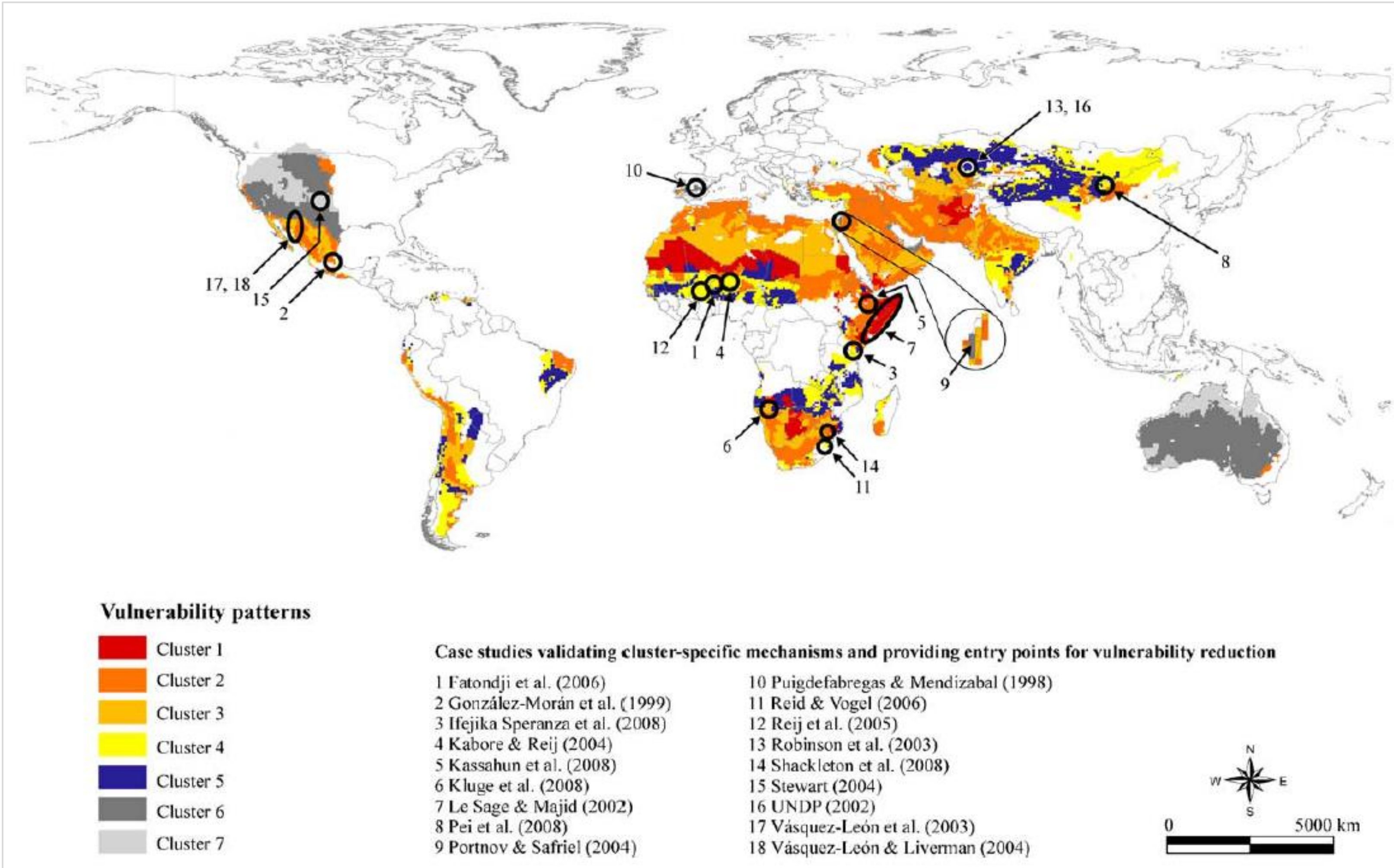

Figure 1.3 Distribution of global dryland vulnerability patterns (with case studies listed)
Source: Sietz et al., 2011

Figure 1.4 Geographic location of Inner Mongolia in China
Source: All China Marketing Research Co., Ltd (ACMR), 2012

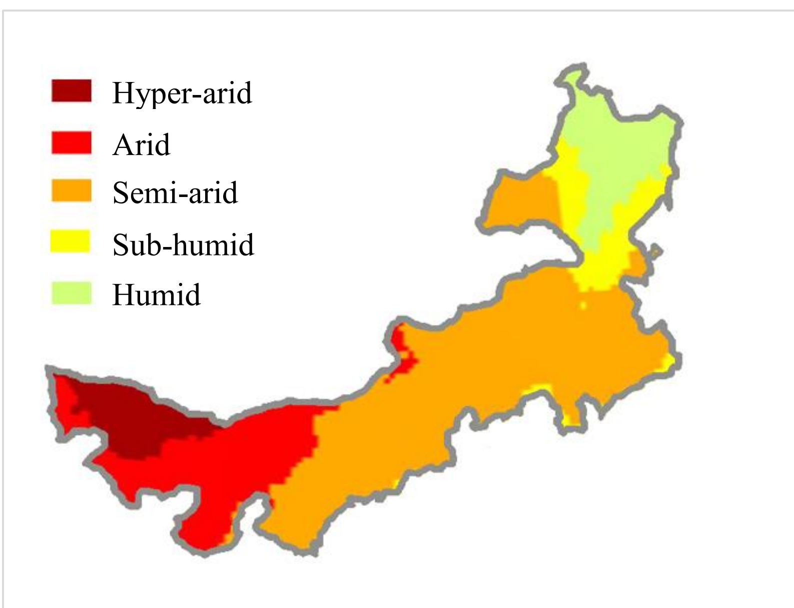

Figure 1. 5 Distribution of drylands in Inner Mongolia
Source: FAO, 2009a

Agriculture is an important component of Inner Mongolia's economy. With a total area of 1.18 million km^2, rangeland accounts for more than 73% of the total land area in Inner Mongolia, followed by 20% forests and 6% cultivated land. In 2010, rural residents accounted for 44% of the total population, and agriculture accounted for 10.3% of the gross output value of the local economy. Within the agricultural sector, farming and animal husbandry are the two most important income sources for Inner Mongolia's rural residents. Statistics from the Statistic Bureau of Inner Mongolia (SBIM, 2011) give a clear illustration of the significance of these income sources: crop production and animal husbandry contributed 35.6% and 44.6% respectively to the gross output value of agriculture in 2010. Inner Mongolia is an ideal region to study arid and semi-arid development issues under the effects of climate change due to the following reasons. First, Inner Mongolia covers a wide range of arid and semi-arid zones. It is an important component of the largest contiguous biome in the world: the Eurasia Steppe. Corresponding with its moisture gradient (moving from west to east) and the aridity index depicted in Figure 1.5, Inner Mongolia's ecosystems include typical desert, steppe desert, desert steppe, mountain deciduous forest and steppe, typical steppe, meadow steppe, and mountain Taiga forest (Han, Owens, Wu, Wu, & Huang, 2009). Based on the *Global Map of Aridity* (FAO, 2009a) developed by the Food and Agriculture Organization (FAO), even when looking to all other continents, it is difficult to find another area that has all of the dryland types and the number of steppe types that Inner Mongolia has. Thus, Inner Mongolia provides a comprehensive research environment that other provincial/state-level or even country-level areas cannot provide.

Second, Inner Mongolia is facing tremendous challenges from climate change and land desertification. The desertification-induced sandstorms negatively affect not only northern China, but also neighboring countries such as Russia, Korea, Japan, and even the state of California in the United States; meanwhile, desertification and land degradation also put local agricultural production under enormous stress, challenging local farmers' livelihoods (see section 1.1.3.2. for details).

Third, located within the world largest developing country, Inner Mongolia has undergone rapid and vast socioeconomic changes since the establishment of the People's Republic of China in 1949. Such changes, including the conversion of land use, shifting land use rights, population growth, cultural conflicts, political upheaval and globalization, all have had considerable impact on the environment and the people's livelihoods (see section 1.1.3.3 for details).

1.1.3.2 Land degradation and climate change in Inner Mongolia

Inner Mongolia has long suffered from land degradation and desertification (Akiyama & Kawamura, 2007; Christensen, Coughenour, Ellis, & Chen, 2003; Christensen, Coughenour, Ellis, & Chen, 2004; Zhu et al., 1999). Under land degradation, in general, there is a trend of lowered plant productivity and biodiversity in the grassland ecosystems (Han et al., 2008). In China, rangeland degradation was first documented in the late 1960s; each decade since, the degraded area has increased by 15% (Han et al., 2008). In Inner Mongolia, the velocity of degradation expansion is around 2% per year (Angerer, Han, Fujisaki, & Havstad, 2008). By 1999, more than

60% of the rangelands in Inner Mongolia was degraded, compared with 40% in 1990 (Han et al., 2008).

Such severe land degradation and desertification in Inner Mongolia has led to reduced human welfare. In the last two decades, Inner Mongolia has drawn wide attention from the international community because of the widespread sandstorms that partially originated in this area. These sandstorms have affected several countries/states in the region, and have caused problems such as air pollution, disruption of human activities, and respiratory diseases (Chen, Gu, Jiang, Zhou, & Song, 2013; Duan, Zhao, &Li, 2013; Meyer, 2006; Normile, 2007). Ma, Shi, Zhao, & Wang (2008) estimated that in 2005, desertification-induced direct economic loss in Inner Mongolia equaled to 1.99 billion yuans (320 million U.S. dollars), and desertification-induced damage through environmental pollution accounted for 5.69 billion yuans (930 million U.S. dollars).

Land degradation and desertification has also challenged the health of natural and man-made ecosystems. At the end of the 20th century, desertification-induced economic loss in China summed to 128.41 billion yuans (20.98 billion U.S. dollars), of which 20.84% was caused by productivity decrease in agriculture (Liu, 2006). According to Ma et al. (2008), in 2005, total desertification induced economic loss in Inner Mongolia reached 26.19 billion yuans (4.28 billion U.S. dollars), among which land loss accounted for 9.98 billion yuans (1.63 billion U.S. dollars), decreased rangeland carrying capacity accounted for 2.68 billion yuans (0.44 billion U.S. dollars), and soil nutrients loss attributed to 5.86 billion yuans (0.96 billion U.S. dollars).

Accompanying land degradation are changes in the local climate in Inner Mongolia. Through an analysis of 51 years of meteorological data, Lu et al. (2009) found that Inner Mongolia, especially in the grassland and dessert areas of the region, had been getting warmer and drier in the last half century. In Xilin Hot, a county-level administrative area in central Inner Mongolia, the annual mean temperature rose by 2.66 °C and the mean temperature in the growing season increased by 2.10 °C from 1953 to 2000 (Yiruhan, Ailikun, Ma, & Shiyomi, 2011). According to a prediction made by the United Nations Framework Convention on Climate Change (UNFCCC, 2007), the climate condition would continue to get warmer and drier in East Asia (where Inner Mongolia is located), and despite the general trend of getting drier, the incidence of extreme weather events in this region, such as extreme rainfall and winds caused by tropical cyclones, would increase.

Due to climate change, local agricultural ecosystems are also undergoing critical shifts in conditions. Incorporating the precipitation records of 208 meteorological observation sites, Li and Pan (2012) redefined the boundary of the transition zone of pasture and farming ecotones in Inner Mongolia, the newly defined area of the transition zones increased by approximately 360 square kilometers, and the boundary shifted towards the southeast in eastern Inner Mongolia and towards the west in northern Inner Mongolia. Climate change has also led to a reduction in NPP in Inner Mongolia (Angerer et al., 2008; Zhao & Running, 2010).

As discussed in section 1.1.2, looming climate change may exacerbate land desertification. Yet land degradation and desertification may also contribute to climate change (Adeel, Safriel, Niemeijer, & White, 2005). Such an unfavorable co-evolving direction of climate change and land degradation and desertification calls for proper intervention and adaptation from human society.

1.1.3.3 Inner Mongolia under socioeconomic changes

Like many other areas in developing countries (Adger, 2003; Hassan, 2010; Simoes et al., 2010), the arid and semi-arid Inner Mongolian land is facing challenges from fast social and economic changes. Human forces, such as population growth, livestock overstocking and overgrazing, shifting land uses, and changes to land use rights, could all worsen the situation of land degradation and desertification in Inner Mongolia.

From 1953 to 2010, Inner Mongolia's population increased from 6.1 million to 24.7 million, a growth of nearly 440% (SBIM, 2011). This growth in population has led to an increase in demand for food, including a demand for livestock products. From 1947 to 2003, livestock production increased more than eight fold, from 8.4 million to 71.1 million heads (Meyer, 2006), which far exceeded the carrying capacity of the rangeland (Yu, Ellis, & Epstein, 2004). The over-exploitation of limited resources in Inner Mongolia is another important driver of land degradation and desertification (Han et al., 2008; Jiang, 2006; Longworth & Williamson, 1993; Su, Li, Cui, & Zhao, 2005), which in turn may lead to increased albedo and changes in wind regimes (Sheng et al., 2000).

Land cover change (for example, the conversion from rangeland to cropland) is another factor contributing to land degradation and desertification (Jiang, 2005). A significant portion of the cultivated land in Inner Mongolia was converted from rangeland during the last 60 years (Han et al., 2009). In the Xilin River Basin of Inner Mongolia, after 36 years of conversion from grassland to cultivated land, the proportions of total organic carbon, dissolved organic carbon, and microbial biomass carbon in the soil all significantly decreased by 12.3% to 77.1% (Qi et al., 2012).

Changes in land use rights (for example, common right shared by a community to use a certain grazing land converts to private rights in which different households own different parts of the grazing land) are another subject affecting land degradation. In the early 1980s to early 1990s, the lag between the privatization of livestock and the privatization of rangeland use rights led to a problem known as the "Tragedy of the Commons" (Hardin, 1968; Li, Ali, & Zhang, 2007). After the 1990s, the privatization of land use rights induced the enclosure of rangeland and the sedentary lifestyle of livestock raisers, which made a seasonal rotational use of rangelands impossible. In turn, this sedentary lifestyle exacerbated the degradation and desertification issue (Taylor, 2006; Williams, 1996).

As discussed, factors including climate, population, land cover change, and land use right all contribute to the land degradation puzzle in Inner Mongolia. It is a complicated issue with multiple, interrelated drivers from both the human and climatic systems.

1.1.4 Research focus

Due to the impacts of climate change and the unprecedented social and economic transitions facing the world today, there is a significant need to analyze the relationships among climate change, human activities, and local agricultural production in dryland systems in order to achieve sustainable development in the arid and semi-arid areas that support 1/3 of the world's population. Inner Mongolia, as a typical arid and semi-arid area facing challenges from both climate and socioeconomic changes, offers a unique land area to study such issues.

The foci of my research are: 1) the roles of climate change and adaptations in the development of two agricultural sectors in Inner Mongolia, and 2) rural livelihoods under land degradation, and socio-economic changes in the study region.

In this dissertation, three articles (See Chapters II, III and IV) related to my research theme are presented. In these three articles, the factors that enhance agricultural production and rural livelihoods are identified. Then recommendations on development policies are provided for local government agencies' reference.

The findings of this research will benefit not only the study area, but also similar agricultural regions around the world, because many of the arid and semi-arid rangelands in the developing areas of Asia, Africa, and Latin America face similar challenges from climate and socioeconomic change (Angerer et al., 2008; Archer & Predick, 2008; Galvin, 2009; Hoffman & Vogel, 2008; Yahdjian & Sala, 2008).

1.2 Theoretical framework

In this section, the theoretical framework for analyzing the development of dryland systems is presented. An argument is made that climate change and natural and human systems have complex, intertwined relationships; thus it is of great importance to take into consideration three key systems. In addition, the climate adaptation issue is, in essence, a development issue for people living in developing nations. Therefore, analysis of climate change should also incorporate issues regarding development. The three analyses provided in Chapters II, III and IV are designed and implemented based on this framework.

1.2.1 Climate change and natural and human systems

To meet the challenges facing global natural systems, especially global drylands, it is of great importance to understand the relationships among climate change, natural systems, and human systems. In this section, I will use the framework developed by Parry et al. (2007) to explain these relationships (Figure 1.6).

First, as shown in Figure 1.6, human and natural systems interact with each other. On the one hand, human activities have imposed increasingly significant impacts on natural systems around the world (Carpenter et al., 2009; MEA, 2005; UNDP, 2007). Scientists have noticed this phenomenon since the mid-19th century (Marsh, 1864). It was proposed that the earth had entered a new epoch ─ *the Anthropocene* - where the impacts of human activities exceed those of natural forces in multiple ways (Crutzen & Stoermer, 2000). Researchers (Adger, 2003; Parry et al., 2007) demonstrated that climate change, especially the increase in the world's surface air temperature, could be attributed (at least partially) to anthropogenic factors such as land use change, combustion of fossil fuels, and certain industrial production activities. On the other hand, changes in the natural environment directly impact humans' livelihoods, thus calling for mitigation and adaptation. For example, the increasing frequency of extreme weather events requires human beings to establish disaster management systems (Preston, 2013; Sun, Zhou, Zhang, Min, & Yin, 2013).

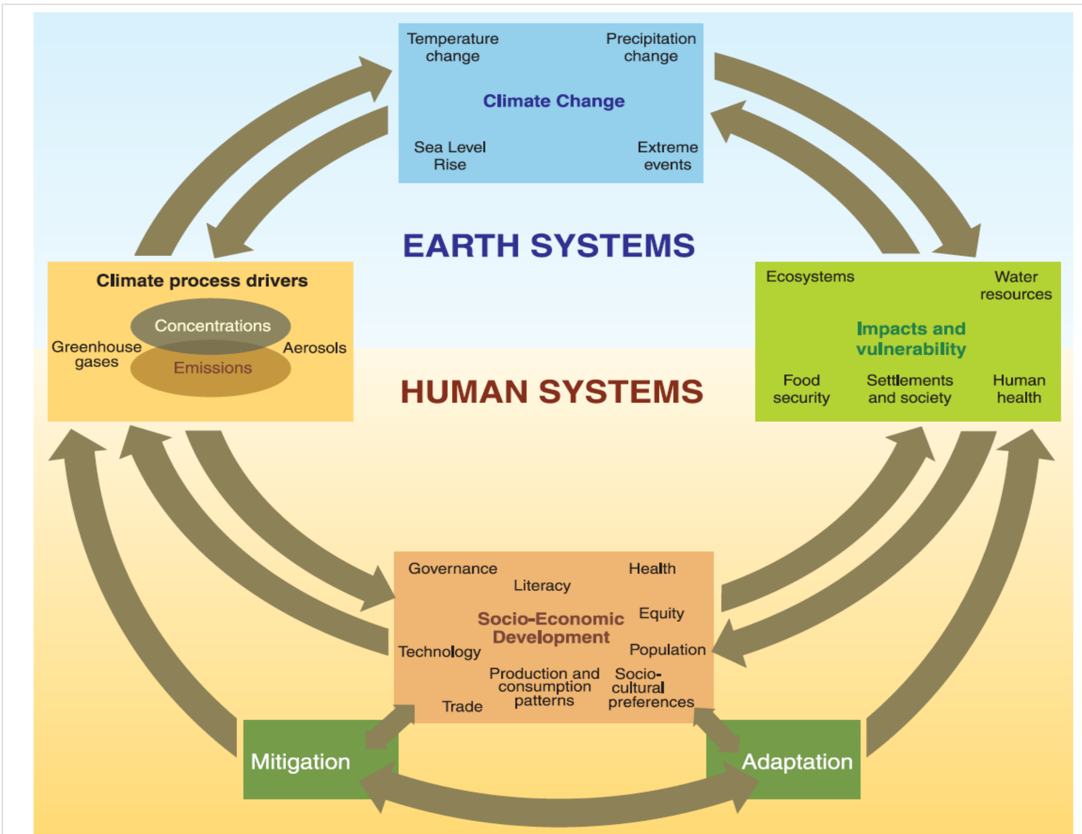

Figure 1.6 Theoretical framework of the dissertation
Source: (Parry et al., 2007)

Secondly, nested within the earth's various systems, climatic and other natural systems also bear interactive relationships. On the one hand, as presented in Section 1.1, climate change has imposed a tremendous influence on global terrestrial and marine ecosystems. On the other hand, changes in the earth's natural systems also have had countereffects on the climate. For example, through decreased carbon sequestraion capacity and increased land-surface albedo, desertification can lead to biodiversity loss, and enhance global climate change (Adeel, Safriel, Niemeijer, & White, 2005). Thus, dryland desertification and climate change are intricate and co-evolving processes (Han, Xue, Wang, Zhang, & Huang, 2008).

Third, climatic and human systems are also interactive, although such interactions are often indirect, bridged by the earth's natural systems and the climate's process drivers. Some human activities such as the increase in combustion of fossil fuels and the increase in the aerial greenhouse gas concentration, result in an increased air temperature (Ross & Piketh, 2006). Other human activities, such as deforestation, not only increase the vulnerability of human and natural systems, but also lead to an increase in albedo and, thus, contribute to temperature rise (Berbert & Costa, 2003; Mylne & Rowntree, 1992). However, humans also can act to reduce the extent of climate change by engaging in mitigation activities (see Section 1.2.2 for details).

Since human, climatic, and natural systems are intertwined in complex realtionships, careful examination of factors from all three systems mentioned above are essential in order to address the issues pertaining to the development of dryland systems. This is manifested in each of the three analyses presented in this dissertation (see Chapters II, III and IV).

1.2.2 Climate issue is a development issue

The climate issue, within the context of developing countries, is a development issue (Parry, 2009). In this section, human strategies designed to combat the negative effects of climate change – namely, mitigation and adaptation – and their relationships, will be discussed first. Then, the relationship between adaptation and development will be explored.

1.2.2.1 Human strategies for dealing with climate change

There are two categories of action in which humans may engage in order to address challenges resulting from climate change: mitigation and adaptation.

Mitigation

Mitigation refers to actions that are implemented to alleviate or avoid the negative impacts from the environment. Within the context of climate change, "mitigation is an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (McCarthy, 2001)".

The aim of mitigation is to stabilize the atmosphere's greenhouse gas concentration at a certain level, and therefore eliminate the trend of human activities causing an increase in climate change. For example, most of the signatories of UNFCCC and the Kyoto Protocol aimed to reduce their greenhouse gases emissions by 5% below the 1990 levels during the period of 2008 to 2012 (United Nations, 1998). There are many activities directed towards mitigation, such as increasing fuel efficiency, developing green energies, planting more trees, and establishing carbon trade systems.

Adaptation

Adaptation refers to the changes, adjustments, and actions taken to become more suited to an environment. Within the context of climate change, there is a divergence in defining the concept. Some focus on increasing the resilience of human society (Nelson, Adger, & Brown, 2007), and some claim that adaptation should also include a transformation to a new social and political structure that would be better able to adjust to climate change (Pelling, 2011). In general, adaptation refers to actions that increase the capacity of a unit (a society, an organization, or an individual) to act against the negative impacts of climate change and/or to take advantage of the positive impacts of climate change.

Adaptive activities can be implemented at all the levels of human society, from the individual to the international community. There is a substantial spectrum of adaptive activities, ranging from technology advancement to institutional reforms and from managerial improvement to policy development. Currently, proposed adaptive activities include (but are not limited to) the following categories (Nelson et al., 2007; Parry et al., 2007; Pelling, 2011; UNDP, 2007): technological: for example, developing crop varieties that are more drought- or flood-resistant, and developing technologies that will reduce production costs; infrastructural: for example, building reservoirs and dams against water-level changes caused by drought or glacier melting, and constructing high quality roads to facilitate transportation to and from remote rural areas; managerial: for example, promoting the diversification of crop and livestock species and livelihoods; Institutional: for example, establishing farmers' production and trading associations, establishing risk management and early warning systems, and establishing global carbon trade markets; regulatory: for example, implementing conservation policies; political: for example, reducing poverty and increasing social equity; and cultural: for example, transforming from a high-carbon lifestyle to a low carbon lifestyle.

Unavoidable mitigation and adaptation

As seen from the above definitions, mitigation and adaptation have different objectives; the former aims to intervene directly with the current trend in climate change, while the latter aims to survive, live with, or develop under climate change.

Between mitigation and adaptation there can be both trade-offs and synergies (Kane & Shogren, 2000; La Rovere, Avzaradel, & Guimaraes Monteiro, 2009; Lobell, Baldos, & Hertel, 2013; Moser, 2012). However, the two are co-evolving as the climate changes under their respective impacts (Bosello, Carraro, & De Cian, 2013; Klein et al., 2007). Therefore, both mitigation and adaptation are progressive concepts, and both are unavoidable under climate change. Without mitigation efforts, no adaptive actions will be able to assure development in certain areas. However, even the most stringent mitigation measures cannot obviate adaptation. This is because of the damage already done by current climate change, the inertia of climate change, and the lag-effects of greenhouse gases on climate change (Klein et al., 2007; Wigley, 2005).

1.2.2.2 Adaptation and adaptive capacity

Currently, due to reasons including the existing backward economic and technological development, it is the world's developing countries that are impacted the most by climate change and which bear most of the negative impacts (Mertz, Halsnaes, Olesen, & Rasmussen, 2009; Parry et al, 2007). However, in the future, all of humanity will be at risk (Yohe et al., 2006; UNDP, 2007). Adaptation is unavoidable for sustainable development of humans.

Adaptation takes place in the form of specific activities and projects. However, it is largely the system's adaptive capacity that determines whether and to what extent such activities and projects can be implemented, and whether they can be implemented in time (Burton, Diringer, & Smith, 2006).

Adaptive capacity is "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC, 2008). Adaptive capacity depends upon a wide array of characteristics including a system's social, economic, geographic, political, and even cultural aspects. A list of determinants of adaptive capacity was proposed by Yohe and Moss (2000), including:

- *The range of available technological options for adaptation;*
- *The availability of resources and their distribution across the population;*
- *The structure of critical institutions and the derivative allocation of decision making authority;*
- *The stock of human capital, including education and personal security;*
- *The stock of social capital including the definition of property rights;*
- *The system's access to risk spreading processes;*
- *The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible; and*
- *The credibility of the decision-makers, themselves, and public perception of attribution.*

The distinction between specific adaptive activities and enhanced adaptive capacity is not always clear. For example, activities such as the training of farmers in new agricultural management skills have the potential to serve both purposes. Indeed, the determinants of adaptive capacity reflect a system's fundamental ability to respond to any type of risk, either imposed by climate or otherwise (Burton et al., 2006). Without question, these determinants also indicate a system's capacity for sustainable development.

1.2.2.3 Integration of climate mitigation, adaptation, and sustainable development

Integrating mitigation and adaptation and sustainable development is crucial to ensuring a promising future. This is due to the following reasons. First, current threats from climate change are caused partially by the unsustainable development paths employed in the past. Anthropogenic factors, especially the combustion of fossil fuels, emission of aerosols, and human-induced changes in land cover are among major contributors to global warming (Solomon et al., 2007).

Second, development pathways play a key role in determining the earth's future vulnerability to climate change. For instance, it was estimated that a considerably greater number of people would be exposed to the risk of coastal floods under IPCC's unsustainable A2 scenario (a rapidly increasing population, low per capita income, and many individuals qualified as below the poverty line) than under sustainable B1 and B2 scenarios (global and regional governance) (Klein et al., 2007; Parry, 2009).

Third, simply "adding on" mitigation and adaptation activities to current development pathways without putting forth efforts towards a more sustainable pathway is extremely costly. As Parry (2009) argued, protecting billions of people against the impacts of climate change is far more expensive than raising people out of poverty.

Fourth, some activities contributing to sustainable development also serve the purpose of increasing adaptive capacity (Folke et al., 2002). Therefore, it is necessary for countries, especially underdeveloped countries, to 'mainstream' climate change adaptation with development plans (Klein et al., 2007).

As discussed, development paths are closely related to the current and future climate change, to reduce the cost caused by future climate, it is vital to synergize climate change adaptations and sustainable development. As argued by Parry (2009), "climate change is a development issue, and only sustainable development can confront the challenge".

1.3 Research goal and objectives

To address the issue of climate change-induced problems with agricultural production and rural livelihoods in Inner Mongolia, the relationships among agricultural output, rural income and climate, and other social and economic factors affecting this region, will be explored. The specific objectives of this dissertation are:

1) To assess the impacts of temperature and precipitation changes and adaptive activities on grain output values in Inner Mongolia, China;

2) To evaluate the impacts of temperature and precipitation changes and adaptive activities on livestock output values in Inner Mongolia, China; and

3) To examine the relationships between rural household income and factors such as environmental conditions, diversification of livelihoods (see section 2.2 for details), education, technical assistance, market access, occupation and ethnicity in Xilin Gol, a typical arid and semi-arid area in Inner Mongolia, China.

1.4 Organization of the dissertation

This dissertation is written in the chapter format and organized into five chapters that correspond with the above objectives.

In Chapter I, the problems facing global dryland systems, especially Inner Mongolia – under the effects of climate change, are stated, a theoretical framework to address this issue is provided, the research goals and objectives are illustrated, and the organization of the dissertation is described.

Following the general introduction, three analyses are presented in Chapters II, III and IV, addressing research objectives 1), 2) and 3), respectively.

In Chapter V, the results from Chapters II, III and IV are summarized, and the overall conclusions are drown.

CHAPTER II

THE IMPACTS OF TEMPERATURE, PRECIPITATION, AND ADAPTIVE ACTIVITIES ON GRAIN OUTPUT VALUE IN INNER MONGOLIA, CHINA

2.1 Introduction

2.1.1 Grain production and food security in China

Food security has always been a national priority for China and grain production is a priority for achieving national food security (Khan, Hanjra, & Mu, 2009; NDRC, 2008, 2009). In the 1960s, the Great Famine cost millions of lives due to agricultural failures (Ashton, Hill, Piazza, & Zeitz, 1984). As soon as the Great Leap Forward and the Cultural Revolution ended, the Chinese government launched a grand range of measures to ensure a sufficient national grain supply; these measures included (but were not limited to) institutional reform, price adjustments, increased agricultural subsidies, land conservation programs, and cancellation of agricultural taxes (Wang, Zhang, & Cai, 2009). In November of 2013, the Communist Party of China (CPC, 2013) announced that while the land use rights in rural China would be protected, a user-rights market would be established to facilitate a reallocation of the nation's land resources.

Through these policy changes and reforms, China has made significant progress in increasing grain productivity and total grain yield, as well as in improving the livelihood of the rural population (Lin, 1992; Fan, 1991; Ravallion & Chen, 2007). From 1978 to 2011, total grain production increased by 87% and per capita grain production increased by 33.3% (Veeck, 2013). China has now, basically, achieved grain self-sufficiency (Wang et al., 2009) and has shown itself able to sustain this self-sufficiency even when global food prices soared and food riots occurred in many other developing countries in 2007 and 2008 (Liao, 2010).

China's demand for food is still increasing and will continue to rise in response to changes in diet pattern associated with the rapid development of the country's economy and the process of urbanization (Veeck, 2013; Zhou, 2010). On the one hand, China's rapid economic progress is associated with a rapid increase in income. Chern (2000) found that the income elasticity of the demand for meat was very high; as people achieve economic prosperity, they begin to seek more food of animal origin such as eggs, milk, and meat. On the other hand, from 1978 to 2010, the urban population in China increased from 17.92% to 51.27%, representing an increase of 518.34 million people (NSC, 2011). This urban population, usually with a higher average income than rural population, not only consumes more of most types of food, but also has a higher demand for animal-based food (Fuller, Tuan, & Wailes, 2002; Hsu, Chern, & Gale, 2002). Researching using a household survey of China in 2000 revealed that urban per capita meat consumption was 40% greater than the rural equivalent, while urban per capita consumption of eggs and poultry was more than 2.5 times higher than that in rural areas (Hsu, Chern, & Gale, 2002). The feed conversion ratio of meat varies from 3 to 10, which means that producing one pound of meat requires three to ten pounds of feed, depending on the types of meat and feed (Porteous, 2000). The recent soaring prices of meat, especially pork, beef, and mutton, indicate that the supply of meat cannot meet the demand in China (please refer to Section 3.1 for detailed price changes). Therefore, in the future, more grains will be needed to produce more meat and other animal-based sources of food.

2.1.2 Climate change threatens China's grain production

Looking to the future, the tasks necessary to further increase grain yield are significantly challenging. There are many threats to grain production, among which climate change and related factors are especially daunting.

Climate change can affect grain production in many ways in China. For example, climate change, especially changes in temperature and precipitation, has induced changes in boundaries of land zones dedicated to grazing and farming (Li & Pan, 2012), caused shifts in crop phenology, affected crop yields (Tao, Yokozawa, Xu, Hayashi, & Zhang, 2006) and altered the transmission dynamics of pests and the infection rates of crop diseases in some areas (Piao et al, 2010).

Climate change could also exacerbate the existing water scarcity issue facing agriculture. Climate change, including changes in the earth's precipitation, temperature, and radiation, was considered to have major impacts on the hydrological cycle in China. As predicted by Tao, Yokozawa, Hayashi, & Lin (2003), rain-fed crops in both northeast and north China will face water challenges due to factors including soil-moisture deficit and decreased precipitation.

With climate change, the range of agricultural production activities affected by extreme weather events has also increased. Extreme weather events, including droughts and floods, can directly damage crop production (Rosenzweig, Iglesias, Yang, Epstein, & Chivian, 2001). From the 1980s to 2000s, drought or flood induced harvest failure increased from about four million hectors to about five million hectors (Piao et al., 2010).

Climate change could also expedite the land degradation process. Analyzing agricultural production and climate data from 1950s to 2000s in semiarid north China, Wang, Chen, & Dong (2006) found that the Aeolian drift potential and the frequency of sand-driving winds had strongly affected land desertification.

2.1.3 Grain production and climate challenges in Inner Mongolia

In Inner Mongolia, 6% of the area, or 7.15 million hectares, is crop land. Located in the temperate climate zone, the growing season is typically from April to September, although wheat is typically sown in March. Local cultivation practices are dependent on both machine power and man power. In 2010, 75.5% of the planted area was sown with machinery, and 35.9% was harvested with machinery (SBIM, 2011). In the same year, the grain (including tubers and beans) output reached 21.56 million tons, ranking 11^{th} among the 31 provincial level administrative units in mainland China (NSB, 2011; SBIM, 2011). Major grain crops in Inner Mongolia include corn, wheat, and rice; tubers and beans (especially soybean) also account for a significant portion of food production (SBIM, 2011). The output shares of major crops are displayed in Figure 2.1.

As an arid and semi-arid area, grain production in Inner Mongolia is even more challenging. This area not only faces all the climatic challenges discussed above, but also faces complicated ecosystems. Located in north and northwest China, Inner Mongolia has a diverse profile of ecosystems, including forests, meadow steppes, typical steppes, desert steppes, steppe deserts and deserts (Yu et al., 2004). It contains both farming and grazing systems; and lately the boundaries between these two land zones have been shifting (Li & Pan, 2012). In addition, Inner Mongolia is characterized by severe land degradation and desertification. All the above factors bring complexity or difficulties to grain production in this area. To develop strategies that secure grain production in Inner Mongolia, it is necessary to evaluate the impact of climate change, as well as adaptive activities that contribute to an increase in grain output.

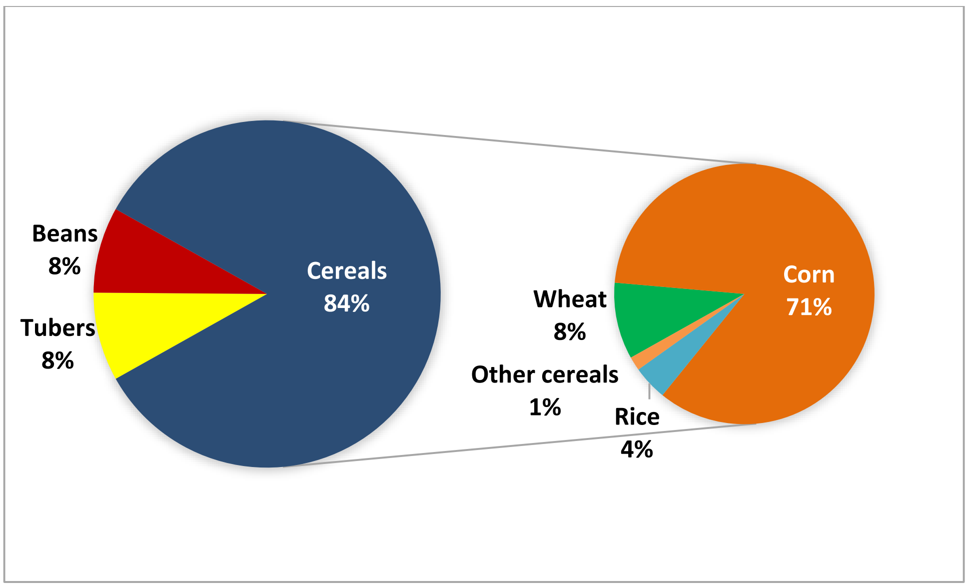

Figure 2. 1 Grain output shares in Inner Mongolia in 2010

With respect to future strategies to ensure grain supply, researchers have agreed that science and technology for increasing crop yields, improvement in rural infrastructures and institutional reforms are all necessary (Chen, 2010; Huang, Pray, & Rozelle, 2002; Lin, 1998; Zhang, Chen, & Vitousek, 2013). In this chapter, the relationships between grain output value and the following factors are examined in Inner Mongolia: 1) climate factors (measured by temperature and precipitation, 2) the general strength of the current level of science and technology (measured by the total number of special technical personnel), 3) higher education (measured by the number of college graduates), 4) road density (measured by the length of highways per 100 square kilometers), and 5) diversification of agricultural production.

2.2 Literature review

Both climate and human impact affect agricultural production. In this section, the current literature related to these two aspects is reviewed. The impact of climate factors on grain production and predictions on future impact are presented first and then the current literature on adaptive activities is first discussed. In addition, the methods used by researchers in order to assess the impact of climate change and adaptations on grain production is reviewed.

2.2.1 Current and future climate impacts on grain production

Analyses of historical data have revealed that climate changes affected agriculture production in a variety of areas around the world (Lobell & Field, 2007; Parry, Rosenzweig, & Livermore, 2005). From 1980 to 2008, due to climate change, global maize outputs dropped by 3.8%, and global wheat output decreased by 5.5%, (Lobell, Schlenker, & Costa-Roberts, 2011). An analysis of data obtained from five research stations in China indicated that from 1981 to 2000, changes in temperature were significantly associated with a shift in crop phenology and changes to the yields of all major crops in China: maize, wheat, and rice (Tao et al., 2006). Cross-sectional data modeling via the Ricardian approach revealed that in 31 provinces in China, overall an increased temperature had a positive impact on net crop revenue per hectare, while increased precipitation had a negative impact (Chen et al., 2013).

However, in the arid and semi-arid regions of Asia, looking forward, it was predicted that an increase of 1^{o}C in temperature could lead to at least a 10% increase in the demand of agricultural irrigation (Fischer, Shah, & van Velthuizen, 2002; Liu, 2002). It was also predicted that in northern and northeastern China, crops on the plains would face challenges from increased water demands, soil moisture deficits, and a decline in precipitation in the coming decades (Tao et al., 2003).

The impact of climate change on crop production not only depends upon temperature and precipitation regimes, but also on the fertilization effect of CO_2, crop breeding, nutrient applications, and irrigation (Lin et al., 2005). However, current research is not sufficient to assess the precise impacts of climate change on agriculture in China; and further research is needed (Piao et al., 2010).

2.2.2 Impacts of adaptive activities on agricultural production

To couple adaptation with development, an understanding of adaptive activities that can both enhance adaptive capacity and promote sustainable development is needed. A review of the literature on the relationships among the following factors and grain production: education, roads, technical assistance, and diversification of livelihoods is the focus of this section.

2.2.2.1 Education

Education benefits agricultural production via two channels: *the worker effect* (increasing agricultural productivity) and *the allocative effect* (enhancing farmers' ability to acquire and interpret information related to agricultural production) (Welch, 1970). Research on education as it affects different geological regions supports the notion that education makes a positive contribution to agricultural productivity. Using a simultaneous equations model (SEM) on provincial-level panel data in China from 1953 to 2000, Fan, Zhang, and Zhang (2004) found a direct significant positive impact of average years of schooling of the rural population on agricultural productivity (measured by agricultural GDP per agricultural laborer).With advanced panel data from 95 developing countries from 1961 to 2002, Reimers and Klasen (2013) discovered that one additional year of average schooling was associated with a 3.2% growth in agricultural output per hectare. Analyzing the household rice production data of 141 villages in Bangladesh, Asadullah and Rahman (2009) claimed that education was not only associated with increased rice productivity and enhanced potential output in the research area, but was also significantly associated with reduced inefficiencies in production.

With respect to the *allocative effect*, more educated farmers tend to adopt new technologies. For example, in India the adoption of High Yield Variety seeds among farmers was positively correlated to education level (Foster & Rosenzweig, 2010). In Ethiopia, Asfaw and Admassie (2004) found that one additional year of school for the most educated household member (except the household head) added 2.7% to the probability of the household adopting the use of synthetic fertilizers. Additionally, more educated farmers tend to be more capable of allocating their resources. For example, Huffman (1974) revealed that among Midwestern U.S. corn farmers, an increase in education moved farmers towards an equilibrium usage of nitrogen fertilizers.

2.2.2.2 Roads

Roads benefit agricultural production by increasing availability and reducing the price of agricultural input (Fan, Hazell, & Thorat, 2000; Khandker, Bakht, & Koolwal, 2009), reducing the time farmers spend in marketing their agricultural products (Dercon, Gilligan, Hoddinott, & Woldehanna, 2009), and reducing "transaction costs of all sorts" (Binswanger, Shahidur, & Rosenzweig, 1993).

Agricultural production was found to be negatively correlated with the time needed to travel to markets. In an analysis combining household surveys and a commune census, Minten and Stifel (2008) found a significant negative relationship between isolation (measured by the time and cost of transportation to the nearest urban center) and yields of rice, maize, and cassava in Madagascar. Analyzing the production of 20 crops in 42 Sub-Saharan countries, Dorosh, Wang, You, and Schmidt (2010) found agricultural production to be significantly negatively correlated with proximity (measured by travel time) to an urban market.

Distance to certain roads has also been found to be significantly negatively correlated with agricultural growth. For example, through analyzing district-level data in Uganda in 1992, 1995, and 1999, Fan and Zhang (2008) found that a shortened distance to feeder roads (dirt roads connecting rural communities to "commercial and socio-economic centers" or classified road networks) was significantly associated with an increase in agricultural labor productivity.

In multiple countries, government investment in roads was found to be significantly associated with agricultural production or an increase in agricultural productivity (Fan et al., 2000; Fan & Zhang, 2004; Fan & Chan-Kang, 2008). Road density was also found to be positively correlated with agricultural productivity. For example, in the same research mentioned in Section 2.2.2.1, Fan et al. (2004) also found a significant and direct positive association between rural road density (road length in kilometers per thousand square kilometers of geographic area) and agricultural productivity (agricultural GDP per agricultural laborer).

Researchers have also found that not all types of roads have the same impact on agricultural production. For example, Fan and Zhang (2008) found no significant correlation between agricultural productivity and a shortened distance to high-level roads (all-season murram roads and tarred roads). Fan and Chan-Kang (2008) found that agricultural productivity was significantly correlated with low-grade roads but not high-grade roads.

2.2.2.3 Technology

In long term economic development, technological advance, together with population growth, and capital accumulation, are major drivers for productivity increase (Solow, 1956; Swan, 1956). The Green Revolution provides a great example on how technological process can substantially increase agricultural productivity (Huang et al., 2002). With advances in science and technology, including the breeding of high-yield varieties, the implementation of irrigation systems, and the application of synthetic fertilizers and pesticides, from 1970 to 1985 the Green Revolution doubled the production of cereal in Asia (Hazell, 2002).

Science and technology also have contributed greatly to modern Chinese agriculture. From 1976 to 1991, benefiting from the breeding and adoption of hybrid rice, China's rice production increased by 200 million tons (Yuan, Yang, & Yang, 1994). In a study of 23 agricultural commodities in China from 1990 to 2004, researchers found that most of the total productivity factors in China were boosted by technical change (Jin, Ma, Huang, Hu, & Rozelle, 2010).

Researchers believe that a greater focus on yield improvement by science and technology will be among the most important factors in meeting future food demands in China (Lin, 1998; Huang et al., 2002). Such science and technology will include advances in molecular biology, genetic engineering, and natural resource management (Huang et al., 2002).

The number and structure of special technical personnel (including personnel in engineering, agriculture, scientific research, health care, and teaching) in a given region represents the general strength of science and technology in that region. However, few researchers have examined the relationship between this factor and agricultural production.

2.2.2.4 Diversification of livelihoods

Diversification of livelihoods has been a key element of rural development theory since the 1990s. The idea of *diversification* refers to a reallocation of resources such as capital, labor, and equipment into more agricultural or non-agricultural activities to protect against the challenges and shocks resulting from a changing social and natural environment. It is a risk-reduction strategy.

Diversification has at least two dimensions in terms of rural development: 1) diversification within the agricultural sector; and 2) diversification of income sources, not only from the agricultural sector but also from non-agricultural areas. In this section the literature on both of these dimensions with respect to grain production and rural income generation is presented.

Researchers have shown that proper diversification of crop varieties across time and space can increase crop yield, control pests and crop diseases, and increase soil fertility (Finckh, 2008). For example, through a controlled experiment in China's Yunnan Province from 1998 to 1999, Zhu et al. (2005) found that compared with monocultural rice, mixed planted rice varieties had both a higher yield and a lower rate of infection of panicle blast, a common rice disease. Ali, Awan, Ahmad, Saleem, and Akhtar (2012) found that in a controlled experiment in Pakistan from 2007 to 2008, introducing leguminous crops into a normal rice-wheat production system not only increased grain yields but also improved soil quality.

Diversified agro-ecosystems are also more resilient to issues resulting from climate change (Lin, 2011). For example, Tengö and Belfrage (2004) compared agricultural management practices in Sweden and Tanzania and found that agricultural ecosystems with more ecological complexity (including wild varieties) and with increased crop diversity across time and space had a greater potential of protecting the systems from climate variation and secure production. By examining 880 paired agricultural plots from southern to northern Nicaragua after Hurricane Mitch in 1998, Holt-Giménez (2002) found that those plots with greater diversity and structural complexity suffered less damage from the hurricane, including less erosion, more vegetation, and lower economic loss.

Non-farm activities also have the potential to promote agricultural growth. For example, evidence was found in Kenya that non-farm activities insulated households from the risks associated with being sole-farming households; with the income obtained from non-farming activities, farmers were able to adopt new production technologies and increase their overall agricultural output (Evans & Ngau, 1991).

Diversification also functioned as a strategy for securing income in different areas of many countries around the world (Deininger & Olinto, 2001; Govereh & Jayne, 2003; Himanshu, Lanjouw, Murgai, & Stern, 2013; Reardon, Delgado, & Matlon, 1992). In Inner Mongolia, some traditionally diversified agricultural practices have been abandoned under the overwhelming socio-economic changes (Zhang, Li, & Fan, 2013), yet in some areas, certain newly established policies and regulations have resulted in a higher level of diversification in both agricultural and non-agricultural sectors (Xu, Kang, & Jiang, 2012). However, little research has been done in order to assess the relationship between a diversification of agriculture and grain output in this area.

2.2.3 Methods of assessing the impacts of climate change and adaptions on grain production

Researchers have used a variety of models to assess the impacts of climate change and adaptation activities on grain production. In this section, a brief review of some methods to address this issue are presented, including statistical regression models, yield functions, Ricardian models, simultaneous equations models (SEMs), and simulations combining crop yield models and climate and social change scenarios.

Statistical regression models often have been used to identify the association between crop yields and climate factors. For example, based on a set of time series data, Lobell and Field (2007) used a multiple linear regression model to evaluate the relationships between climate and crop yield on a global scale. Lobell et al. (2005) used a multivariate linear regression model to assess the relationships between wheat yield and climate in Mexico. Lobell et al. (2011) used non-linear regression with panel data to measure the relationships among temperature, precipitation and the yields of several major crops (maize, wheat, soybeans, and rice) around the world.

Using production functions models is another oft-used method of assessing climate and socio-economic impacts on grain production. For example, with a Cob-Douglas form yield function, You, Rosegrant, Wood, and Sun (2009) used panel data obtained from 1979 to 2000 to assess the impact of growing season temperatures on wheat yields in China. In this model, the independent variables included conventional inputs (seeds, fertilizers, pesticides, machinery, irrigation, manure, and animal power), the share of wheat area in the total planted area, temperature, rainfall, and solar radiation. Similarly, based on a panel data set obtained from 29 provinces in China across 14 years and using a production function, Fan (1991) estimated the effects of technological change and institutional reform on China's growth in agricultural production.

A Ricardian model is frequently used in assessing the impact of climate and socio-economic factors on grain production. For example, using farm-level cross-sectional data, Chen et al. (2013) built a linear mixed model (LMM) (a linear model incorporating both random and fixed effects) to measure the impacts of annual temperature and precipitation changes on net per hectare crop revenue in 31 provinces in China. In their model, both climate factors and socio-economic factors were incorporated as independent variables.

SEMs are also regularly used to address this issue. For example, using a simultaneous equations model with provincial-level semi-panel data (there are gaps in years), Fan et al. (2004) evaluated the associations between grain productivity and socio-economic factors, especially the average school years of rural residents, rural road density, percentage of irrigated cropped land, government investment/spending on agricultural research, and government investment/spending on infrastructure.

As discussed in this section, education, roads, advances in science and technology, and diversification all seem to influence agricultural production although the impact could vary from case to case. Analyses using different modeling methods indicated that these factors contribute to enhanced adaptive capacity. Built on the results of previous research, and inspired by various research methods used in previous research, in this chapter, the relationships between these factors and grain output value in Inner Mongolia are analyzed on a county-level from 2000 to 2008.

2.3 Research hypotheses and method

2.3.1 Research hypotheses

The following research hypotheses were tested:

1) Temperature is significantly correlated to the annual grain output value of Inner Mongolian counties;

2) Precipitation is significantly correlated to the annual grain output value of Inner Mongolian counties;

3) The number of special technical personnel is positively correlated to the annual grain output value of Inner Mongolian counties;

4) Highway density (the length of highway per 100 square kilometers) is positively correlated to the annual grain output value of Inner Mongolian counties;

5) The annual total number of college graduates in the municipal area is positively correlated to the annual grain output value of Inner Mongolian counties; and

6) Diversification in the agricultural sector is positively correlated to the annual grain output value of Inner Mongolian counties.

2.3.2 Research method

2.3.2.1 Unit of analysis, time, and scope

The unit of analysis used in this study was the county, or an equivalent administrational unit. This research was based on panel data representing counties with grain production in Inner Mongolia during the time period of 2000 to 2008.

2.3.2.2 Data Sources

Data used in this analysis were derived from the Inner Mongolia Statistical Yearbook (SBIM, 2001-2009), FAO world soil map (FAO, 2009b), China GIS map (ACMR, 2012), China Yearbook of Agricultural Price Survey (NBS, 2007-2009), and public reports obtained from the National Bureau of Statistics of China (NBS, 2013).

Data collected from the Inner Mongolia Statistical Yearbook are from three levels: the county-level data included the number of large animals, sheep, goats, and pigs at the year end, yields of different agricultural products (including grains, beetroots, oil-bearing crops, different livestock meats, and wool), population, total labor supply in rural areas, number of agricultural workers, land area, planted area of grain crops, the length of highway, and number of special technical personnel; city-level data included monthly average temperature, monthly precipitation, annual total number of college graduates, and output values of different agricultural sectors; and the provincial level data included Consumer Price Index (CPI), and price indices of different agricultural products.

Price information on wheat, rapeseed oil, pork, beef, and mutton was collected from the China Yearbook of Agricultural Price Survey (NBS, 2007-2009) and public reports published on the website of the National Bureau of Statistics of China (NBS, 2013). The county-level soil map data were generated by combining the FAO world soil map (FAO, 2009b) and the China GIS map (ACMR, 2012).

2.3.2.3 Data treatment

1) Calculating grain output value

Inner Mongolia has a variety of grain crops mainly including wheat, corn, rice, sorghum, and millet. The Inner Mongolia Statistic Yearbooks published the sum of the outputs of these grain crops, potatoes, and soybeans, without the value and proportion of output for each crop. As wheat is the major grain crop, the product of the grain output and the price of wheat was used as an estimate of the output value of all grain products. The nominal price of wheat each year was converted to the 2000 value by using the consumer price index. The formulas used are as follows:

$P_{rt}=P_{nt} * (CPI_{2000}/CPI_t)$

where

P_{rt} is the real price in year t (in the value of year 2000),

CPI_t is the consumer price index of year t compared with year 2000, and

$2001 <= t <= 2008$.

2) Calculating the diversification index within agricultural sector

A diversification indicator was created based on the model by Hackbart and Anderson (1975). The calculation method used is as follows:

$D = \sum_1^n -p_i \log p_i$

where

n is the number of agricultural production sectors, and

p_i is the relative share of sector i in the total output value of the n sectors in farming and animal husbandry, including the output values of grains, beetroots, oil seeds, beef, pork, mutton, and wool. To facilitate the analysis, the index was multiplied by 100 in the regression modeling.

3) Identifying major soil type

The FAO world soil classification system divides the world's soil into 26 groups, under which there are 106 units (FAO, 2009b). Based on this system, there are 19 types of units in Inner Mongolia, as displayed in Figure 2.2. For each county, the unit with the largest area was chosen as the major soil type. This narrowed down the units to nine: Bk (Calcic Cambisols), DS (Dunes or Shifting Sands), Ge (Eutric Gleysols), Gm (Mollic Gleysols), I (Lithosols), Kh (Haplic Kastanozems), Kl (Luvic Kastanozems), Xk (Calcic Xerosols), and Xl (Luvic Xerosols). The major soil type of each county was then regrouped based on the groupings of soil type. As a result, there were six major soil types used in the analysis (i.e., Cambisols, Dunes or Shifting Sands, Gleysols, Lithosols, Kastanozems, and Xerosols). These soil types were incorporated in the model as dummy variables.

2.3.2.4 Modeling

A multiple regression model was used to examine the statistical significance, direction (sign), and magnitude of the relationships between the output value of grain and the explanatory variables. The model can be written as follows:

$$Y_{it} = \alpha_i + \gamma_t + \beta X_{it} + \varepsilon_{it}$$

where

$i = 1, 2, \ldots, n$ (the number of counties in the data set); $t=1, 2, \ldots, 9$ (from year 2000=1 to 2008=9);

Y_{it} is the grain output value of county i in year t;

α is the county effect;

γ is the time effect;

β is a 1xk vector of coefficients;

X is a kx1 vector of explanatory variables, including monthly, seasonal and annual average temperature; monthly, seasonal, and annual precipitation; major soil type; planted area of grain crops; the length of highway per 100 square kilometers; diversification index; number of special technical personnel; the annual total number of college graduates in the municipal area; the amount of synthetic fertilizers consumed; the number of agricultural workers; the headcount of each livestock species; and ε is the error term.

2.3.2.5 Model estimation

The model estimation process contained a series of procedures and tests, including the selection of variables, fixed or random effects, validity testing, and selection of a final regression method.

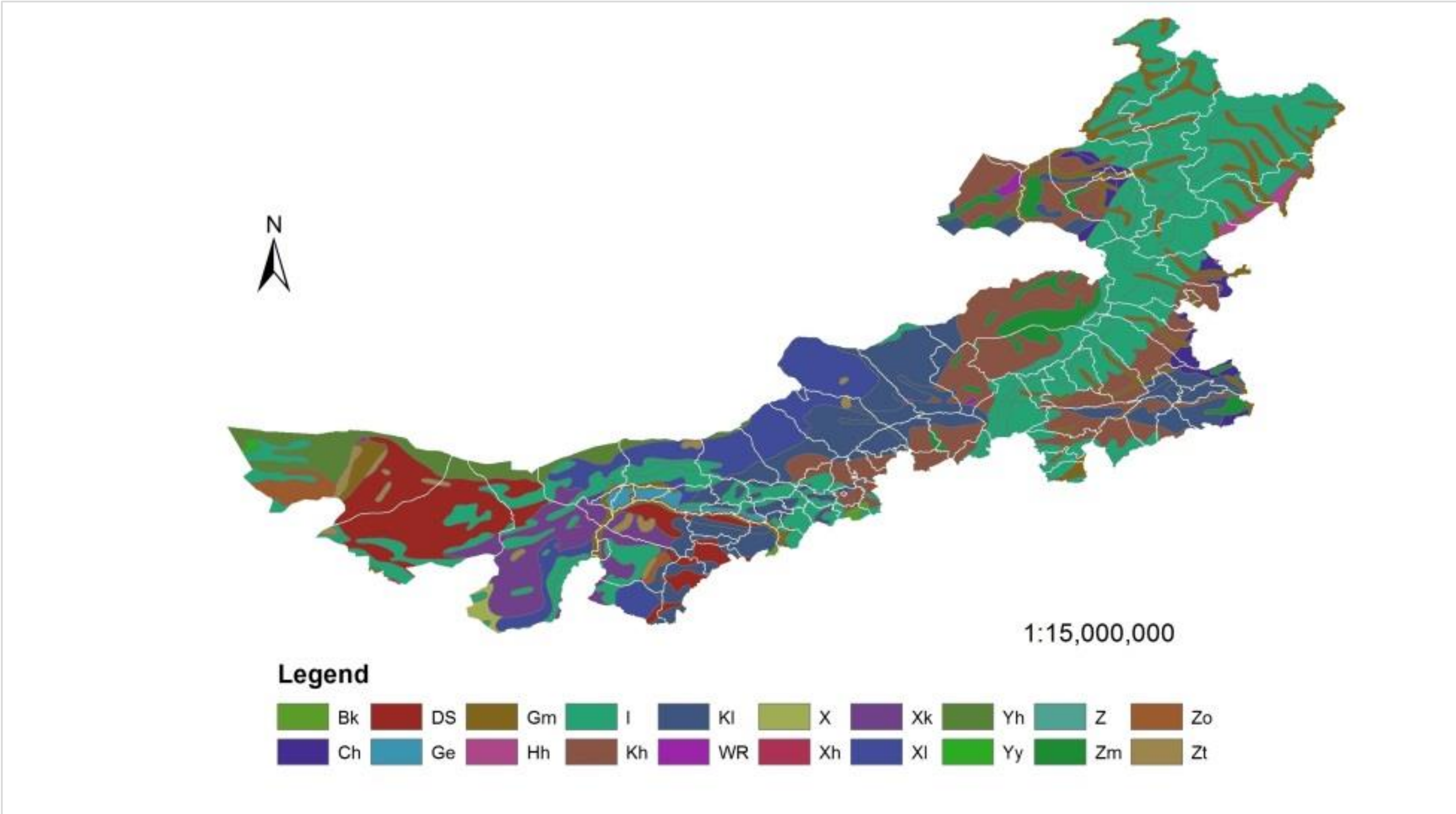

Figure 2.2 Inner Mongolia soil map

First, a pairwise correlation was used to select independent variables. After these variables were put into the model, those with insignificant results were dropped. At this point, some of the variables were rescaled to better fit the model. Then multicollinearity was tested with the variance inflation factor (VIF) according to the standard that any VIF value greater than 3.0 raises caution. When the regression model was reduced to a parsimonious form, a test of overidentification restrictions (Arellano, 1993; Wooldridge, 2002, pp.290-291) was implemented in order to specify if a fixed effects model or random effects model was more suitable for the data. The test was proposed by Arellano (1993) and Wooldridge (2002, pp. 290-291); unlike Hausman test (Hausman, 1978; Hausman & Taylor, 1981), this test has more power because it is functional on heteroskedastic data.

The results of overidentification restrictions test indicated that the fixed effects model was more appropriate for the data (rejected the null hypothesis at 1% level, $p < 0.0001$). The Pasaran CD test was used to test for cross-sectional dependence, a modified Wald statistic for groupwise heteroskedasiticity was implemented to test for heteroskedasticity, and a Wooldridge test for autocorrelation of the panel data (Drukker, 2003; Wooldridge, 2002) was implemented to test for serial correlation.

For the final regression model, the null hypothesis that there were no one-way or two-way fixed effects at the 1% significance level was rejected in the F-test ($p < 0.0001$). The null hypothesis that the model residuals were not correlated was rejected by the Pasaran CD test ($p < 0.0001$), indicating that there was a cross-sectional dependence/contemporaneous correlation in the data set. In addition, the null hypothesis of no first order autocorrelations was rejected by the Wooldridge test for autocorrelation. Finally, the modified Wald statistic for groupwise heteroskedasticity indicated the existence of heteroskedasticity in the data set.

Because of these test results and because the number of counties (92) was significantly larger than the number of time periods (nine) in the data set, the Prais–Winsten estimation method (Prais & Winsten, 1954) was selected. The Prais-Winsten estimation is a linear regression method with panel-corrected standard errors (PCSE), which controls heteroskedasticity and contemporaneous correlation. Using the "*xtpcse*" command in the STATA software, the Prais-Winsten estimation can be implemented with panel data, during which time and group effects can be controlled by including years and counties as dummy variables, and autocorrelation can be controlled by defining the type of autocorrelation.

2.4 Results

2.4.1 General descriptive statistics

From 2000 to 2008, 92 counties (828 observations in total) produced grain in Inner Mongolia, accounting for 91.09% of the 101 county-level administrative units. During this time period, Inner Mongolia's yearly total grain output value from the 92 units increased 2.5 fold, from 12.22 billion yuans ($1.96 billion) in 2000 to 31.06 billion yuans ($4.97 billion) in 2008. The grain output values of each county during each year, and the mean value of each county across all nine years are illustrated in Figure 2.3.

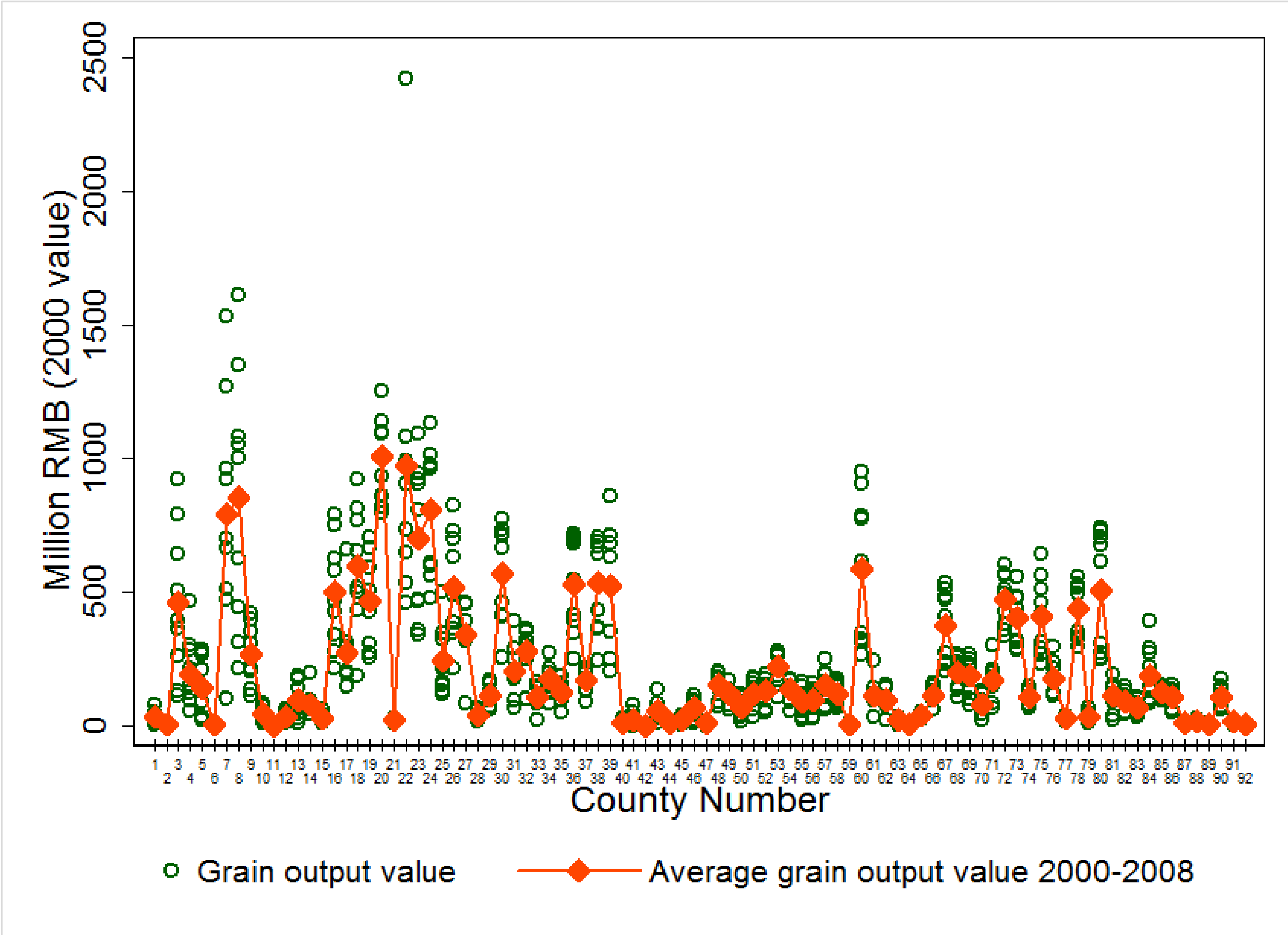

Figure 2.3 Grain output values of all counties

In Figure 2.3, each number on the x-axis represents an individual county. Correspondingly, above each number there are nine green circles displayed in a column, representing the nine annual grain output values of that county from 2000 to 2008. There is also an orange diamond in each column, representing the mean annual grain output value of this county across the nine years. As shown in the figure, the mean grain output values fluctuate from county to county, and the grain output values fluctuate from year to year.

The grain output value of each county for each year and the yearly means of all the 92 counties are plotted in Figure 2.4. In the figure, each number on the x-axis represent a year. Correspondingly, above each year, there are 92 green circles displayed in a column, representing the annual grain output values of the 92 counties in that year.

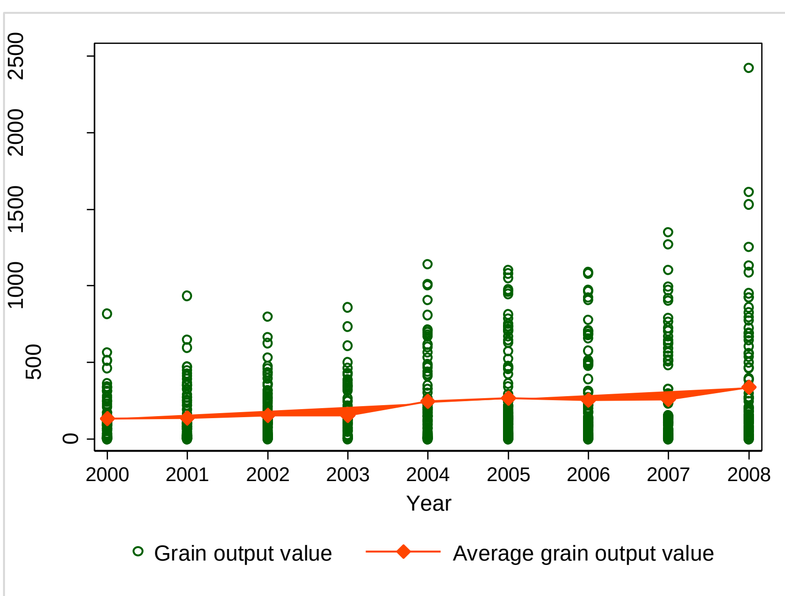

Figure 2.4 Grain output values over different years

An analysis of variance (ANOVA) with repeated measures indicated that the mean grain output values for the 92 counties were significantly different across the years (Greenhouse-Geisser method) at the 1% level, due to: 1) F value = 35.49, degree of freedom (df) = 1.674, p-value < 0.001, 2) effect size = 0.28 (large), and 3) observed power = 1.000 (high). A trend analysis indicated that there was a significant increasing linear trend in the data due to: 1) F value = 47.004, df = 1, p-value < 0.001, 2) effect size = 0.341(large), 3) observed power = 1 (high), and 4) the linear trend accounted for 88.34% of the sum of the squares in the factor. The details of the trend analysis are presented in Figure A.1 and Table A.3 of Appendix A.

The minimum values, maximum values, means, and standard deviations of 1) all 828 observations, 2) the county means, and 3) the yearly mean of all the counties are displayed in Table 2.1 in million yuan (1 yuan = 0.16 U.S. dollar).

Table 2. 1 Grain output values of 92 Inner Mongolian counties 2000-2008 (million yuan)

	Minimum	Maximum	Mean	Standard deviation
All observations	0.06	2,400	214.67	272.14
County mean	0.36	1,009.67	214.67	239.28
Yearly mean	132.87	337.63	214.67	68.85

The measurements and means of the major natural, social, and economic factors (independent variables) are presented in Table 2.2. Because temperature, precipitation and soil types included a large number of variables, the descriptive statistics of these variable are not presented in Table 2.2. Instead, they are given in Table A.1 of Appendix A.

Table 2.2 Descriptive statistics of the major explanatory variables in the grain model

Variable name	Unit of measurement	Mean	Standard deviation
Planted area of grain crops	1,000 hectares	49.61	58.11
No. of agricultural workers	1,000 people	58.13	45.36
Use of synthetic fertilizers	1,000 tons	11.88	15.45
Annual number of graduates in the municipal area (per 1,000 people)	person	18.20	39.66
Number of special technical personnel	1,000	4.36	3.87
Highway density	km/100 km^2	18.72	19.34
100* Diversification factor	Index	53.73	9.63
No. of large animals	1,000 head	74.61	72.35
No. of sheep	1,000 head	481.26	477.70
No. of pigs	1,000 head	.01	0.01

Based on the major explanatory variables listed in Table 2.2 and Table A.1 of Appendix A, a multiple regression model was developed. The results of this model is presented in the following section.

2.4.2 Regression results

The results of the final regression model are given in Table 2.3. The model's chi-squared test is significant at the 1% level (p-value <0.0001), and the R^2 value is 0.8985. All the independent variables' VIFs are smaller than 3.0. Therefore, the model is, in general, a good fit.

Due to the large number of variables related to time periods, groups, and soil types, the results of these variables are not presented in the Table. However, the following null hypotheses were rejected at the 1% level in chi-squared tests: 1) time-effect coefficients for all years are jointly equal to zero (p-value < 0.0001), 2) all county-effects coefficients are jointly equal to zero (p-value < 0.0001), and 3) all soil-effects coefficients (soil-effects were measured by soil type dummy variables) are jointly equal to zero (p-value < 0.0001).

Table 2.3 The estimated regression model on the relationships between grain output values (in million yuan) and the explanatory variables

Explanatory variable	Coefficient	Standard error	p-value
Planted area of grain crops (k hectares)	3.9328	0.5597	0.000
Use of synthetic fertilizers (k tons)	3.4965	0.8018	0.000
Precipitation in May (mm)	0.5813	0.1969	0.003
Average temperature in Spring (March to May, °C)	15.7740	6.9138	0.023
Average temperature in July (°C)	-23.3928	6.5750	0.000
No. of special technical personnel (k)	7.1267	2.4328	0.003
Highway density (km/100^2kms)	0.6031	0.1842	0.001
100*County diversification factor	-2.8374	0.5042	0.000
No. of large animals (k)	1.0033	0.2946	0.001
No. of sheep (k)	0.1115	0.0377	0.003

R^2: 0.8985 Wald chi^2 (24) = 17575.90 Prob > chi^2 = 0.0000

Based on the regression results, precipitation, temperature, number of special technical personnel, length of highway per 100 square kilometers, county agriculture diversification factor, numbers of livestock, and basic inputs such as land, labor, and use of synthetic fertilizers were all significantly associated with the county-level grain output in Inner Mongolia at the 5% level, though the directionalities vary from variable to variable. The key results are briefly summarized in the following section.

2.4.2.1 Climate factors and grain output value

In general, both precipitation and temperature had correlations significantly different from zero with the annual grain output values of the 92 counties across the nine year period studied in this analysis. However, out of different precipitation and temperature variables examined (see Table A.1 of Appendix A), only precipitation in May, average temperature in spring and average temperature in July were significant in the model, and the magnitudes and directionalities varied.

The amount of precipitation in May was especially important for grain output according to the model. An increase in precipitation in May was significantly correlated with an increase in grain output value. Holding other factors constant, on average of a one millimeter increase in precipitation in May was associated with an average increase of 0.58 million yuan in grain output value in the same year (p-value = 0.003).

Temperature is also significantly correlated to grain output value. The average temperatures in both spring (March to May) and July were significantly correlated to the grain output values; however, the signs of associations were opposite. A one centigrade increase in average temperature in spring was associated with an average 15.77 million yuan gain in grain output (p-value = 0.023). Alternatively, a one centigrade increase in temperature in July was associated with an average 23.39 million yuan reduction in grain output (p-value < 0.001).

2.4.2.2 Adaptive activities

The number of special technical personnel was used as a proxy for the science and technology force in each county. As shown in Table 2.3, this variable was significantly positively related to the grain output value. On average and holding other factors constant, 1,000 more special technical personnel were associated with an average 7.13 million yuan increase in grain output value (p-value = 0.003).

Holding other factors constant, 1 more kilometer of highway per 100 square kilometers was associated with an average 0.60 million yuan increase in grain output value (p-value < 0.001). The county agriculture diversification factor was negatively correlated with the grain output value. As shown in Table 2.3, on average a 0.01 unit increase in the county agriculture diversification factor was associated with an average 2.84 million yuan decrease in grain output value, holding other factors constant (p-value <0.001).

2.4.2.3 Other findings

Inputs on agriculture, including the planted area of grain crops and application of synthetic fertilizers, were both significantly positively associated with the grain output value at the 5% level, as shown in Table 2.3. Livestock production factors, including the total number of large animals and total number of sheep, were both significantly associated with the grain output value at the 5% level.

2.5 Discussion and conclusion

2.5.1 Discussion

2.5.1.1 Climate's role in Inner Mongolia's grain output value

Among all the precipitation and temperature variables examined in the model, the significance, directionality, and magnitude of their impacts varied. Yet there were both precipitation and temperature variables that were significantly correlated with the annual grain output values.

Temperature in July was negatively correlated with the grain output value. This might be due to the dynamics of pests and plant diseases. Pests tend to be more active in warmer temperatures, increased soil moisture encourages the spread of certain pests, and plant diseases tend to spread faster under a combination of high temperatures and a humid environment (Rosenzweig et al., 2001). As July falls within the rainy season in Inner Mongolia, and grains are still within their growing season, higher temperatures favor the activities of pests and diffuse plant diseases which, in turn, have a negative impact on grain production. Chen et al. (2013) examined the impact of temperature on crop revenue in Inner Mongolia and found that summer (June to August) temperatures positively correlate with net crop revenue. However, there is not necessary a conflict between Chen et al. (2013) and the results of this research. In Chen et al. (2013), crops included grain crops, cash crops, and orchard crops; and crop revenue was different from crop output value. Temperature in spring is positively correlated with grain output. This result is similar to the results of certain other research, although such research covered a broader geographical range (the whole country); and in such research, winter temperatures also usually showed a positive correlation with crop revenue or agricultural revenue (Chen et al., 2013; Wang et al., 2009).

Precipitation in May was significantly positively associated with grain output. This might be due to the fact that in most parts of Inner Mongolia, May is the sowing season, and 73.1% of the planted area in Inner Mongolia is rain-fed (SBIM, 2011). Therefore, rainfall is crucial if seeds are to germinate and grow. Considering the growing water scarcity and increasing competition for water from urban and industrial usage in this region, precipitation will likely continue to play an important role in grain production in Inner Mongolia.

2.5.1.2 Adaptive options for increasing grain output value

The results of the analysis of road density and the positive role it plays in agricultural production resonate; yet these results differ slightly from some previous research results. Both Fan and Zhang (2008) and Fan and Chan-Kang (2008) found a significantly positive impact of low-grade roads on agricultural productivity, and no significant relationship between high-grade roads and agricultural productivity. However, the former was based on data from 1992, 1995, and 1999 in Uganda; the latter was based on data from 1982 to 1999 from the entire country of China. The research results presented in this chapter may shed light on the role of high-grade roads at a different stage of rural development. After all, compared with 1990, the agricultural gross output value of Inner Mongolia increased 9.54 fold in 2008, and the absolute value of the average income of rural residents increased 3.24 fold (SBIM, 2011). If in the 1990s, the contribution of roads to rural agricultural production was mainly in increasing access to agricultural inputs such as synthetic fertilizers, pesticides, and seeds, then after 2000, increasing agricultural products among different regions via highway also became an important function of roads that benefits agricultural production.

The regression model also indicates that an increase in the number of special technical personnel, an indicator of a country's general strength in technology, is positively associated with the country's grain output value. Special technical personnel do not directly participate in agricultural production; however, they contribute to agricultural production through infrastructure enhancement, agricultural extensions, agricultural research, medical care, and education.

As discussed in Section 2.2, diversification of the agricultural industry is considered to be an important approach to securing agricultural production. However, the regression results of this study show that an increase in the diversification of the agricultural industry is not necessarily linked to an increase in the grain output value. Just the opposite, in the estimated regression model, the agricultural diversification index was negatively correlated to the yearly grain output value. As farming and livestock production are the most important sectors of the economy of Inner Mongolia, a major increase in the value of the diversification factor is very likely to come from an increased output value of other agriculture sectors such as forestry and fishery. The regression results indicate that the growth of such sectors does not favor the growth of grain production. This might be due to competition for land, water, and fertilizers from other sectors of agriculture. The model also indicates that during the research period, the number of large animals and sheep both positively correlated with the grain output values. This might be because the manure of such animals can be used as fertilizer for grain crops; such animals are also consumers of grains or the side-products of grains (such as stalk and straw). An explanation of the relationships among the different sectors of agricultural production in Inner Mongolia will require further research with more detailed and comprehensive data.

2.5.1.3 Limitation and recommendations for future research

Due to the limitations of the data set, some variables in this analysis lacked in detail; thus, the results of the analysis might be biased. For example, while most of the other variables were obtained at the county level, both monthly temperature and precipitation were at the city level. However, due to resource limitations, most research in the literature examining climate's impact on agriculture in China also used temperature and precipitation data from selected meteorological stations (for example, Chen et al., 2013; Wang et al., 2009); and in such research different observations that were geologically close had to share precipitation and temperature data. What is more, this research is the first to incorporate data from all grain-producing counties in Inner Mongolia from 2000 to 2008. Yet there is no doubt that research with more comprehensive data and data of greater detail, especially data with county-level precipitation information, county-level college graduates (with information on both the number of graduates and their majors), and more detailed information on technical assistance, will complement and enhance the results presented in this chapter.

In addition, as Inner Mongolia's agriculture is composed of several sectors besides grain production, research on the relationships between these climatic, social, and economic factors and the output of other agricultural sectors, and research on the relationships between grain production and other agricultural sectors will complement the research presented in this chapter, offering a holistic picture of agricultural development facing climate change and adaptations in this region.

2.5.2 Conclusion

Food security is of great importance to China in the 21st century. Inner Mongolia, as one of the main grain-producing areas in China, is challenged by changing climate in grain production. In order to secure grain output in Inner Mongolia, it is necessary to evaluate the precise impacts of climate factors on grain production, as well as the effectiveness of related adaptive activities.

In order to examine such relationships, a regression model with county-level panel data in Inner Mongolia from 2000 to 2008 was developed. The model indicated that average temperature in spring, precipitation in May, highway density, and number of special technical personnel were significantly positively associated with grain output value; while average temperature in July and diversification of agriculture were significantly negatively associated with grain output value in Inner Mongolia.

Historical records has shown that Inner Mongolia has been getting warmer and drier in the last half century (Lu et al., 2009). It has also been predicted that this trend will continue (UNFCCC, 2007). Although warmer temperatures in spring benefit grain production, warmer temperatures in July are likely associated with more pest activities and crop diseases. Facing increasing temperatures, investment and research in disease and pest control should be among the priorities of local adaptation strategies.

Higher temperature in general is linked to more water demand (Fischer et al., 2002; Liu, 2002). Yet it has been predicted that in the future Inner Mongolia is getting less precipitation. Considering that 73.1% of grain crops in this area are rain-fed (SBIM, 2011), irrigation infrastructure construction, adoption of water-saving technologies, and introduction of proper drought-resist grain varieties will be in urgent need.

The results of this analysis indicate the positive association between the number of special technical personnel and grain output value. To better meet the challenge of climate change, strengthening this team will be among the key actions. Without a stronger technical personnel team, especially those in agricultural research, agricultural infrastructure building, and agricultural extension, it will be impossible to implement the adaptation strategies mentioned above.

CHAPTER III

THE IMPACTS OF TEMPERATURE, PRECIPITATION, AND ADAPTIVE ACTIVITIES ON LIVESTOCK OUTPUT VALUE IN INNER MONGOLIA, CHINA

3.1 Introduction

3.1.1 Surging demands for meat in China

According to NBSC (2014a), China's livestock outputs, especially the outputs of pork, mutton, and beef, have increased by 4.71, 9.02, and 24.65 fold, respectively, from 1980 to 2012 (Figure 3.1). In 2012, China's total meat output reached 64.06 million tons, of which 83.40% was pork, 6.26% mutton, and 10.34% beef.

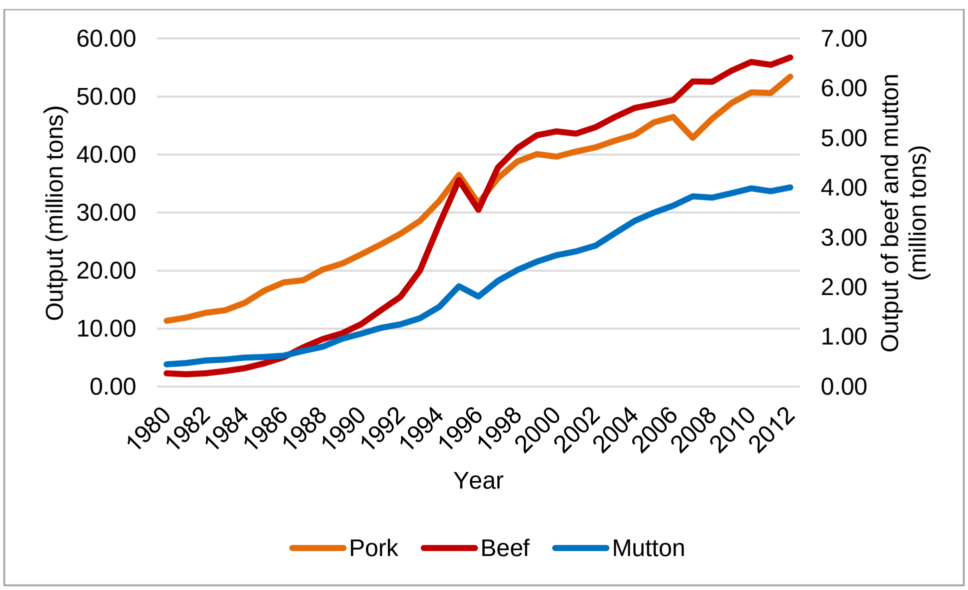

Figure 3. 1 China's national outputs of pork, beef, and mutton from 1980 to 2012

This increase in domestic production is driven, at least partially, by an increase in demand and consumption. Huang (2010) pointed out that currently China's domestic consumption of grain, meat, and vegetable was in the transition from a traditional ratio of 8:1:1 (grain: meat: vegetable) towards a new ratio of 4:3:3. Another factor that affects meat demand is the increase of the Chinese population, which increased from 0.91 billion in 1974 to 1.35 billion in 2012 (NBSC, 2014a). As a result, China's national total meat consumption increased from 7.3 metric tons in 1974 to 71.0 metric tons in 2012, a nearly 10 fold change; in 2012, China's total meat consumption was more than twice that of the United States (Larsen, 2012).

A comparison of the production and consumption data (Larsen, 2012; NBSC, 2014a) shows that there is a huge gap between China's domestic meat supply and its consumption. For example, in 2012 the gap was approximately 7 million metric tons.

Such a shortage in domestic meat supply has led to a substantial increase in meat imports. According to the Ministry of Commerce of China (MOFCOM, 2013), in 2012 China spent 31.51 billion U.S. dollars on animal meat imports, a 24.2% increase since 2011. The amounts of the three major meat products imported from the three largest exporters in 2012, the percentage changes compared with 2011, and major exporters, based on data released by MOFCOM (2013) are displayed in Table 3.1. The total amount of pork, beef, mutton, and their byproducts imported in 2012 was approximately 1.5 million tons, an increase in all three imports as compared to 2011.

Table 3. 1 China's meat products imports from major markets in 2012

Meat product type	Amount (kilotons)	% change from 2011	First 3 largest import markets
Pork and byproducts	1358.20	+ 0.6%	United States, Denmark, Germany
Beef and byproducts	70.47	+ 164%	Australia, Uruguay, Brazil
Mutton and byproducts	126.74	+ 49%	New Zealand, Australia, Uruguay

The gap between supply and demand has also led to a surge in meat prices. The changes in real prices of major animal products from 2005 to 2014, based on data released by the Ministry of Agriculture of China (MOA, 2005-2014), and related consumer price indices (NBSC, 2014a), are graphed in Figure 3.2. Included in the figure prices from 2005 to 2013 are real prices of related years compared with year 2005; all prices were from January. Prices in 2014 were the prices in the first week of January 2014. Compared to 2005, the real price of pork increased 1.36 times, beef 2.82 times, and mutton 2.95 times.

Increased production, imports, and prices of meat in China indicate the increasing demands for such products in China. Meeting such demands will not only rely on meat imports, but also on an increase in domestic livestock production. In this chapter, insights into the relationships among climate, socio-economic factors, and livestock output values are provided.

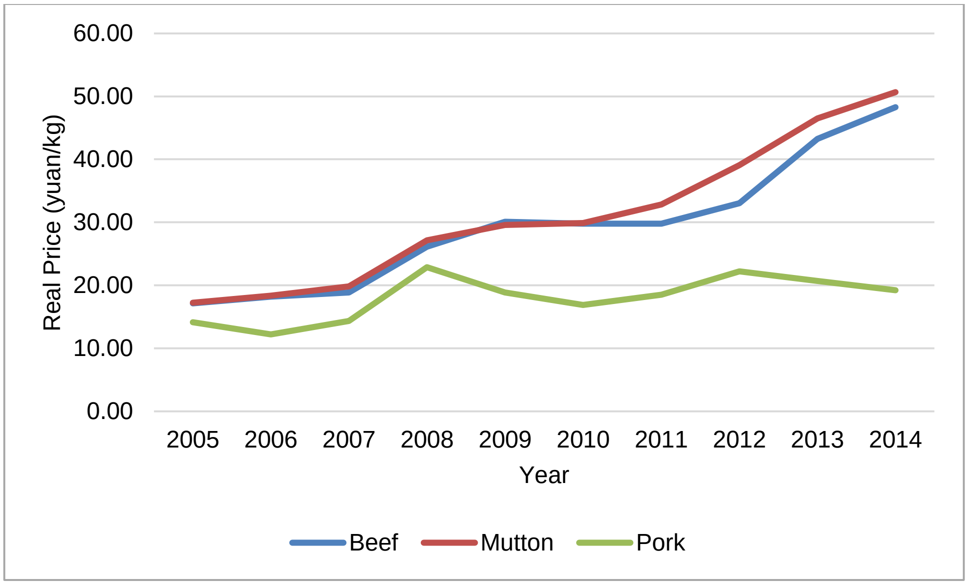

Figure 3. 2 China's real beef, mutton and pork prices from 2005 to 2014

3.1.2 Inner Mongolia as a major livestock production region facing challenges

Inner Mongolia is one of the major livestock producers and suppliers in China. It is the largest province-level mutton, milk, wool, and cashmere producer, and the fourth largest beef producer in China. In 2011, Inner Mongolia produced 22.35% of the nation's mutton, more than a quarter of the nation's milk, wool, and cashmere, and 7.61% of beef: in total, 1.39 million kilograms of meat. Although Inner Mongolia's pork production only accounted for 1.42% of the national production, in 2010 the area produced 0.72 million kilograms of pork (NSB, 2011). Ensuring livestock production in Inner Mongolia is of great importance if the increasing national demands are to be met.

The livestock industry is also an important segment of Inner Mongolia's system of agriculture and rural livelihood. With more than 73% of its total land area used as rangeland, 96 out of 101 counties or county-level administrative units in Inner Mongolia have livestock production; in 2010, animal husbandry contributed to 44.6% of the total gross output of the agricultural industry in the region (SBIM, 2011).

In the last six decades, to keep up with the increasing demand for livestock products, the total amount of livestock in Inner Mongolia increased more than 11 times. However, the area of cultivated land increased only 1.8 times, as shown in Table 3.2 (SBIM, 2008; SBIM, 2011). Not surprisingly, such an imbalance has caused problems such as land degradation and desertification (Jiang, 2006; Longworth & Williamson, 1993; Su et al., 2005), and is suspected of having led to an increased albedo and change in wind regimes (Sheng et al., 2000).

Table 3. 2 Cultivated area and livestock changes from 1947 to 2010 in Inner Mongolia

Year	Cultivated area (10k)	Total Livestock (10k)	Large animals (10k)	Sheep and goats (10k)	Pigs (10k)
1947	3967	931.9	271	570.8	90.1
2010	7149	10798.5	1140.1	8408	1250.5
2010/1997	1.80	11.59	4.21	14.73	13.88

As discussed in section 1.1.3, Inner Mongolia is undergoing critical shifts in its climate conditions (Angerer et al., 2008; Li, and Pan, 2012; Zhao & Running, 2010). In addition, the existing land degradation and climate changes tend to have a co-evolving direction that does not favor agricultural production (Adeel, Safriel, Niemeijer, & White, 2005; Boko et al., 2007; Hulme, 1996; Holmgren et al., 2006; MEA, 2005; Sheng et al., 2000). Facing challenges from climate change and land degradation, in order to ensure livestock products supply, it is necessary to identify the impacts of climate change, and identify proper adaptation from human society; this process of identification is the objective of this chapter.

In this chapter, the existing literature on the climate's impacts on livestock production is reviewed. Then a regression model is developed using a set of panel data covering all of the livestock production counties in Inner Mongolia from 2000 to 2008, in order to assess the relationships among livestock output values and the climatic and adaptive activities examined in Chapter II.

3.2 Literature review

As discussed in Chapter I, there are two factors that affect agricultural production, referred to here as the climate system and the human system. In this section the relationships between the climate system and livestock production is reviewed as it is analyzed in the current literature. Since the literature on agricultural production and education, highway density, science and technology, and diversification was reviewed in Chapter II, and there is little current literature specifically in terms of livestock production, a similar literature review will not appear in this chapter. For a similar reason, the modeling methods of the associations between livestock output value and temperature, precipitation, the general strength of the current level of science and technology (measured by the total number of special technical personnel), higher education (measured by the number of college graduate), road density (measured by the length of highways per 100 square kilometers), and diversification of agricultural production, are also omitted. Please refer to Chapter II for information on such issues.

3.2.1 Climate impacts on livestock production

The livestock industry both impacts and is impacted by climate change. There is expert consensus that livestock production is among the major anthropogenic activities that contribute to global warming (Herrero et al., 2011). It was argued that about 18% of the anthropogenic global greenhouse gas emissions could be attributed, directly or indirectly, to the world's livestock production; such greenhouse gases include carbon dioxide, methane, nitrous oxides, and ammonia that are generated from livestock manure, during livestock feed production, enteric fermentation, as well as livestock product processing and transportation (Steinfeld et al., 2007).

Concurrently, climate change also has imposed severe challenges on the global livestock industry, both directly and indirectly. A drought followed by a harsh winter in 2000 caused a widespread reduction in the livestock population in Inner Mongolia. A study on livestock production in northeastern Colorado revealed that over the long term, livestock production decreases when there is an increase in air temperature and a decrease in forage quality (Hanson, Baker, & Bourdon, 1993). In Kenya, it was predicted that the livestock sector would suffer from heavy losses due to climate change (mainly from increased precipitation), which would in turn lead to an increase in poverty and overall loss of livelihood (Kabubo-Mariara, 2009).

The impacts of climate change on livestock production vary from place to place, as the responses to climate change from livestock and grassland ecosystems are very complex (Thornton, van de Steeg, Notenbaert, & Herrero, 2009). Xiao, Ojima, Parton, Chen, and Chen (1995) found that Inner Mongolia grasslands were extremely sensitive to changes in temperature and precipitation. Li and Pan (2012) also found, based on existing meteorological data, the transition zone of pasture and farming ecotones in Inner Mongolia expanded by approximately 360 square kilometers in the last 50 years. This change could provide favorable conditions for livestock because it might generate more grassland areas. However, as the farming-pastoral transition region is prone to land desertification; if no protection measures are implemented it will be difficult to predict the future environment and whether this environment will be advantageous for livestock (Li & Zhou, 2001; Qiu, Zhao, & Wang, 2001).

There has been little research assessing the directionality and magnitude of temperature and precipitation's impacts on livestock production in Inner Mongolia. Without such assessments, it is difficult to make predictions with confidence, and thus prepare countermeasures to prevent possible losses or take advantage of any opportunities presented by climate change.

3.3 Research hypotheses and method

3.3.1 Research hypotheses

The following research hypotheses were tested:

1) Temperature is significantly correlated to the annual livestock output values of Inner Mongolian counties;

2) Precipitation is significantly correlated to the annual livestock output values of Inner Mongolian counties;

3) The number of special technical personnel is positively correlated to the annual livestock output values of Inner Mongolian counties;

4) Highway density (the length of highway per 100 square kilometers) is positively correlated to the annual grain output values of Inner Mongolian counties;

5) The annual total number of college graduates in the municipal area is positively correlated with the annual grain output values of Inner Mongolian counties; and

6) Diversification in the agricultural sector is positively correlated to the annual grain output values of Inner Mongolian counties.

3.3.2 Research method

3.3.2.1 Unit of analysis, time, and scope

The unit of analysis used in this research was the county or an equivalent administrational unit, as defined in the Chinese administrative system. This analysis was based on panel data representing those counties with livestock production in Inner Mongolia over the time period beginning in 2000 and ending in 2008.

3.3.2.2 Modeling

A multiple regression model was used to examine the significance, signs, and magnitude of relations between livestock output values and the explanatory variables, as specified in the above hypotheses. The model takes the following form:

$$Y_{it} = \alpha_i + \gamma_t + \beta X_{it} + \varepsilon_{it}$$

where

$i = 1, 2, \ldots, n$ (the number of counties with livestock production);

$t=1, 2, \ldots, 9$ (from year 2000=1 to 2008=9);

Y_{it} is the livestock output value of county i in year t;

α is the county effect,

γ is the time effect,

β is a 1xk vector of the coefficients;

X is a kx1 vector of the explanatory variables, including monthly, seasonal and annual average temperature; monthly, seasonal, and annual precipitation; major soil type; yield of grain crops; length of highway per 100 square kilometers; diversification index; number of special technical personnel; the annual total number of college graduates in the municipal area; the amount of synthetic fertilizers consumed; number of agricultural workers; number of different livestock species; the headcount of each livestock species; and ε is the error term.

3.3.2.3 Data sources

The sources for the data used in this analysis included the Inner Mongolia Statistical Yearbook (SBIM, 2001-2009), FAO world soil map (FAO, 2009b), China GIS map (ACMR, 2012), China Yearbook of Agricultural Price Survey (NBSC, 2007-2009), and public reports from the National Bureau of Statistics of China.

Data collected from the Inner Mongolia Statistical Yearbook were from three levels: the county-level data included the number of large animals at year end, number of sheep and goats at year end, number of pigs at year end, outputs of the different agricultural products (including grain, beetroots, oil-bearing crops, different livestock meats and wool), population, number of laborers in rural area, number of labors in the agricultural sector, land area, planted area of grain crops, length of highway per 100 square kilometers of land area, and number of special technical personnel. The city-level data included monthly average temperature, monthly precipitation, total number of college graduates for the current year, and output values of the different agricultural sectors. The provincial-level data included the Consumer Price Index (CPI) and price indices of different agricultural products.

Price information on wheat, rapeseed oil, pork, beef, and mutton is collected through the China Yearbook of Agricultural Price Survey (NBSC, 2007-2009) and public reports published on the website of the National Bureau of Statistics of China. The county-level soil map data were generated by combining the FAO world soil map (FAO, 2009b) and the China GIS map (ACMR, 2012).

3.3.2.4 Data treatment and model estimation

The livestock output value of each county is the sum of the output values of beef, pork, mutton, and wool. The prices of these products were converted to the 2000 values by using the nominal animal products prices of that year and related consumer indices. Please refer to Section 2.3.2.4 for calculation details.

The calculation of the diversification factor and identification of the major soil types are the same as they were in Chapter II. The model estimation process is also the same as the process described in Chapter II.

3.4 Results

3.4.1 General descriptive statistics

From 2000 to 2008, 96 counties (864 observations) raised livestock in Inner Mongolia, accounting for 95.05% of the 101 county-level administrative units. During this period, Inner Mongolia's total livestock output value increased 2.9 fold, from 12.8

billion yuans ($2.05 billion) in 2000 to 36.89 billion yuans ($5.91 billion) in 2008. The livestock output values of each county during each year and the average output values of each county across all nine years are plotted in Figure 3.3.

In Figure 3.3, each number on the x-axis represents an individual county, above which there are nine green circles displayed in a column, representing the nine annual livestock output values of that county from 2000 to 2008. There is also an orange diamond in each column, representing the mean annual livestock output value of this county across the nine years. As shown in the figure, the mean livestock output values fluctuate from county to county, and the livestock output values fluctuate from year to year.

The livestock output value of each county for each year and the yearly means of all the 96 counties are plotted in Figure 3.4. In the figure, each number on the x-axis represent a year, above which there are 96 green circles displayed in a column, representing the annual livestock output values of the 96 counties in that year.

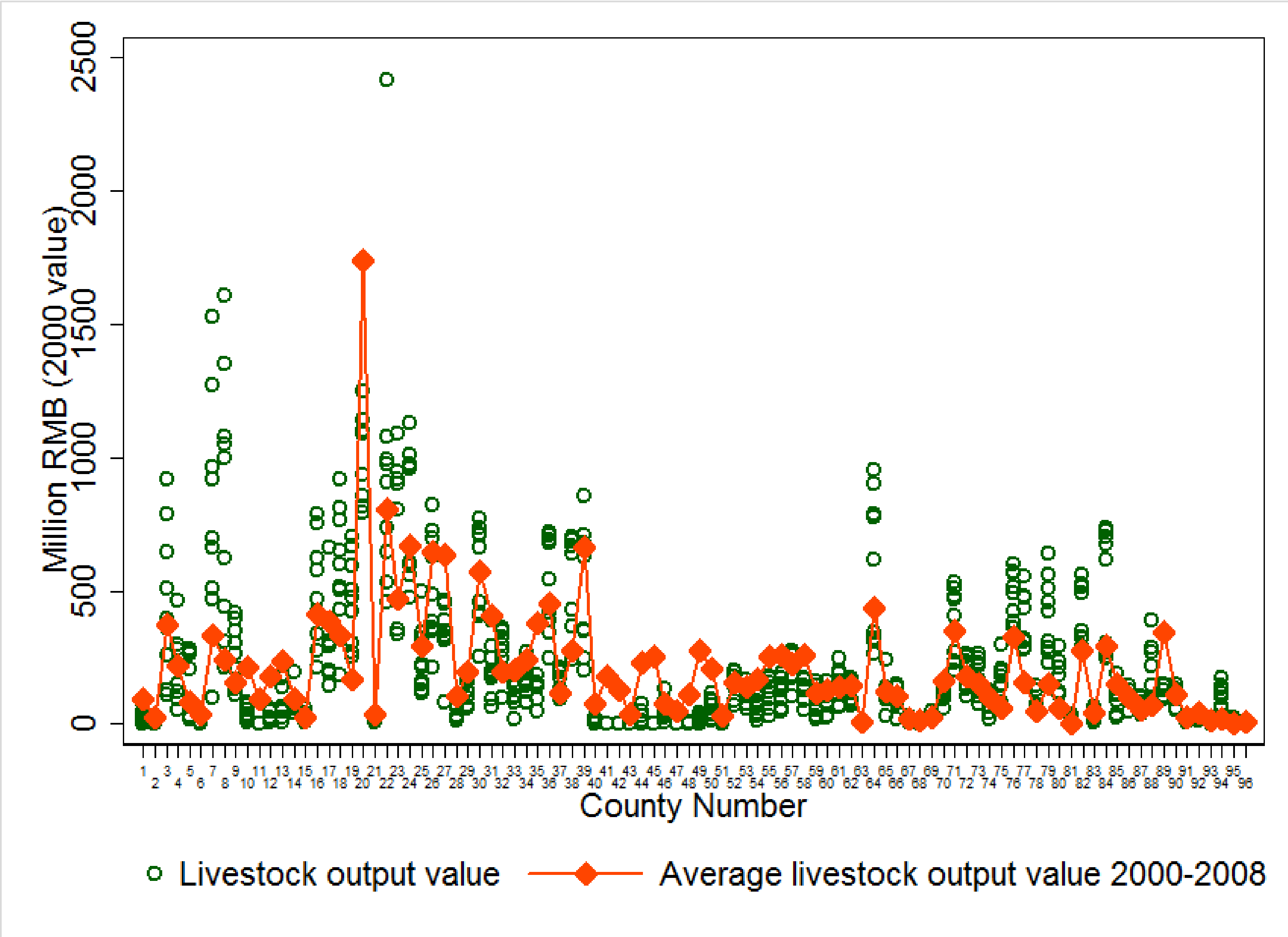

Figure 3.3 Livestock output values for all counties

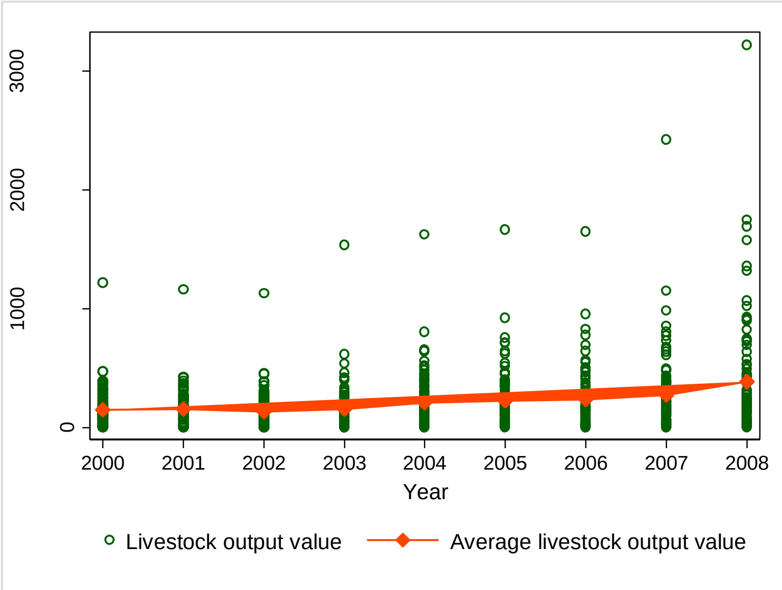

Figure 3.4 Livestock output values for counties in Inner Mongolia in different years

The livestock output values of each county for each year and the yearly means of all the 96 counties are plotted in Figure 3.4. The ANOVA with repeated measures indicated that the mean output values were significantly different across the years (using the Greenhouse-Geisser method) at the 1% level, due to: 1) F value = 38.806, df = 1.398, p-value < 0.001, 2) effect size = 0.29 (large), and 3) observed power = 1.000 (high). A trend analysis indicated a significant increasing linear trend in the output value over the years, due to: 1) F value = 47.262, df = 1, p-value < 0.001, 2) effect size = 0.332 (medium), 3) observed power = 1.000 (high), and 4) the linear trend accounts for 80.71% of the sum of the squares in the factor. The details of the trend analysis are presented in Figure A.2 and Table A.4 of Appendix A.

The minimum values, maximum values, means, and standard deviations of 1) all 854 observations, 2) the county means, and 3) the yearly means of all the counties are displayed in Table 3.3 in million yuan (1 yuan = 0.16 U.S. dollar).

Table 3. 3 Livestock output values of 96 Inner Mongolian counties 2000-2008 (million yuans)

	Minimum	Maximum	Mean	Standard deviation
All observations	1.12	3221.55	213.31	268.75
Individual mean	2.13	1737.27	213.31	229.86
Yearly mean	133.37	384.32	213.31	74.99

The unit of measurement and the means are given in Table 3.4, where large animals included cattle, horses, donkeys, mules, and camels. Due to the large number of variables related to temperature, precipitation, and soil type, the variables are not presented in this table. However, a description of these variables can be found in Table A.2 of Appendix A.

3.4.2 Regression model results

The results of the final regression model are given in Table 3.5. The model's chi-square test is significant at the 1% level (p-value <0.0001), and the R^2 value is 0.8388. All the independent variables' VIFs are smaller than 3.0. The model is, in general, a good fit.

Table 3. 4 Descriptive statistics of explanatory variables in the livestock model

Variable name	Unit of measurement	Mean	Standard deviation
No. of large animals	1,000 head	73.26	71.39
No. of sheep	1,000 head	488.53	471.92
No. of pigs	1,000 head	71.79	101.51
No. of agricultural workers	1,000 persons	56,16	45.37
Consumption of synthetic fertilizers	1,000 tons	11.53	15.35
Sown area of grain crops	1,000 hectares	48.51	57.92
Annual number of graduates in the municipal area (per 1,000 people)	person	17.67	38.93
No. of special technical personnel	1,000 persons	4.23	3.84
Highway density	km/100 km2	18.13	19.15
Grain output value	million yuans	205.74	269.83
100*county diversification factor	Index	53.33	9.77

Due to the large number of variables related to time periods, groups, and soil types, the results of these variables are not presented in the table. However, the following null hypotheses were rejected by the chi-square tests at the 1% significance level (p-value <0.0001): 1) all years coefficients were jointly equal to zero (p-value < 0.0001), 2) all countries' coefficients were jointly equal to zero (p-value < 0.0001), and 3) all soil types' coefficients were jointly equal to zero (p-value = 0.049).

Table 3.5 The estimated regression model describing the relationships between livestock output value (in million yuans) and the explanatory variables

Explanatory variable	Coefficient	Standard error	p-value
No. of large animals (k)	1.3530	0.4103	0.001
No. of pigs (k)	1.4446	0.3664	0.000
Consumption of synthetic fertilizers (k ton)	3.4839	1.0630	0.001
Annual number of graduates in the municipal area (per 1,000 people)	-0.6473	0.1334	0.000
Minimum monthly precipitation of May, June and July (mm)	0.6220	0.2581	0.016
Average temperature of the year (oC)	33.4404	1.0630	0.012
R2: 0.8388 Wald $chi^2(18) = 423.92$ Prob > $chi^2 = 0.0000$			

Based on the regression results, the following variables were all significantly correlated with the grain output values in Inner Mongolia at the 5% level: minimum monthly precipitation in May, June and July, average annual temperature, number of college graduates, number of large animals, number of pigs, and consumption of synthetic fertilizers. The following sections summarize the key results.

3.4.2.1 Climate factors and livestock output values

Both precipitation and temperature were significantly associated with the annual livestock output values of the 96 counties across the nine year period of this analysis. However, only certain periods' precipitation and average temperature were significant in the model.

According to the model, the minimum monthly precipitation of May, June and July was significantly positively associated with the livestock output values. On average, holding other factors constant, a one millimeter increase in the minimum precipitation of

May, June and July associated with an average 0.62 million yuan gain in livestock output value (p-value = 0.016)

The average annual temperature was also significantly positively associated with the livestock output value. On average, holding all other factors constant, a one centigrade gain in the average annual temperature associated with an average 33.44 million yuan gain in the livestock output value (p-value = 0.012).

3.4.2.2 Adaptive activities

The number of graduates from institutions of higher education in the municipal area was negatively correlated with the annual livestock output level. Holding all the other factors constant, if the number of college graduates in the municipal region increased by 1,000 people, the livestock output value decreased by an average 0.65 million yuan, accordingly.

3.4.2.3 Other findings

Consumption of synthetic fertilizers, the number of large animals (including cattle, horses, camels, mules, and donkeys), and the number of pigs were all significantly positively associated with the livestock output value. No significant correlation was found between the number of sheep and the annual livestock output value.

3.5 Discussion and conclusion

3.5.1 Discussion

3.5.1.1 Discussion of the model

A SEM was run among counties with both grain and livestock production in Inner Mongolia in order to compare the results with the regression results outlined in

Chapters II and III. In the SEM, the endogenous variables were grain output value and livestock output value, and the exogenous variables were the same as those used in Chapters II and III.

There were 92 counties that had both grain and livestock production from 2000 to 2008. This accounts for 91.09% of all 101 county-level administrative units in Inner Mongolia. The regression results are displayed in Table 3.6.

As shown in Table 3.6, the chi-square tests for both the grain equation and the livestock equation in the SEM are significant at the 1% level, with both the p-values smaller than 0.0001. Comparing these results with both regression models in Chapters II and III, it can be seen that all the significant variables are the same, all the signs of association are the same, and the magnitudes of association are very close.

3.5.1.2 Climate's role in livestock output values in Inner Mongolia

The average annual temperature was significantly positively correlated with the livestock output value. This can be explained, at least partially, by the spread of C4 plants in Inner Mongolia. Wittmer, Auerswald, Bai, Schaeufele, and Schnyder (2010) observed a northwards spread of C4 plants in Inner Mongolia triggered by increasing temperatures. As C4 plants are more adapted to higher temperatures and are more efficient in carbon fixation, a higher temperature contributes to the abundance of forage production.

Table 3.6 Simultaneous equations model (SEM)

	Coefficient	Standard error	p-value
Grain output value (million yuans)			
Planted area of grain crops (k hectares)	3.7091	0.2604	0.000
Use of synthetic fertilizers (k tons)	3.2297	0.4797	0.000
Precipitation in May (mm)	0.5870	0.1531	0.000
Average temperature in Spring (March to May, °C)	15.1065	5.0404	0.003
Average temperature in July (°C)	-26.0283	4.1228	0.000
No. of special technical personnel (k)	7.1881	2.7161	0.008
Highway density (km/100^2kms)	0.5976	0.2680	0.026
100*County diversification factor	-2.8638	0.5065	0.000
No. of large animals (k)	1.2155	0.1565	0.000
No. of sheep (k)	0.1082	0.0172	0.000
Livestock output value (million yuans)			
No. of large animals (k)	1.6756	0.1866	0.000
No. of pigs (k)	1.4417	0.1081	0.000
Consumption of synthetic fertilizers (k ton)	2.9058	0.5615	0.000
No. of graduates in the municipal area (k)	-0.5362	0.1751	0.002
Minimum monthly precipitation of May, June and July (mm)	0.7280	0.2541	0.004
Average temperature of the year (°C)	35.3685	8.9501	0.008

Grain equation: "R^2" = 0.9282 Chi^2 = 10024.87 P> Chi^2 < 0.0001

Livestock equation: "R^2" = 0.8972 Chi^2 = 6760.87 P> Chi^2 < 0.0001

The minimum monthly precipitation from May to July was positively correlated with the annual livestock output value. This is probably due to the fact that while, in general, the grassland growing season in Inner Mongolia is from April to September, some counties might have shorter growing seasons (for example, the counties in higher latitudes). But all of the counties are generally in their growing seasons from May to July. The minimum monthly precipitation from May to July from 2000 to 2008 had a median of 16mm, with more than 10% of the values smaller than 2.5mm. The positive association between livestock output value and minimum precipitation from May to July seems like a reflection of the association between livestock output value and drought. Yet, research supported with more detailed data on drought is needed to validate this relationship.

3.5.1.3 Adaptive options for increasing the livestock output value

The number of college graduates in the municipal area is negatively correlated with the annual livestock output value. However, to assure the directionality and magnitude of this association, more precise data are needed because 1) only a small portion of the college graduates had majored in the agriculture sciences, agricultural business, or related fields; and 2) college students tend to stay and work in urban areas after graduation.

With regards to technical assistance, no significant association was found between the number of special technical personnel and the annual livestock output value. However, this does not necessarily lead to the conclusion that the general science and technology level does not have a positive association with production in the livestock industry. Possible reasons for this conclusion include 1) the mismatch of current technology and livestock production, 2) a lack of efficiency in the extension of agriculture, and 3) livestock producers are less likely to respond to technology than grain producers in Inner Mongolia. In addition, the composition of technical personnel, especially how many are livestock experts, is not available in the data. Data of a "higher resolution" are needed to further explore this relationship.

3.5.1.4 Limitation and recommendations for future research

The lack of detail in some variables in this analysis might have affected the precision of this analysis. Thus, further research with more comprehensive and detailed data, especially data with county-level precipitation information, county-level college graduates (with information on both the number of graduates and their majors), and more detailed information on technical assistance, is needed to increase the precision of this analysis. More data on droughts, floods, solar radiation, and more specific data on livestock (including the number and age distribution of each livestock type) and livestock products (including milk products) are also needed to enhance the results of this analysis. In addition, research on the direct impacts of climate change and adaptive activities on grass production and animal growth is needed to shed light on the path how climate and adaptations finally affect livestock output.

3.5.2 Conclusion

China's demand for meat has been sharply increasing in the last few decades, reflecting a gap between supply and demand. As one of the most important livestock production regions in China, Inner Mongolia served a crucial role in providing the Chinese with abundant beef, mutton and pork. Under challenges from looming climate change, in order to ensure livestock production, it is necessary to evaluate the potential impacts of climate factors on livestock outputs, as well as the effectiveness of related adaptive activities.

In order to examine such relationships, a regression model was developed using county-level panel data relating to Inner Mongolia from 2000 to 2008. The average annual temperature, minimum precipitation in May were found to be significantly positively correlated with livestock output value; the number of college graduates in the municipal area was found to be significantly negatively associated with livestock output value; and no significant associations were found between livestock output value and the number of special technical personnel, high way density, and agricultural diversification index.

Based on the prediction that Inner Mongolia will get warmer and drier (UNFCCC, 2007), the changing climate will both provide opportunities and raise challenges to livestock production in this area. According to the results of this analysis, a warmer climate is in general associated with greater livestock output values while a drier climate is unfavorable for local livestock output. To meet the challenge of drier climate, irrigation infrastructure construction, adoption of water saving technologies, and possible shift in livestock feed (for example, decreasing the portion of grass feed and increasing the portion of grain feed) should be among the top strategies.

Meanwhile, an improvement in both the quality and quantity of technical personnel in livestock production will be needed. In this analysis, no significant association was found between the number of special technical personnel and livestock output value. However, this cannot lead to the conclusion that special technical personnel cannot make positive contribution to livestock production. On the contrary, it could be interpreted as the current technical personnel team is not effective as they are supposed to be. In addition, none of the adoption of the strategies mentioned above could take place without the facilitation of effective technical personnel, especially extension agents who could effectively persuade livestock raisers to change their livestock raising practices.

CHAPTER IV

THE IMPACTS OF ENVIRONMENTAL, SOCIAL, AND ECONOMIC FACTORS ON RURAL HOUSEHOLD INCOME IN XILN GOL, INNER MONGOLIA

4.1 Introduction

In Chapters II and III, the impacts of precipitation, temperature, and adaptive activities on the grain and livestock output values of Inner Mongolia was discussed. The focus of this chapter is how rural households in this area ensure their income under the current circumstances, especially when facing land degradation, conservation, and opportunities/challenges coming with urbanization.

4.1.1 Diverse rural livelihoods in China

Today, livelihoods in rural China involve much more than subsistence agriculture. The development of Township and Village Enterprises (TVEs) and the rapid urbanization process both provide rural residents with various nonfarm opportunities to enhance their livelihoods.

In the late 1970s and early 1980s, the so-called TVEs already started booming in rural China. Through TVEs, rural residents actively involved themselves in agricultural processing, machinery production (usually through subcontracts from urban factories) and labor-intensive manufacturing targeting both domestic and foreign markets. TVEs have been credited with greatly boosting the rural economy (Naughton, 2007) and providing a significant number of nonfarm jobs for rural dwellers (150 million jobs were provided in 2007, according to the NBSC, 2008).

Today China supports 497 million more urban dwellers than it did 30 years ago (NBSC, 2014a). Such a grand scale of urbanization and booming urban economy have also provided more job opportunities for the rural population, either in nearby townships or in cities far away. In 2012, there were more than 260 million rural workers, or 40% of the overall rural population, working in urban China in manufacture, construction, transportation, resale, accommodation, catering, and other services industries; 62% (more than 160 million) of these people worked outside of their respective hometowns (NBSC, 2013b).

Besides employment in TVEs and urban areas, a rising percentage of rural workforce has been engaged in self-employment, in forms such as transportation, trade, and small enterprises (Mohapatra, Rozelle, & Goodhue, 2007). The results of a household survey in six typical Chinese provinces indicated that, from 1981 to 1995, the portion of self-employed rural workforce increased by 4 times from 4% to 16% (Mohapatra et al., 2007). In the same provinces, the percentage increased to about 20% in 2008 (Wang, Huang, Zhang, & Rozelle, 2011). Some migrant workers, after returning to their rural hometown, also started their own business and contributed to the revitalization of rural economy (Démurger & Xu, 2011).

Therefore, rural China currently has a diverse income portfolio. Based on the statistics provided by NBSC (2014a), in 2012, the contribution of agriculture to rural household net per capita income was only 27% while the contribution of wage/salary and household non-agricultural business was more than 60%, as depicted in Figure 4.1.

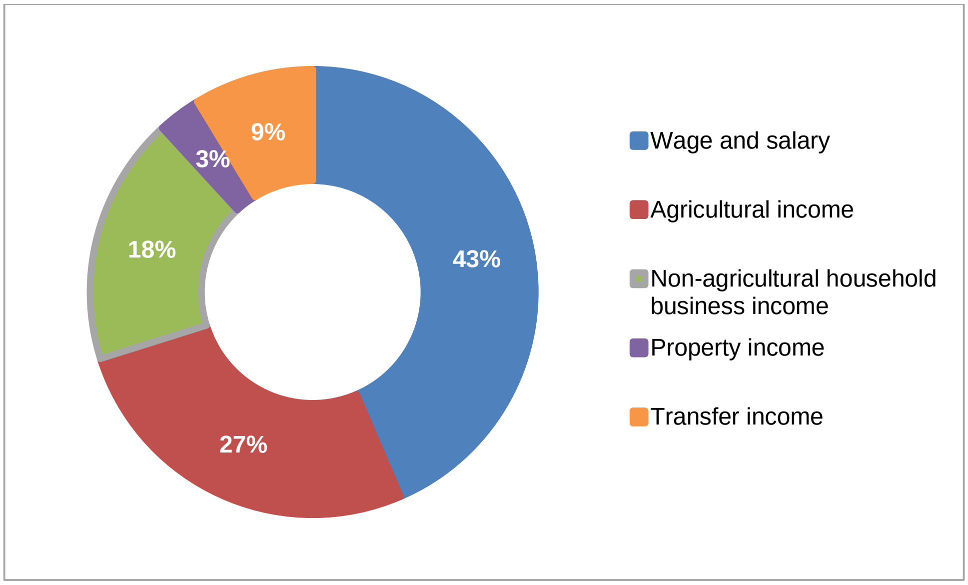

Figure 4. 1 China's rural household net per capita income composition in 2012
Source: NBSC, 2014a

4.1.2 Opportunities and challenges facing dryland Inner Mongolia

The rural development environment in Inner Mongolia both follows the national trend in rural-to-urban migration, TVEs and self-employment, and has its own characteristics as a remote dryland area. Compared with the national average, Inner Mongolia has a higher level of urbanization rate but a lower level of rural income diversification into non-agricultural activities.

Like many regions in China, Inner Mongolia is undergoing rapid urbanization. From 1990 to 2012, the percentage of urban population in Inner Mongolia increased from 36% to 58%, an increase of 6.56 million urban people. At the same time, the number of rural residents decreased from 13.81 million to 10.52 million (NBSC, 2014a).

In 2006, only 8.4% of the total rural labor in Inner Mongolia (0.75 million) worked in urban areas; among these people, only 29.32% worked in other provinces (SBIM, 2008b). As displayed in Figure 4.2, Inner Mongolia's rural income portfolio was quite different from the national average in the sense that agricultural income accounted for 75% of the total annual income.

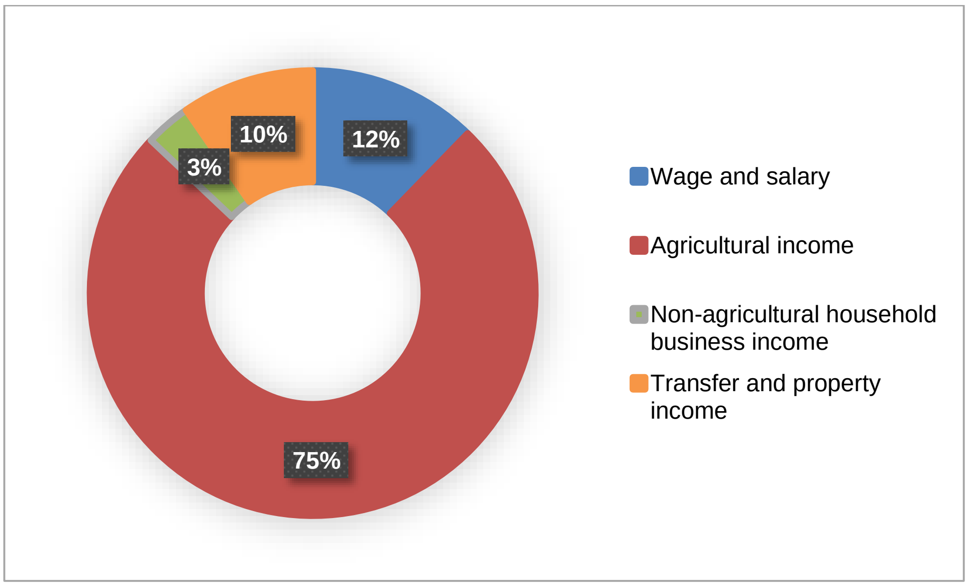

Figure 4.2 Composition of gross per-capita income of rural households in Inner Mongolia 2012
Source: NBSC, 2014a

While agriculture is responsible for a large portion of rural household income, agricultural production in Inner Mongolia has been critically challenged by land degradation. As discussed in Section 1.1.3, most of Inner Mongolia is categorized as type 2 and type 4 drylands, characterized by severe land degradation (Sietz et al., 2011).

In the past few decades, the harsh land condition was further degenerated by anthropogenic activities, such as over grazing (Su et al., 2005; Yu, Ellis, & Epstein, 2004), land cover changes (Han et al., 2009) and land use rights changes (Taylor, 2006; Williams, 1996). In 1999, more than 60% rangeland in Inner Mongolia was degraded (Han et al., 2008). In 2005, land degradation led to a total 4.28 billion U.S. dollar economic loss (Ma et al., 2008).

In order to fight land degradation, several major conservation programs were implemented in Inner Mongolia. In 1978, the Three Norths Shelter Forest System Project, a large scale afforestation effort, took off. In 2001, the Green for Grain Program was introduced to Inner Mongolia, targeting on converting severely degraded crop land back to grassland or forest. In 2003, the Grazing Withdrawal Program was introduced to Inner Mongolia. The target was to restore heavily degraded grassland through rotational grazing, seasonal grazing, grazing suspension (Mu et al, 2013) and for some sub-areas, resettlement of herders and pastoralists (Dickinson & Webber, 2007). All of the programs covered multiple provinces including Inner Mongolia. In the last decade, the degradation trend in Inner Mongolia has reversed to some extent (Li, Verburg, Lv, Wu, & Li, 2012). Meanwhile, the conservation programs have brought significant changes to rural livelihoods; unfortunately, not all the changes were satisfactory (Dickinson & Webber, 2007).

The looming climate change also imposes threats to Inner Mongolia's agricultural production, as discussed in Section 1.1.3 (Angerer et al., 2008; Li and Pan, 2012; Zhao & Running, 2010). In addition, Inner Mongolia is also a region with frequent natural disasters, including drought, snow storm, and flood (Tuya, Jirigala, & Yin, 2013). In more than half of land areas in Inner Mongolia, natural disaster, degraded environmental condition, and poverty intervened with each other (Burenjirigala, Alatantuya, & Guo, 2013; Tuya et al., 2013). This has made rural development especially difficult.

Under such circumstances, how exactly rural dwellers make a living in Inner Mongolia? To what extent are their lives impacted by environmental degradation and opportunities in the non-agricultural sector? How can they make the best out of the current situation? In this chapter, in an effort to answer the above questions, the relationships between rural household income and a series of demographic, natural, and social factors in Inner Mongolia are examined through a household survey conducted in a typical sub-area in Inner Mongolia.

4.2 Literature review

In the previous chapters the literature on land degradation, income diversification and climate change's impact on agricultural production were reviewed. In this chapter, existing literature on the roles of land conservation programs, farm and nonfarm employment, high value agricultural and vertical integration in rural income generation are presented.

4.2.1 Conservation programs

As discussed in Section 4.1.2, three major conservation programs were implemented in Inner Mongolia. Among these programs, the Three Norths Shelter Forest System Project was not considered as successful in north China, especially in the arid and semi-arid areas (Cao, 2008; Cao, 2011). Since 1949, the average survival rate of newly planted trees in arid and semi-arid China was about 15% (Cao, 2008). During the implementation of the Three Norths Shelter Forest System Project, due to neglecting local soil, hydrology and landscape conditions, the large scale afforestation in the arid and semi-arid areas has exacerbated land degradation, led to decreased vegetation cover and worsened water shortages (Cao et al., 2011).

Multiple research analyses indicated the degradation trend of grassland has been controlled, or even reversed, in Inner Mongolia after the introduction of the Grain for Green Program and the Grazing Withdrawal Program. For example, in Hunshandak Sandy land, after three years of grazing suspension, the grassland was restored to the 1960s level (Jiang, Han, & Wu, 2006). In the whole Inner Mongolia Autonomous Region, from 2001 to 2009, the grassland area increased by 77,993 km^2, and the total annual grassland NPP increased by 21.44% (Mu et al., 2013).

In addition, the loss of crop-land in the Grain for Green Program in Inner Mongolia did not have significant negative impact on grain production. Simulating different land loss and grain productivity change scenarios, researchers concluded that this project would reduce the national grain supply by 2-3%; for Inner Mongolia, the reduction would be less than 0.1% (Feng, Yang, Zhang, Zhang, & Li, 2005).

Both the Grain for Green Program and the Grazing Withdrawal Program have stimulated changes in rural livelihoods. After these programs were introduced, more and more rural dwellers gradually started diversifying their livelihoods toward nonfarm activities (Han, Huang, Zhen, & Li, 2011). Such diversification was significant among those who were resettled, although not much progress in economic gain was found among the resettled rural dwellers (Dickinson & Webber, 2007).

Are there differences in the impacts of land degradation and conservation programs on rural households with different income levels? Few researchers have answered these question. Such is the interest of this chapter.

4.2.2 Farm and nonfarm income

A review of literature on more than 40 developing countries from 1986 to 2006 indicated that nonfarm income, on average, roughly constituted for 40% of rural household income in Africa, Latin America and Asia (Reardon, Berdegué, Barrett, & Stamoulis, 2007). Rigg (2006) argued that land and farming were increasingly delinked from rural livelihoods; rural dwellers should be considered as agrarian entrepreneurs instead of peasants since they were gaining more and more percentage of their income from nonfarm activities.

Evidence existed in multiple countries that diversification into nonfarm activities had contributed to rural household income growth and poverty reduction (Babatunde, & Qaim, 2010; Barrett, Reardon, & Webb, 2001; Yang, 2004). Examining livestock raising households in 31 Chinese provinces from 1995 to 2005, Rae and Zhang (2009) found that diversified households were significantly less impacted than the specialized (non-diversified) households by the unfavorable price changes from 1995 to 2005.

Despite the contribution of nonfarm activities, agriculture and agricultural income growth were still considered as very important in poverty reduction in many developing countries (Cervantes-Godoy & Dewbre, 2010; Christiaensen, Pan, & Wang, 2013; Montalvo & Ravallion, 2010). In addition, successful agriculture was credited as supporting the rest of the economy, including nonagricultural activities (Byerlee, De Janvry, & Sadoulet, 2009; De Janvry & Sadoulet, 2010; Knight & Song, 1990).

Agricultural and non-agricultural activities, or farm and nonfarm activities, might function effectively on different groups of rural dwellers. Analyzing data from more than 80 countries from the 1980s to 2000s, Christiaensen, Demery and Kuhl (2011) found that for the poorest (under $1 a day), agriculture was significantly more effective to reduce poverty; while for the better-off poor (under $2 a day), nonfarm activities had the advantage. Through analyzing panel data collected annually between 2000 and 2004 from more than 1,500 households in rural Gansu and Inner Mongolia, Christiaensen, Pan and Wang (2013) found that in both of the two lagging regions agriculture played a substantial role in poverty reduction while diversification only helped at the margin. A study on fruit farmers in Shandong Province indicated that while nonfarm employment favored the young and educated, fruit production served best the older and less educated in increasing income (Huang, Wu, & Rozelle, 2009).

Nonetheless, trend of diversification has been found in rural Inner Mongolia. Examining 541 livestock raising households in Inner Mongolia in 2010, Wang, Brown, and Agrawal (2013) found that diversification to nonfarm activities was one of the most important adaptive activity of livestock raisers facing climate change and land degradation; 1/3 of the interviewed households had their own business. Han et al. (2011) found, through a survey of 240 households in two Inner Mongolian counties in 2008, that among different rural dwellers, vegetable growers were more concentrated on agricultural production while dairy farmers tended to diverse its livelihood to nonfarm activities.

While diversification and nonfarm activities have been studied in Inner Mongolia, such studies still lack certain details. For example, how much do the rural households in Inner Mongolia diversify their income sources? How important is diversification for rural households with different income levels? To what extent rural households rely on nonfarm activities? Does having nonfarm activities as major income source make a significant difference in household income level? To give such questions a close examination is another focus of this chapter.

4.2.3 High value agriculture

High value agriculture is a concept comparable to that of staple agriculture. It includes practices such as vegetable farming, fruit gardening, horticulture, and livestock raising. High value agriculture has an increasing market in developing countries due to diet structure changes, the spread of supermarkets and agricultural trade liberalization with developed countries (Huang, 2011; Minot & Roy, 2007). High value agriculture is the only Asian agricultural sector that outpaced population growth in the last two to three decades (Gulati, Minot, Delgado, & Bora, 2007).

High value agriculture usually absorbs more labor than does staple agriculture; because some types of high value agriculture also require only limited land resources and capital input, they are believed to be especially suitable for increasing small agricultural holders' income (Birthal, Joshi, Roy, & Thorat, 2013). One successful example of high value agriculture benefiting small farmers was the introduction of mushroom farming in Taiwan in the 1950s and 1960s. As mushrooms could be cultivated in winter, this crop made use of idle labor forces in the off-farming seasons; and as it did not require much land resources or much capital, small holders could easily participate. Thus, mushroom farming became very popular and successful in the middle and northern parts of the island in the 1960s and a mushroom canning industry was developed which since dominated the world's canned mushroom market for decades (Benziger, 1996).

High value agriculture has proven to be successful in multiple developing countries in Asia and certain countries in Africa (Byerlee et al., 2009; Delgado, 1999; Gulati, Minot, Delgado, & Bora, 2007; Joshi, Birthal, & Minot, 2006). Due to limited land resources and a large rural population, China's agricultural production is mostly based on small agricultural holders. Thus high value agriculture is believed to be useful in generating income and absorbing the labor surplus (Huang, 2011). In China, high value agricultural products cover a wide range, including vegetables, livestock products, medicinal herbs, aquaculture products and horticultural products (Chen, 2003; Miyata, Minot, & Hu, 2009; Wang, Zhang, & Wu, 2011). International supermarket chains and wholesale markets are among the major direct buyers of such products (Michelson et al., 2013; Reardon, Timmer, & Berdegue, 2004).

4.2.4 Vertical integration

High value agriculture provides small agricultural holders with the opportunity to generate more income with limited land resources. However, to realize this goal there are several obstacles that must be overcome. From initial capital input, choice of high value crops or livestock, cultivation techniques, packing and processing, to market access, very often these elements are out of the range of capability of small, poor rural dwellers. Such is the reason for vertical integration.

Vertical integration of agriculture, broadly defined, is (to the extent possible) to put agricultural production, distribution, and marketing procedures under a single, common ownership or contract relationship, thus reducing the transaction costs that accumulate during the distribution and marketing process (Balmann, Dautzenberg, Happe, & Kellermann, 2006; Michelson et al., 2013). Vertical integration has been studied in the development arena since the 1970s, at first in the form of contract farming (Glover, 1984; Minot, 1986; Morrisey, 1974) and then gradually including farmers' associations/cooperatives (Huang, 2011; Michelson et al., 2013; Shen, Rozelle, Zhang, & Huang, 2005). Recently, global retail chains also have become a topic of interest in vertical integration (Gulati, Minot, Delgado, & Bora, 2007; Reardon, Timmer, & Minten, 2012).

In rural China, trade in agricultural products usually takes place between small traders and small agricultural holders, either in local trade markets or villages (Jia & Huang, 2011). To promote vertical integration, the Chinese government has encouraged three types of cooperation since the 1990s: dragon-dead companies, farmers' associations (or cooperatives) and direct farm programs (Michelson et al., 2013).

Dragon-head companies are agribusiness companies that cooperate with small farmers, with the support of the Chinese government. Such companies receive subsidies encouraging them to contract with small farmers in agricultural production, by providing capital input and technology guidance and by identifying potential income-increasing opportunities (Gale & Collender, 2005; Yuan, 2011).

Farmers' associations/cooperatives are organizations founded by farmers with mutual interests, serving members in fields such as agricultural production technology, management and market access (Shen et al., 2005). The Chinese government began supporting the development of farmers' professional associations in the early 2000s, including enacting the Farmers Association Law in 2006 which established a registry system and ensured the legal status of such organizations (Deng, Huang, Xu, & Rozelle, 2010). Farmers' associations/cooperatives also often serve as negotiators between small agricultural households and big buyers (Hu, Reardon, Rozelle, Timmer, & Wang, 2004; Jia & Huang, 2011). According to Deng et al. (2010), by 2008, 21% of Chinese villages had formed farmers' associations, serving 24 million rural households.

The Direct Farm Program was launched by the Chinese Ministry of Commerce (COMOF) in 2008 in an attempt to directly link small farmers and supermarkets in trading fresh agricultural goods, provide market access to small farmers, reduce the transaction costs spent on middle-traders and increase small farmers’ incomes (MOFCOM, 2012). With government support in the form of subsidies and awards, multiple national supermarkets, international supermarket groups, local supermarkets and wholesale stores joined in the program, contributing to rural income increase as well as building a significant storage, distribution, and certification infrastructure in rural China (Michelson et al., 2013).

4.3 Selection of research site

Xilin Gol was selected as the research site because in many ways it is a good representation of the most common development problems in rural Inner Mongolia. Located in the middle of Inner Mongolia (see Figure 4.3), it supports both grain and livestock production. Urbanization and land degradation are among the major challenges and opportunities facing the rural community.

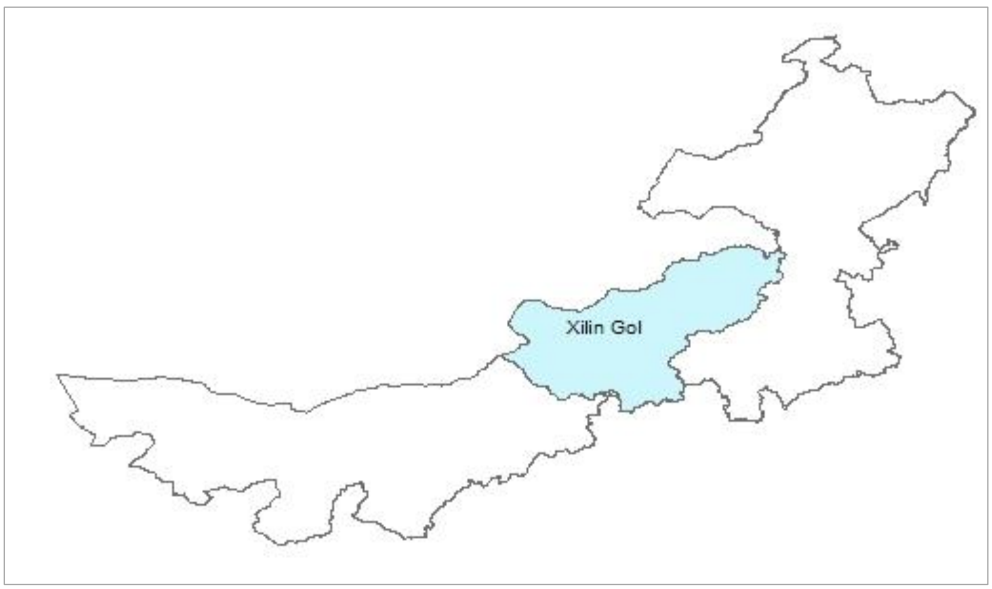

Figure 4. 3 Location of Xilin Gol in Inner Mongolia
Source: ACMR, 2012

Xilin Gol is a good representation of the two major agricultural production activities in Inner Mongolia (i.e., grain production and animal husbandry). In the southern-most part of Xilin Gol, the majority of rural dwellers are farmers; as one moves north, increasingly more rural residents undertake animal husbandry. The economic development in rural Xilin Gol is uneven. In 2010, the average per capita income of Xilin Gol's 12 county-level administrational units was 7,171 yuans ($1,149). However, the income range was wide, from 4,748 yuans ($761) to 11,528 yuans ($1,847), and the standard deviation was 2,242 yuans ($359) (SBIM, 2011).

Xilin Gol is facing rapid urbanization. In 2012, only 0.40 million out of 1.04 million people, or 38% of the local population, were from rural areas (XGSB, 2013). According to the second agricultural census in this area (XGBS, 2008), at the end of 2006, migrant workers who worked outside their hometowns accounted for only 7.28% of total local rural labor supply.

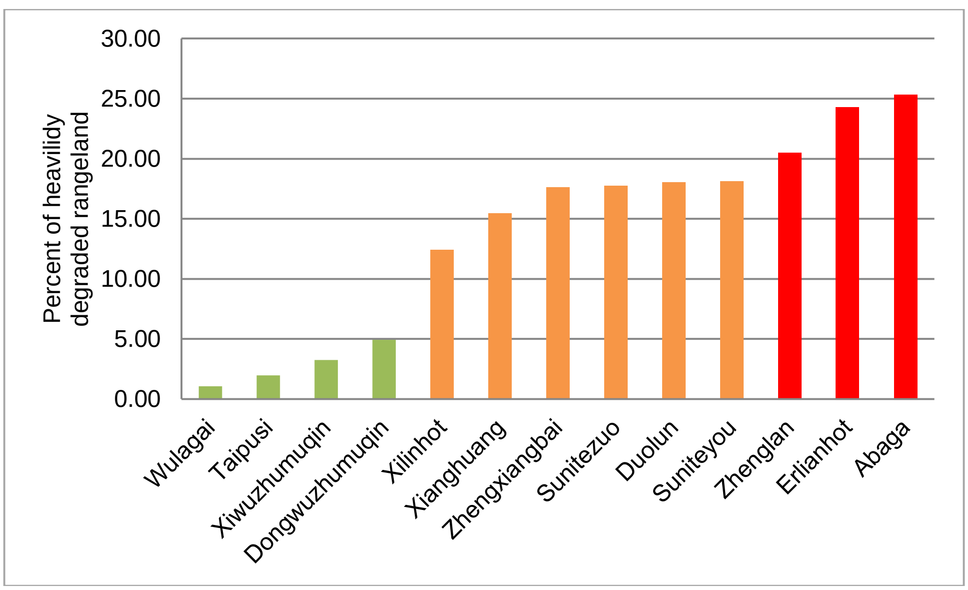

Figure 4. 4 Percentage of rangeland under heavy degradation in Xilin Gol counties
Data source: Inner Mongolia Rangeland Survey and Design Institute (IMGSPI), 2003
Note: Wulagai is a sub-area of Suniteyou Banner (county)

According to the Inner Mongolia Grassland Survey and Planning Institute (IMGSPI), in 2000 more than 75% of the rangeland area in Xilin Gol was either degraded, in the process of desertification, or salinized. In particular, nearly 11% of the rangeland was experiencing severe degradation, and more than 13% severe desertification (IMGSPI, 2003). The percentage of severe rangeland degradation in the 12 county-level administrative areas of Xilin Gol is displayed in Figure 4.4.

In addition, the Hunshandake Sandland (as shown in Figure 4.5), located in the southwest corner of Xilin Gol, is among the major deserts in Inner Mongolia. Being 180 kilometers north of Beijing, Hunshandake is the closest sandland to the capital of China and has been recognized as one of the main sources for spring dust storms in Beijing (Normile, 2007).

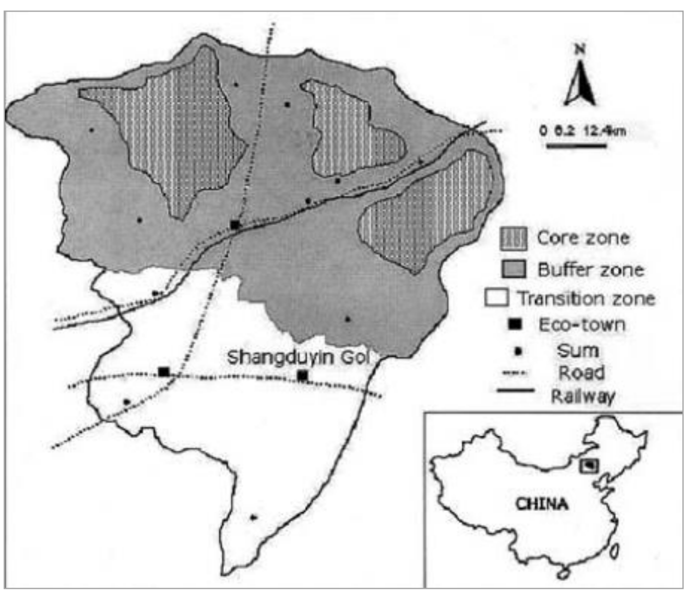

Figure 4. 5 Location of Hunshandake Sandland in China
Source: Peng et al. 2005

As discussed above, rural Xilin Gol represents a typical area in rural Inner Mongolia in that it contains both grain and livestock production, is undergoing rapid urbanization, experiencing rural-to-urban migration, and suffering from environmental degradation. Thus, Xilin Gol was selected for this study of the relationships between rural income and related demographic, environmental, and socio-economic factors.

4.4 Research hypotheses

In this chapter, the relationships between rural household income and demographic, environmental, and socio-economic factors in Xilin Gol are examined. The variables of interest in this analysis include: household size, total land area, total livestock number, vegetable plantation, land degradation level, number of conservation programs, technical assistance gained, percentage of family members with an education level of primary school or below, ethnicity, occupation (farmer, livestock raiser, or ecological migrant), market access (measured by if there are companies or traders purchasing agricultural products directly from households), major income source type, major expenses in the last five years and diversification of income source (measured by the number of income sources). As listed above, these variable include basic demographic information, basic agricultural production information, land degradation information and adaptation activities including conservation, technology, high-value agriculture, diversification and vertical integration.

The research hypotheses are: each of the variables of interest mentioned above separately makes a significant difference in identifying the different income levels of household groups in rural Xilin Gol.

4.5 Questionnaire design and interview implementation

4.5.1 Questionnaire design

The data required was collected through a field survey using a questionnaire that I developed. The questionnaire (Appendix B) was designed to cover the following aspects of rural livelihoods:

1) Demographic information, including household size, ethnicity, family members' level of education, number of students in the household and major expenditures occurred in the last five years.

2) Livelihood information, including land area, agricultural practice types, possession of livestock, land management methods, income sources, market access of agricultural products and per capita net income in the past year (2009).

3) Social and institutional information, including farmers' association memberships, technical assistance gained, financial aid gained, conservation project types and conservation-related subsidies.

4.5.2 Survey implementation

Based on Figure 4.4, the counties in Xilin Gol were divided into three land degradation groups: the low-degradation group contained counties with less than 10% of heavily degraded land, mid-degradation group 10%-20%, and the high-degradation group more than 20% heavily degraded land. In each group, one county located close to a city center was selected as the research county (as shown in Figure 4.6). In each county, one township was selected; within that township, two to four villages were selected based on village size. The townships and villages were selected based on suggestions from local government officials as typical of the local economy. In each village, 30 households were randomly selected to complete a questionnaire via personal interviews given by the researcher or her trained assistants. For villages with less than 30 available households at the time of the survey, questionnaires were answered by all available households. Then, a certain number of questionnaires were answered by households randomly selected in a neighboring village (with similar economic parameters) to obtain the required 30 households. Each person who answered the questionnaire was either the household head or an adult who claimed that he or she could represent the household head's opinions.

The original research design did not include ecological migrants. However, during the survey the researcher realized that an increasing number of rural dwellers were relocating to Inner Mongolia due to severe environmental degradation. These people had to change their lifestyles to adapt to the new environment. Based on the descriptions provided by local government officials, some ecological migrants were greatly challenged by this process. Therefore, it was decided to interview one migrant village for comparison. As this decision was made on site, the location was chosen based on a recommendation from local government officials. In the village, 30 households were interviewed through random sampling.

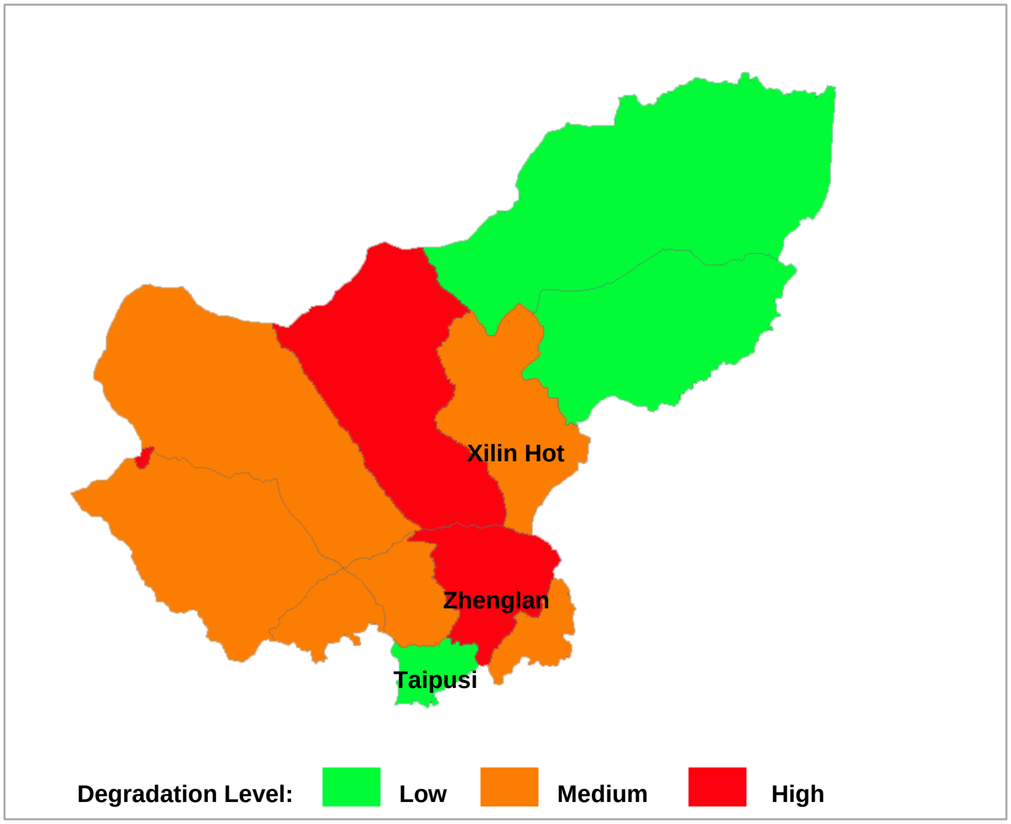

Figure 4. 6 Location of selected counties in Xilin Gol

The three types of rural households interviewed in the survey were defined as:

Farmer: a household whose major agricultural activity is planting grain crops and/or vegetables, and possibly raising livestock in the household's feedlot on a small scale (in the survey only some farmers raise livestock).

Livestock raiser: a household whose major agricultural activity is raising livestock, but does not include planting grain crops or vegetables.

Ecological migrant: a former livestock raiser household who, due to severe land degradation, had to be relocated from its rangeland to a government-provided, newly built village close to a city center; the household still owns the user rights to its rangeland but is limited to harvesting forage in fall and possibly raising livestock in the household's feedlots.

To ensure objectivity and consistency, the three research assistants were given a standardized training on the content of the questionnaire and the interview process. Interpretation services were used if the interviewees could not understand mandarin Chinese well. Interpreters were provided by local government agencies.

During each interview, the net income of the interviewed household (defined as the net money flow, as explained below) was requested from the interviewee. Income tends to be considered a private matter in countries such as the United States. However, due to cultural differences, it was not an especially sensitive topic in rural China. In addition, to make sure that the interviewees gave truthful answers, my research assistants and I assured them both at the beginning of the interview and while asking this question that such information would be kept confidential. Moreover, the question was put at the end of the interview in a hope that the earlier interactions during the interview would allow the interviewee to relax and that a level of trust could be established between the interviewer and the interviewee. Finally, to increase the accuracy of this variable in representing a household's income in the general sense, a question on major expenses in the last five years was asked and was included in the research model as a dependent variable.

In total, 189 households from three different counties were validly interviewed. The distribution of townships, villages and household occupations are given in Table 4.1.

Table 4. 1 Distribution of interviewees among the three tested counties

County	Townships	Villages	Farmer	Livestock Raiser	Ecological Migrant	Total Households
Taipusi	2	3	60	30	0	90
Zhenglan	1	3	0	55	0	55
Xilin Hot	1	2	0	14	30	44
Total	4	8	60	99	30	189

4.6 Data analysis methods

4.6.1 Research models

4.6.1.1 Multinomial logistic regression model

A multinomial logistic regression was built to analyze the relationships among household income and environmental, demographic and socio-economic factors. The reasons for choosing a multinomial logistic regression model were as follows:

Multinomial logistic regression is used to predict the probabilities of different memberships of a non-metric dependent variable, given a set of explanatory variables. Therefore, it can be used to model the impacts of different independent variables on the memberships of different income groups.

Originally, the dependent variable in this analysis was designed to be metric. However, due to the following reasons, it was better to group the variable into non-metric measurements. In the questionnaire, the net income of each household in 2009 was defined as the money flow that the household experienced in that year, calculated as *money earned – money spent*. The name "net income" and the method of calculation were based on conventional calculations among farmers, previous research (Khan, Griffin, Riskin, & Zhao, 1992) and the statistical survey measure used by NBSC (2014) while investigating rural income. During the interview process, the interviewees were asked to estimate the money flow of their households in 2009. Quite a few households answered that their net income in 2009 was 0, claiming the money spent and money gained in 2009 were the same. Considering that this was an estimation made during the short period of the interview, it is possible that the estimation might deviate slightly from the precise value of the actual money flow. When an interviewee reported the family's income as 0, it was considered possible that the actual value was either slightly below or slightly above 0. In order to deal with this uncertainty, the households were divided into five groups based on their levels of net per capita income, as shown in Table 4.2.

Table 4. 2 Income groups and their distribution within the sample

Group Name	Income Range (Yuan)	No. of Cases	Percentage
Group One	[-50000, -6000)	31	17.1%
Group Two	[-6000, -1000)	36	19.9%
Group Three	[-6000, -1000)	43	23.8%
Group Four	[1000, 6000)	35	19.3%
Group Five	[6000, 25000]	36	19.9%
		189	100%

Note: 1 Yuan ≈ 0.16 U.S. Dollar

In multinomial logistic regression analysis, the independent variables can either be metric or non-metric. Independent variables do not require normality, linearity or homogeneity of variance. Considering that the survey did not use simple random sampling, these relaxations in data quality ensured the validity of the analysis.

4.6.1.2 Nonparametric tests on income rank

While building the multinomial logistic regression model, some values of several categorical independent variables including occupation (farmer, livestock raiser, ecological migrant), ethnicity (Han, minority) and vegetable dummy, did not have a presence in all of the income groups. Thus, these variables could not be incorporated in the model. However, these variables were still of interest in this analysis. Therefore, a separate Kruskal-Wallis test was conducted between the income rank and such categorical independent variables (ethnicity was omitted in the analysis due to high collinearity with occupation). Kruskall-Wallis is a nonparametric statistical test designed for ordinal dependent variable.

As the vegetable dummy was nested under the farmers' category, no livestock raisers or ecological migrants produced vegetables in the year 2009. A Mann-Whitney U test was conducted to test the income rank difference between vegetable growers and non-vegetable growers.

4.6.2 Data treatment

4.6.2.1 Defining the income group

The 189 households were divided into five groups based on their net per capita income values. The five groups represented the following income ranges: 1) [-50000, -6000), 2) [-6000, -1000), 3) [-1000, 1000), 4) [1000, 6000) and 5) [6000, 25000]. The households were divided in such a way that the percentage of households in each group were approximately even. The distribution of households within the five groups is displayed in Table 4.2.

4.6.2.2 Calculating sheep unit

The sheep unit was used to aggregate the forage demands of different livestock animals and represent the aggregated livestock capital a household had. The "animal unit" is a standardized measure defining the intake of forage based on certain standardized animals (Waller, Moser, & Anderson, 1986). In this analysis, the sheep unit was used according to He and Liu's design (1996, p. 259-260); their calculation methods were based on the physical conditions of typical Chinese livestock species.

In the analysis, first, each type of livestock animal in a given household was converted into a sheep unit. Then, the converted values of the different livestock were added up to obtain the household's total sheep units. The conversion rates used were as follows:

1 sheep = 1 sheep unit, 1 goat=0.9 sheep unit, 1 pig= 1 sheep unit,

1 beef cow=5 sheep units, 1 dairy cow=5 sheep units, and

1 horse = 5 sheep units.

4.6.3 Model estimation

4.6.3.1 Multinomial logistic regression model

IBM SPSS 21 was used to estimate the multinomial logistic regression model. The estimation process contained a series of procedures and tests, including a selection of variables and validity tests for the model.

During the model estimation, the highest income category was chosen as the baseline for calculating the odds of a household falling into its own group, rather than the baseline group. First, all of the explanatory variables were individually regressed to the dependent variable. Variables for which the chi-square tests were significant at the 10% level were considered for the multivariate logistic regression. Second, pairwise correlations were implemented in the independent variables under consideration. If two variables were highly correlated (rho>0.80), the variable with the lowest p-value was chosen for the model in order to avoid collinearity (Varga et al., 2012). Then, all selected variables were put into the multinomial logistic regression model in IBM SPSS 21, and manual deletions were used for insignificant variables in order to reduce the model to a parsimonious form. Finally, the overall goodness of fit and classification accuracy were examined for the model's validity.

4.6.3.2 Nonparametric models

The Kruskal-Wallis test and the Mann-Whitney U test were conducted through GraphPad Prism 6 (GraphPad Software, 2014a). In the Kruskal-Wallis test, first, all the values in the sample are ranked from low to high regardless of group membership. Thus the smallest value gains a rank of 1, and the largest value gains a rank of N, where N is the sample size. For ordinal variables, multiple tied values are generated due to the group memberships, and each variable with the same tied value are assigned with the average of the ranks for which they tie. Then the p-value is estimated based on the chi-square distribution (GraphPad Software, 2014a). When the test result was found statistically significant, Dunn's post test was conducted to compare the differences among the mean ranks between difference occupation groups.

While conducting the Mann-Whitney U test, a similar ranking is also first conducted. However, the p-value is estimated through Gaussian approximation (GraphPad Software, 2014b).

4.7 Results

In this section, first, the descriptive statistics in the survey is presented, including the basic economic practices, especially the agricultural practices of the interviewed households, average household income in general, income in terms of land degradation levels, ethnicity, and occupation and the descriptive statistics of independent variables. Then, the results of the multinomial logistic regression model and nonparametric models are presented.

4.7.1 General descriptive statistics

The descriptive statistics for the explanatory variables in the regression model are reported in Table 4.3. An "average household" in the survey had between three and four family members. In each household, approximately 2/3 of the family members had only attended primary school or had no formal education. Each household had approximately 1,400 mu (93.3 ha) of land, more than 100 sheep units, and two to three income sources.

Table 4.3 Descriptions of independent variables

Variable Name	Mean /Percentage	Standard deviation	Minimum	Maximum
Household size	3.62	1.19	1.00	9.00
Per capita land area (mu)	386.30	631.50	0.00	5000
Total sheep units	108.36	144.54	0.00	750
No. of income sources	2.31	1.31	1.00	7.00
No. of conservation programs	1.48	0.50	1.00	2.00
No. of students	0.61	0.70	0.00	3.00
% of members with education level of primary school or below	67.0%	0.31	0.00	1.00
Ethnicity				
Minority	55.6%			
Han	44.4%			
Occupation				
Farmer	31.7%			
Livestock raiser	52.4%			
Ecological migrant	15.9%			
Vegetable dummy				
Yes	24.3%			
No	65.7%			
Tree dummy				
Yes	38.6%			
No	61.4%			
Land degradation level				
Low	47.6%			
Med	23/3%			
High	29.1%			
Technical assistance dummy				
With technical assistance	24.5%			
Without technical assistance	75.5%			
Association membership				
Yes	13.8%			
No	86.2%			
Company purchase dummy				
Yes	34.8%			
No	65.2%			
Financial support dummy				
Yes	21.7%			
No	78.3%			

Among the 189 households surveyed, more than half were ethnic minorities (all except one minority household were Mongolian); approximately 1/3 were farmers, more than half were livestock raisers, and 1/6 were ecological migrants. In the last five years, only about a quarter of the households had obtained technical assistance from any source, about 1/5 had received some kind of financial support, and about 2/3 had major expenses attributable to events such as marriage, house construction, and serious medical conditions. The majority of households (2/3) had market access for their agricultural products in the form of company or trader purchases directly from the household. However, the households were not especially active in farmers' organizations; less than 1/7 were members of farmers' associations.

The majority of the households (77.2%) depended on agriculture as their most important income source. However, chi-square tests implied there were significant differences among occupations with regards to major income source (p-value<0.001). Among different occupation groups, 80.0% of ecological migrants were dependent on nonfarm activities as major income source. This ratio was less than 15.0% for both farmers and livestock raisers.

While the interviewed households on average had 2.31 income sources, 2/3 of the households only had one or two income sources, and 80.0% of the households had no more than three income sources. Among different occupations, the farmers had the most diversified income sources, with all the households had more than one income sources, and 85.0% of them had three or more income sources. Only one ecological migrant household had three income sources. The rest of the ecological migrant households had one (36.7% of the households) or two (60.0%) income sources. The livestock raisers also mainly had one (48.5% of the households) or two (40.4%) income sources. The Kruskal-Wallis test indicated that the farmer group had a significantly higher mean income source ranks than the other two groups.

The year 2009 was not a good year for rural households in Xilin Gol. Among the 189 households interviewed, though some households did enjoy a positive money flow as high as 25,000 yuans ($4,006) per person, many suffered a per capita loss of as much as 50,000 yuans ($8,012). On average, the net per capita money flow was -675 yuans (-$108).

Among the different occupation groups, a farmer's average net per capita income was 7,075 yuans ($1,134). On average, both ecological migrants and livestock raisers lost money. For ecological migrants, the average loss was 1,733 yuans ($278), and for livestock raisers 2,260 yuans ($362).

Among the different land degradation groups, the average household in Taipusi (with the lowest degradation percentage) gained 4,924 yuans ($789), the average household in Xilin Hot (with a medium degradation percentage) lost 1,174 yuans ($188), and the average household in Zhenglan (with the highest degradation percentage) lost 4,302 yuans (-$689).

4.7.2 Multinomial logistic regression results

For the final multinomial logistic regression model, the model chi-square was 167.826 with a degree of freedom of 28, and was significant at the 0.1% level ($p < 0.001$). Therefore, the combination of the independent variables and the dependent variable had a significant relationship. The null hypothesis that there was no difference between the model without the independent variables and the model with the independent variables was rejected.

Table 4.4 Likelihood ratio tests for individual independent variables

Independent Variables	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	394.566	.000	0	.
Land degradation level	440.706	46.140	4	.000
No. of conservation programs	408.236	13.670	4	.008
No. of income sources	408.763	14.197	4	.007
Total sheep units	412.328	17.762	4	.001
Access to company purchases	411.736	17.170	4	.002
Major expenses in the last 5 years	404.666	10.100	4	.039
Major income sources	404.945	10.379	4	.035

Altogether there were seven independent variables found to be statistically significant at the 5% level. These variables were reported in Table 4.4. The analysis' by chance accuracy rate of was $(17.1\%)^2 + (19.9\%)^2 + (23.\%)^2 + (19.3\%)^2 + (19.9\%)^2 =$ 20.23%. The overall classification rate of the model was 54.4% (as given in Table 4.5), greater than the 25% improvement of the by change accuracy rate. This further confirmed that the model was valid.

Table 4.5 Classification matrix for different income groups

Observed income group membership	Predicted income group membership					
	Group One	Group Two	Group Three	Group Four	Group Five	% accurate
Group One	13	9	8	0	0	43.4%
Group Two	8	23	2	1	1	65.7%
Group Three	3	4	28	3	6	63.6%
Group Four	3	3	11	12	7	33.3%
Group Five	1	1	8	4	23	62.2%
				Overall percentage accuracy		54.4%

Table 4.6 Multinomial logistic regression results

Income Groups	Independent Variables	β	S.E.	Wald	df	*p*-Value	Odds Ratio	95% C.I. for Odds Ratio Lower	Upper
Group One [-50000, -6000)	Intercept	2.557	1.864	1.883	1	0.170			
	Land degradation level	1.856	0.670	7.683	1	0.006**	6.397	1.722	23.762
	No. of conservation programs	-2.454	1.257	3.812	1	0.051	0.086	0.007	1.010
	Total sheep units	-0.011	0.003	10.727	1	0.001***	0.989	0.983	0.996
	No. of income sources	-0.911	0.450	4.093	1	0.043*	0.402	0.166	0.972
	Without company purchases	3.784	1.348	7.876	1	0.005**	43.976	3.131	617.737
	Major income sources non-ag	-0.328	0.779	0.178	1	0.673	0.720	0.156	3.316
	No major expenses	-0.831	0.930	0.797	1	0.372	0.436	0.070	2.698
Group Two [-6000, -1000)	Intercept	1.453	1.929	0.567	1	0.451			
	Land degradation level	2.540	0.691	13.497	1	0.000***	12.675	3.270	49.134
	No. of conservation programs	-4.002	1.265	10.009	1	0.002**	0.018	0.002	0.218
	Total sheep units	-0.012	0.004	12.447	1	0.000***	0.988	0.981	0.995
	No. of income sources	-0.365	0.420	0.754	1	0.385	0.694	0.305	1.582
	Without company purchases	4.487	1.338	11.251	1	0.001***	88.816	6.456	1221.919
	Major income sources non-ag	-1.101	0.938	1.377	1	0.241	0.333	0.053	2.092
	Without major expenses	1.395	0.741	3.541	1	0.060	4.035	0.944	17.255

Note. Reference group: Group Five [6000, 25000]

S.E. = standard error

C.I. = confidence interval

* = significant at 5% level, ** = significant at 1% level, *** = significant at 0.1% level

Table 4.6 Continued

Income Groups	Independent Variables	β	S.E.	Wald	df	*p*-value	Odds Ratio	95% C.I. for Odds Ratio Lower	Upper
Group Three [-1000, 1000)	Intercept	4.152	1.590	6.818	1	0.009			
	Land degradation level	-0.194	0.620	0.098	1	0.754	0.823	0.244	2.777
	No. of conservation programs	-0.794	0.881	0.812	1	0.368	0.452	0.080	2.542
	Total sheep units	-0.007	0.003	7.000	1	0.008***	0.993	0.988	0.998
	No. of income sources	-1.029	0.321	10.270	1	0.001***	0.357	0.190	0.670
	Without company purchases	3.106	1.067	8.470	1	0.004**	22.340	2.758	180.975
	Major income sources non-ag	0.863	0.710	1.474	1	0.225	2.369	0.589	9.536
	Without major expenses	0.074	0.612	0.015	1	0.904	1.076	0.324	3.572
Group Four [1000, 6000)	Intercept	1.897	1.620	1.372	1	0.242			
	Land degradation level	0.769	0.632	1.483	1	0.223	2.158	0.626	7.442
	No. of conservation programs	-0.782	0.894	0.764	1	0.382	0.458	0.079	2.641
	Total sheep units	-0.008	0.003	6.709	1	0.010**	0.992	0.986	0.998
	No. of income sources	-0.460	0.279	2.713	1	0.100	0.631	0.365	1.091
	Without company purchases	1.726	1.019	2.867	1	0.090	5.617	0.762	41.411
	Major income sources non-ag	-0.821	0.812	1.023	1	0.312	0.440	0.090	2.160
	Without major expenses	0.583	0.562	1.075	1	0.300	1.791	0.595	5.384

Note. Reference group: [6000, 25000]
S.E. = standard error
C.I. = confidence interval
* = significant at 5% level, **= significant at 1% level

The multinomial logistic regression results are shown in Table 4.6. As the income Group Five (the group with highest income level) was the baseline group, all of the results shown in the table were comparisons of each lower income group (Groups One to Four) to Group Five. In general, the results indicated that the poorer a household was, the more factors affected its net per capita income in 2009, and vice versa.

For the poorest groups (Groups One and Two), land degradation level, number of conservation programs, total sheep units and access to company purchases were all significant in differentiating such groups from Group Five. Comparing Group One with Group Five, holding all other independent variables constant, for each upward change in land degradation level (i.e., from low to medium, or from medium to high), the odds of a household belonging to Group One rather than Group Five increased 6.40 times. Correspondingly, for each additional conservation program in the village, the odds of the household ending up in Group One decreased by 91.4% (0.086-1=-0.914; *p*-value = 0.051). For each additional income source, the odds of a household ending up in Group One decreased by 59.8% (0.402-1=-0.598). For each unit increase in total sheep units, the odds of a household ending up in Group One decreased by 1.1% (0.989-1=-0.011). If a household did not have access to company purchases, the odds of this household belonging to Group One increased 43.98 times, as compared to if the household had access to company purchases. The results for Group Two were similar except that all of the relative odds increased to some extent, and the number of income sources was not significant.

Comparing Group Three to Group Five, neither land degradation level nor number of conservation programs were statistically significant. Total sheep units and access to company purchases were both significant; the signs were the same as in Groups One and Two but the magnitudes of the odds both decreased. Number of income sources was also significant in identifying membership in Group Three or Group Five.

Only total sheep units was statistically significant in locating a household's membership in Group Four or Group Five, at the 5% level. Market access was significant at the 10% level.

4.7.3 Nonparametric tests results

The Kruskal-Wallis test indicated that there was significant difference between occupational groups in terms of the mean income ranks (p-value < 0.0001), with a mean rank of 136.2 for farmers, 68.49 for livestock raisers, and 80.93 for ecological migrants. Dunn's post test suggested that the farmers had a significant higher mean income ranks than the other two groups, and there was no significant difference between the mean income ranks of livestock raisers and ecological migrants. Comparing the mean income ranks of vegetable growers and non-vegetable growers within the farmer household group, the Mann-Whitney U test suggested that the vegetable growers had a significant higher mean income rank (34.09) than the non-vegetable growers (15.07) (p-value < 0.0001).

4.8 Discussion and conclusion

4.8.1 Discussion

4.8.1.1 Testing alternative grouping methods in multinomial logistic regression model

To compare the multinomial logistic regression models used in this analysis, different grouping methods were used to construct the model, including three groups based on loss, gain, or break-even, four groups based on mean and standard deviations, and five groups based on quartiles. The results of these different multinomial logistic regression models were similar to the results reported in Section 4.7.1 in that land degradation, income source number and market access were significant in all of the models. In addition, the signs of the coefficients were the same in all of the models. However, the method reported in Section 4.7.1 gave the most satisfying classification accuracy and provided the most details.

4.8.1.2 Testing multinomial logistic regression model without ecological migrants

As the decision of interviewing ecological migrants was made on site, there was concern that including this group in the analysis might cause biases in the results. Therefore, a separate multinomial logistic regression was run without the ecological migrants. The model turned out to be significant. In addition, the significance and directionality of variables within each groups were the same with the results reported in Section 4.7.1, the classification accuracy rate was slightly lower (53.9%) and the coefficients as well as *p*-values of the significant variables were slightly different in magnitude. Thus the inclusion of ecological migrants did not significantly alter the results.

4.8.1.3 Land degradation, conservation, and livelihood diversification

Quite a few researchers argued that poverty and environment degradation affected each other and should be addressed closely (Cao, Zhong, Yue, Zeng, & Zeng, 2009; Cleaver & Schreiber, 1994; Scherr, 2000). The analysis in this chapter implied that among the interviewed households, it was the two poorest groups that were hurt the most by land degradation. This result is not difficult to understand. As Brown et al. (2013) found among 750 households along the ecological ingredient of Mongolia and Inner Mongolia, those tended to take more activities in order to increase income in face of variability were households with characteristics including higher level of material wealth. The poor had a low capacity to diversify due to constraints such as limited material wealth and education to diverse into nonfarm activities (Reardon et al., 2007). Yet the conservation programs also benefited the poorest groups most significantly. This might be because on the one hand, the improved land condition contributed to higher agricultural growth; on the other hand, the economic compensation from conservation programs could provide some of the poor with capital for other income generating activities.

Thus land degradation, conservation and income diversification should be jointly considered in improving rural household income in the research area. Through a household survey in 2008, researchers argued that local government successfully assisted the ecological migrants in finding more nonfarm jobs in Zhengxiangbai and

Xianghuang counties in Xilin Gol (Han, et al., 2011), but not very successful with farmers and livestock raisers who were not reallocated. The results of this survey, however, indicated that among the ecological migrant households interviewed, the households' income sources were still fairly limited, as 29 out of 30 households only had one or two income sources. Among those who were not reallocated, farmers had a significantly more diversified income portfolio than livestock raisers. This might be partially due to the occupational characteristics. For example, whether growing plant or vegetable, farmers enjoy an off-season when they can take nonfarm activities. However, for livestock raisers, raising livestock is a year-round job. Another possible reason, as speculated by Han et al. (2011), might be due to the fact that pastoralists in the region lack of advanced knowledge, skills, and techniques for nonfarm activities.

Different from Christiaensen et al. (2011), diversification of income sources helped the poorest and the middle income group the most significantly among the surveyed households. Looking into the income source number distribution in the richest groups (Groups Four and Five), more than 50% households already had more than three income sources. Those with only one income source were either ecological migrants (3 households) or specialized livestock raisers (8 households) with large areas of land (on average 2969 mu, or 198 ha, per household) and large amount of livestock (on average 183 sheep units per household).

4.8.1.4 Market access

Several major forms of market access were found during the survey in Xilin Gol: purchases by companies (either dragon-head companies or non-dragon-head companies), purchases by wholesale traders, and selling at local markets. Most vegetables were sold either in local markets or directly purchased by wholesale traders from other provinces. The major buyers of milk were local diary companies. During our interviews, livestock raisers complained that after the 2008 milk scandal (Pei et al., 2011; Qiao, Guo, Klein, 2010; Xiu & Klein, 2010), local diary companies stopped buying milk products from them. As they did not have other market accesses for their milk, they could not sell it.

Vertical integration was still quite primitive in Inner Mongolia. Most rural households had limited market access. The example of milk selling in this analysis indicated that rural households needed alternative buyers for their products. Compared with big enterprises such as dragon-head companies, as Huang (2011) argued, farmers' associations were better able to represent farmers' interests. Besides technological services, a functional farmers' association could also serve in expanding market accesses for its members.

In this survey, farmers' associations/cooperatives were rare in the research area, and the role of existing farmers' associations was not significant in increasing rural income. This result is consistent with previous research on such organizations in China (Deng et al., 2010; Shen et al., 2005) that found that only a small portion of farmers' associations in China were functional. Deng et al. (2010) discovered that government support accounted for most of the growth in the number of farmers' associations in China. However, little was found in the literature on the determinants of farmers' associations' success. There is a great need for further research.

4.8.2 Conclusion

In this chapter, the relationships between rural net per capita household income (defined as net money flow) and environmental, social as well as economic factors were examined using a multinomial logistic regression model with primary data gained through a household survey in a typical rural setting in Inner Mongolia: Xilin Gol. The household-level analysis approach provided greater detail on the issues and factors affecting rural development, as compared to the county-level approach described in Chapters II and III. Meanwhile, the results of the primary data analysis complemented the results of the analysis of secondary data published by different Chinese government agencies (NBS, 2007-2009; NBS, 2013; SBIM, 2001-2009).

The survey results indicated that although urbanization had provided alternative income sources for rural dwellers, agriculture is still the most important income source for rural households in the survey area, and having non-agricultural activities as major income sources did not significantly contribute to the increase in household income. In addition, the results also indicated that land degradation hurt most of the poorest households, while conservation programs and income diversification most significantly benefited the poorest. Further, the results implicated that growing vegetable significantly contributed to the income growth of farmers. Last but not least, the results revealed that market access was too limited for local agricultural production, and the institutions for market access in the survey area were weak.

To increase the income of rural households, especially the income of the poorest households, conservation, training and educational programs should be given great priority. With conservation programs, households will have a better environment for a higher agricultural growth, which will in turn generate capital for other income generating activities. With education and training, household members will gain the techniques and skills for such activities. It should be noticed that among the Mongolian households interviewed, a large portion of them did not speak or spoke little Mandarin. This, no doubt, puts great constrains to their potential to communicate and trade with the Chinese speaking world, and also limits their ability to learn the knowledge and skills needed, as most of such materials are in Chinese. Therefore, for the ethnic minorities in Inner Mongolia, on the one hand, education programs should provide basic language programs including both Mandarin Chinese and Mongolian; on the other hand, training programs should also take into the consideration of being implemented in Mongolian.

With regards to high-value agriculture, more practices that could take place in the off-season of farming (or do not require too much time for livestock raisers), and do not require much land should be encouraged. Such practices will both create new income sources and contribute to environmental protection. To do so, careful selection of projects and elaborative design of training modules are indispensable.

To increase market access channels, not only should the dragon-head companies and the Direct Farm Program be encouraged, but also the development of farmer's associations should be supported. Although dragon-head companies and the Direct Farm Program provide market access to rural dwellers, farmer's interest is not the center of such practices. But a well-functioned farmer's association could keep seeking new market access channels to serve the best interest of farmers.

CHAPTER V

CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

5.1 Research findings and implications

Climate change has imposed significant challenges on global dryland systems, which account for more than 4/10 of the world's land area, and support more than 1/3 of the world's population. As more than 90% of people living on drylands are from developing countries, where backwards social and economic development has already impeded the enhancement of people's livelihood, climate change for dryland areas, in essence, is a development issue.

In this dissertation, Inner Mongolia, a typical dryland system in the world's largest developing county, China, was chosen to study the relationships between agricultural outputs/rural income and climate factors as well as adaptive activities in dryland systems. The foci of this dissertation include: 1) the impacts of climate change and adaptations on grain and livestock production, and 2) rural livelihoods under land degradation, and socio-economic changes in Inner Mongolia.

To address the research foci, three analyses were presented in Chapters II to IV. In Chapters II and III, the county-level data analysis provided a general picture on the relationships between grain/livestock production and climate factors as well as adaptive activities. In Chapter IV, the household-level analysis provided details on rural livelihood under environmental degradation and socio-economic changes. Results in the three chapters complemented one another, providing a holistic picture of agricultural production and income generation in rural Inner Mongolia.

In Chapter II, through building a regression model with county-level panel data in Inner Mongolia from 2000 to 2008, it was found that average temperature in spring, precipitation in May, highway density, and the number of special technical personnel were positively associated with grain output value, while average temperature in July and diversification of agriculture were negatively associated with grain output value in Inner Mongolia.

In Chapter III, through building a similar regression model with county-level panel data in Inner Mongolia from 2000 to 2008, it was found that average annual temperature and minimum precipitation in May, June and July were positively correlated to livestock output value, whereas the number of college graduates in the municipal area was negatively associated with livestock output value.

In Chapter IV, though building a multinomial logistic regression model with household-level survey data, the impacts of environmental, social and economic factors on rural household income in Xilin Gol, a typical arid and semi-arid region in Inner Mongolia, were evaluated. The research results indicated that land degradation hurts the poor the most; and local conservation programs benefit most significantly the poorest households. In addition, it was found that farmers had a more diversified income portfolio than livestock raisers and ecological migrants. Finally, the results highlighted the positive role of high value agriculture and market access in rural income generation for the majority of surveyed households.

Compared with existing research, the analyses presented in this dissertation provided important details in identifying significant climate factors, environmental factors and adaptive activities on grain production, livestock production and rural income generation in an arid and semi-arid rural setting. The general policy implications for Inner Mongolia agricultural and rural development are:

1) It is important to notice that the changing climate has different impacts on different agricultural sectors. For example, the warming trend would have some negative impacts on grain production, but in general favor livestock production. But the drier trend would have negative effects on both grain and livestock production. Therefore, while the grain production sector needs to develop strategies to respond to both higher temperature and decreased precipitation, the livestock production sector could mainly focus on adapting to the drier weather.

2) Some adaptive activities can benefit both agricultural production sectors through increased adaptive capacity. Such activities include irrigation infrastructure building, adoption of water saving technologies, and improvement of the technical personnel team.

3) While it is of great importance to emphasize food security in Inner Mongolia, it is of equal importance to increase rural income. In order to increase rural income and address land degradation at the same time, land conservation programs, high value agriculture, diversification of income sources, and market access should be given top priority in policy making.

4) The poorest are most vulnerable to land degradation. This may be partly because their income is heavily dependent on agricultural outputs and partly because they lack in ability to adapt to land degradation. Thus, increased land degradation is

likely to enlarge the existing income gap between the poor and the rich. Policies that prevent land degradation or enhance environmental conservation can not only protect the environment but also alleviate income inequality in the rural area in Inner Mongolia.

The results of research in this dissertation also provide implications for rural development in the greater arid and semi-arid areas in the world. The general conclusion and implication drawn from this dissertation include:

1) There is no silver bullet in addressing the challenges from climate change. Each agricultural sector and each rural group (with regards to income and occupation) will need a tailor-made approach.

2) Agricultural growth and rural income improvement in drylands are the joint results of many forces in an interrelated system, where factors such as the natural environment, institutions, infrastructure, market, technology advance, education, and economic diversification all play important roles. It is important to understand the contribution of each factor and not to exacerbate the current issues by focusing on a single factor.

3) A single adaptive activity can barely address the issues in all the agricultural sectors, nor can it address the issues for all types of rural residents. To address challenges from climate change, different objectives might conflict with one another with respect to resource allocation. It is essential for policy makers to identify priorities and build strategies accordingly.

5.2 Limitations and future research

Compared with existing research, the analyses in this dissertation serve as a good start in examining the complicated, interrelated relationships among the climate, human, and natural systems under climate change in an arid and semi-arid setting. Yet, there have been noted limitations to this research work. Such limitations and corresponding suggestions for future research are detailed below:

1) The interpretation of the analysis results can be constrained due to limitations associated with the research data. For example, while most of the other variables were obtained at the county level, both monthly temperature and precipitation were at the city level. Research with more comprehensive and detailed data, especially data with county-level precipitation information, county-level college graduates (with information on both the number of graduates and their majors), and more detailed information on technical assistance, will complement and enhance the results in this dissertation.

2) In addition, as Inner Mongolia's agriculture is composed of several sectors besides grain and livestock production, research on the relationships between climatic, social, and economic factors and the output of other agricultural sectors, and research on the relationship among different agricultural sectors will complement the research presented in this dissertation. This complementary research will provide a more holistic picture of agricultural development facing climate change and adaptations in this region.

3) Finally, the survey analysis provides a glimpse of rural livelihood in Inner Mongolia. Analysis across time and analysis incorporating climate factors such as temperature, precipitation, and extreme weather events, are needed to disclose the dynamics in rural livelihood. Given the significance of vertical integration and high-value agriculture in increasing rural income, the roles of farmers' associations, dragon-head companies and rural entrepreneurship, should also be incorporated in future research in greater detail.

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APENDIX A

DESCRIPTIVE STATISTICS AND TREND ANALYSES RESULTS OF CHAPTERS

II AND III

Table A. 1

Descriptive statistics of temperature, precipitation and soil types in the grain model

Variable name	Unit of measurement	Mean or frequency
T1 (temperature in January) [1]	°C	-13.51
T2 (temperature in February)	°C	-8.84
T3 (temperature in March)	°C	-.73
T4(temperature in April)	°C	8.48
T5(temperature in May)	°C	15.78
T6 (temperature in June)	°C	21.14
T7(temperature in July)	°C	23.14
T8(temperature in August)	°C	21.08
T9 (temperature in September)	°C	15.49
T10(temperature in October)	°C	6.91
T11(temperature in November)	°C	-3.29
T12(temperature in December)	°C	-11.43
T12 LAG1(temperature in December – the year before)	°C	-11.50
TS1(temperature in spring[2])	°C	7.84
TS2(temperature in summer[3])	°C	21.78
TS3(temperature in fall[4])	°C	6.38
TS4(temperature in last winter[5])	°C	-11.05
ATGROW (average temperature in growing season[5])	°C	17.52
MAXTGROW (highest monthly temperature in growing season)	°C	23.27
MINTGROW (lowest monthly temperature in growing season)	°C	8.44
MAXT5-7 (highest temperature from May to July)	°C	23.17
MINT5-7 (lowest monthly temperature form May to July)	°C	15.78
P1 (precipitation in January)	mm	2.83
P2 (precipitation in February)	mm	2.64
P3 (precipitation in March)	mm	6.91
P4 (precipitation in April)	mm	15.44
P5 (precipitation in May)	mm	26.59
P6 (precipitation in June)	mm	52.45
P7 (precipitation in July)	mm	75.15

Table A. 1 continued

Variable name	Unit of measurement	Mean or frequency
P8 (precipitation in August)	mm	62.44
P9 (precipitation in September)	mm	33.66
P10 (precipitation in October)	mm	14.86
P11 (precipitation in November)	mm	4.67
P12 (precipitation in December)	mm	3.69
PT (total precipitation of the current year)	mm	295.45
P12LAG1 (precipitation in December of the year before)	mm	3.85
PS1 (total precipitation in spring)	mm	16.18
PS2 (total precipitation in summer)	mm	63.35
PS3 (total precipitation in fall)	mm	17.70
PS4(total precipitation in last winter)	mm	9.16
PGROW (total precipitation in growing season)	mm	265.68
MAXPGROW (maximum monthly precipitation in growing season)	mm	97.40
MINPGROW (minimum monthly precipitation in growing season)	mm	6.67
MAXP5-7 (maximum monthly precipitation from May to July)	mm	87.17
MINP5-7 (minimum monthly precipitation from May to July)	mm	19.87
Cambisols		9
Dunes or shifting sands		27
Gleysols		72
Lithosols		378
Kastanozems		279
Xerosols		63

Note: [1] Unless specified, the temperature and precipitation data are of the current year
[2] March to May; [3] June to August; [4] September to November;
[5] Last December to this February; [6] April to September

Table A.2
Descriptive statistics of temperature, precipitation and soil types in the livestock model

Variable name	Unit of measurement	Mean or frequency
T1 (temperature in January) [1]	°C	-13.72
T2 (temperature in February)	°C	-9.00
T3 (temperature in March)	°C	-.87
T4(temperature in April)	°C	8.38
T5(temperature in May)	°C	15.69
T6 (temperature in June)	°C	21.10
T7(temperature in July)	°C	23.11
T8(temperature in August)	°C	21.05
T9 (temperature in September)	°C	15.45
T10(temperature in October)	°C	6.81
T11(temperature in November)	°C	-3.44
T12(temperature in December)	°C	-11.63
T12 LAG1(temperature in December – the year before)	°C	-11.71
TS1(temperature in spring[2])	°C	7.73
TS2(temperature in summer[3])	°C	21.75
TS3(temperature in fall[4])	°C	6.28
TS4(temperature in last winter[5])	°C	-11.24
ATGROW (average temperature in growing season[5])	°C	17.47
MAXTGROW (highest monthly temperature in growing season)	°C	23.23
MINTGROW (lowest monthly temperature in growing season)	°C	8.48
MAXT5-7 (highest temperature from May to July)	°C	23.14
MINT5-7 (lowest monthly temperature form May to July)	°C	15.69
P1 (precipitation in January)	mm	2.80
P2 (precipitation in February)	mm	2.60
P3 (precipitation in March)	mm	6.82
P4 (precipitation in April)	mm	15.00
P5 (precipitation in May)	mm	26.47
P6 (precipitation in June)	mm	52.28
P7 (precipitation in July)	mm	73.98

Table A.2 continued

Variable name	Unit of measurement	Mean or frequency
P8 (precipitation in August)	mm	61.74
P9 (precipitation in September)	mm	33.24
P10 (precipitation in October)	mm	14.60
P11 (precipitation in November)	mm	4.64
P12 (precipitation in December)	mm	3.69
PT (total precipitation of the current year)	mm	292.18
P12LAG1 (precipitation in December of the year before)	mm	3.83
PS1 (total precipitation in spring)	mm	15.96
PS2 (total precipitation in summer)	mm	62.67
PS3 (total precipitation in fall)	mm	17.46
PS4(total precipitation in last winter)	mm	9.06
PGROW (total precipitation in growing season)	mm	262.66
MAXPGROW (maximum monthly precipitation in growing season)	mm	97.70
MINPGROW (minimum monthly precipitation in growing season)	mm	7.45
MAXP5-7 (maximum monthly precipitation from May to July)	mm	85.97
MINP5-7 (minimum monthly precipitation from May to July)	mm	19.84
Cambisols		9
Dunes or shifting sands		27
Gleysols		72
Lithosols		378
Kastanozems		306
Xerosols		72

Note: [1] Unless specified, the temperature and precipitation data are of the current year
[2] March to May; [3] June to August; [4] September to November;
[5] Last December to this February; [6] April to September

Table A.3 Trend analysis results for grain output value from 2000 to 2008

Source	Time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power
Time	Linear	3462638.679	1	3462638.679	47.319	.000	.342	1.000
	Quadratic	17375.714	1	17375.714	1.660	.201	.018	.247
	Cubic	9416.288	1	9416.288	1.516	.221	.016	.230
	Order 4	173459.613	1	173459.613	35.653	.000	.281	1.000
	Order 5	152714.541	1	152714.541	29.071	.000	.242	1.000
	Order 6	2970.992	1	2970.992	1.741	.190	.019	.257
	Order 7	55147.438	1	55147.438	11.226	.001	.110	.912
	Order 8	46643.873	1	46643.873	15.250	.000	.144	.972

Table A.4 Trend analysis result for livestock output value from 2000 to 2008

Source	Time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power
Time	Linear	3916628.021	1	3916628.021	47.262	.000	.332	1.000
	Quadratic	652779.308	1	652779.308	31.795	.000	.251	1.000
	Cubic	24205.456	1	24205.456	3.598	.061	.036	.467
	Order 4	138693.099	1	138693.099	20.701	.000	.179	.995
	Order 5	85960.954	1	85960.954	23.222	.000	.196	.998
	Order 6	31686.379	1	31686.379	15.116	.000	.137	.971
	Order 7	251.045	1	251.045	.239	.626	.003	.077
	Order 8	2545.395	1	2545.395	1.852	.177	.019	.270

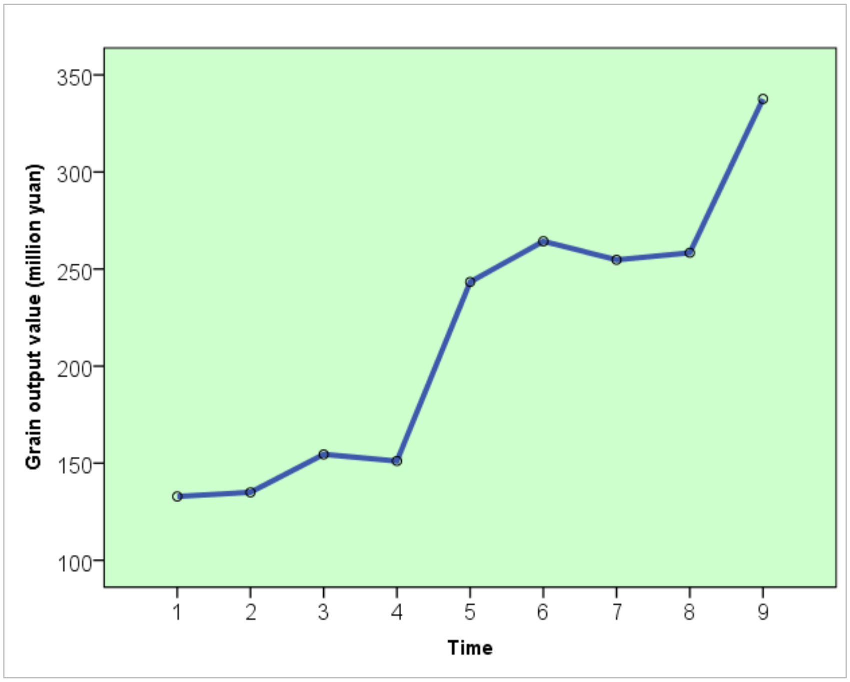

Figure A.1 Mean grain output value from 2000 to 2008

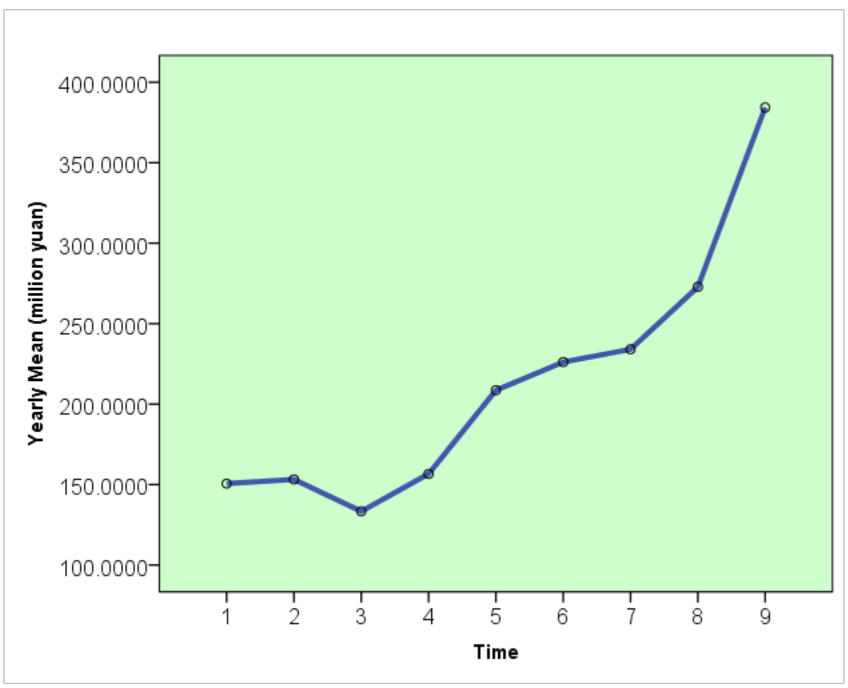

Figure A.2 Mean livestock output value from 2000 to 2008

APENDIX B

HOUSEHOLD SURVEY QUESTIONNAIRE (TRANSLATED)

Number: ________ County: ____________

Township: ____________ Village: _____________

Hello,

We, a research group based in the Department of Ecosystem Science and Management at Texas A&M University, U.S.A., are conducting a survey of rural households in Hunshandake Sand Land. The purpose of this study is to identify some social, economical, and demographical factors that may influence natural resource conservation practices adopted by farmers or herders.

You are randomly chosen to participate in this survey, which will take about 20 minutes to complete. Your participation in the survey is fully voluntary. If you feel uncomfortable about some questions, you can skip them or withdraw. In the latter case, we will dispose your questionnaire.

Your answers will be kept confidential. The data collected through this survey will be used for research purposes only and will not be shared with anybody else except the investigators. If you are interested, you can get a copy of the research report after the survey is completed.

If you have any question about this research, you can either contact the researcher or the Institutional Review Board/Human Subjects' Protection Program Office of Texas A&M University. The contact information is as followed:

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Your answer and response are very important to us. Thank you very much for your participation!

First of all, I am going to ask you some questions related to your household:

1. How many people are there in your household? （　　）
2. Your sex: 1. Male 2. Female
3. In which year were you born?
4. What is your education level?
    a. Primary School b. Middle School
    c. High School (including professional school)
    d. College
    e. Graduate School and above
    f. I do not have formal education in school
5. What is your ethnicity?
    a. Han b. Mongolian c. Other
6. Currently are there any students in your household?
    a. Yes (answer Q.4)
    b. No (Skip to Q.6)
7. How many students are there in your household now? ( )
8. What schools are they in respectively?

	a. Primary School	b. Middle School	c. High School	d. College	e. Graduate School and above
Student 1					
Student 2					
Student 3					
Student 4					

Now I am going to ask some questions related to agricultural production:

9. How much land does your household have? ( ) mu. Among the land:
    9.1 Farm land ( ) mu,
    9.2 Grazing land ( ) mu,

9.3 Other land (   ) mu. (If the number is 0, skip to Q.10)

Please list the usages and area of other land.

	Usage	Area (Mu)
Other Land 1		
Other Land 2		
Other Land 3		
Other Land 4		

10. What kind of crops do you grow this year?

    a. corn   b. wheat   c. hulless oat   d .potato   f. benne
    g. other (please explain: ____)

11. Do you plant trees?

    a. Yes

    Q.11.1 please note how many mu you planted last five years _____, how many trees _______, and how many survived________.

    b. No

12. The numbers of the following animals on your farm are:

    a. Cow ______
    b. Beef Cattle ______
    c. Goat ______
    d. Sheep ______
    e. Horse ______
    f. Pig ______
    g. Chicken ______
    h. Camel ______
    i. Other , please explain: _____
    j. No Animal

13. Besides production activities listed above, other sources of income of your household include:

    a. Small Business (such as convenient store, barber shop, repairing store, etc.)
    b. Collecting wild herbs on grassland/rangeland

c. Local employment (within your county)
d. Non-local employment (outside your county)
e. No other production activities

14. Are there companies directly buy your animal products (such as beef, mutton, milk, wool, etc.)?
    a. Yes
    b. No
15. In the last 5 years, have you ever received any technology assistance from experts and technicians from institutions rather than institutions in the village and township?
    a. Yes
    b. No (skip to Q.17)
16. The technological assistance you have received include:
    a. Choose new crop varieties
    b. Crop planting skills/practices
    c. Choose new animal species
    d. Livestock raising skills/practices
    e. Conservation techniques/practices
    f. Agricultural management skills
    g. Other, please explain: ______________________
17. Are there any farmer's associations in your township/village?
    a. Yes
    b. No (skip to Q.19)
18. Are you a member of any farmers association?
    a. Yes,

       Q.18.1 Please tell me the name(s):____
    b. No.

Now, I am going to ask you some questions related to the rangeland and grazing.

19. Are there any conservation projects in your township/village?

a. Yes

b. No (skip to Q.24)

20. The conservation projects in your village include (multiple choices):

a. Rotational grazing
b. Seasonal grazing
c. Suspension of grazing
d. Reforestation
e. Grass planting (reestablishment)
f. Sand dune stablization
g. Other, please explain:_____________

21. Are the conservation projects voluntary in your village?

21.1Rotational grazing

a.Yes b. No c. No Such Project

21.2Seasonal grazing

a. Yes b. No c. No Such Project

21.3Suspension of grazing

a. Yes b. No c. No Such Project

21.4Reforestation

a. Yes b. No c. No Such Project

21.5Grass planting

a. Yes b. No c. No Such Project

21.6Sand dune stablization

a. Yes b. No c. No Such Project

21.7Other

a. Yes b. No c. No Such Project

22. Is there any compensation for the conservation projects?

a. Yes

Please explain:

22.1 Rotational Grazing ________yuan/mu or ________jin____/mu (grain)

22.2 Seasonal Grazing ________yuan/mu or ________jin____/mu (grain)

22.3 Suspension of Grazing _______yuan/mu or ______jin____/mu (grain)

22.4 Reforestation ________yuan/mu or ________jin____/mu (grain)

Or ________yuan/tree or ________jin____/tree (grain)

22.5 Planting Grass ________yuan/mu or ________jin____/mu (grain)

22.6 Stabilize Sand Dunes ______yuan/mu or ________jin____/mu (grain)

22.7 Other ________yuan/mu or ________jin____/mu (grain)

b. No

23. Has your family participated in the conservation projects?

a. Yes

Please explain:

23.1 Rotational Grazing _______Mu
23.2 Seasonal Grazing _______Mu
23.3 Suspension of Grazing _______Mu
23.4 Reforestation _______Mu
23.5 Plant Grass _______Mu
23.6 Stabilize Sand Dunes _______Mu
23.7 Other, _______Mu

b. No

24. Was the forage produced by your household enough for own use last year?

a. Yes

b. No

Please explain how much you spent on purchasing forage last year: ______ yuan (skip to Q.27)

25. Was there any forage left in your household last year?

a. Yes

b. No (skip to Q.27)

26. What did you do to the left over forage?

a. Sold, please note the income ______ yuan

b. Gave out

c. Saved for this year's usage

d. Threw away

27. How do you manage your land?

a. On my own

b. Via farmers cooperative program

c. Leasing out

d. Other, please explain: ____________________

28. Did you receive any of the following assistance in agricultural production in the last 5 years?

    a. Agricultural training
    b. Loan
    c. Other, please explain:_______________________

29. As far back as you can remember, you feel that rangeland in the village has:

    a. Gradually become better
    b. Gradually been degraded
    c. no observable change

30. In order to improve the rangeland in your township/village, would you like to spend money and time on it?

    a. Neither money nor time
    b. Time only
    c. Money only
    d. Both money and time

Now, please tell me your opinion on the following statements:

31. The natural environment provided by the rangeland is important to me.

    1.Strongly Disagree 2. Disagree 3. Not Sure 4. Agree 5. Strongly Agree

32. The products(such as grass, herbs, etc.) provided by the rangeland is important to me.

    1.Strongly Disagree 2. Disagree 3. Not Sure 4. Agree 5. Strongly Agree

33. It is necessary to protect the rangeland in your township/village.

    1.Strongly Disagree 2. Disagree 3. Not Sure 4. Agree 5. Strongly Agree

34. Conservation projects (rotational grazing, seasonal grazing, suspension of grazing, etc.) have positive effect on the health of rangeland.

    1.Strongly Disagree 2. Disagree 3. Not Sure 4. Agree 5. Strongly Agree

35. Reducing the number of livestock (cow, beef cattle, goat, sheep, horse, camel, etc.) has positive effect on the health of rangeland.

    1.Strongly Disagree 2. Disagree 3. Not Sure 4. Agree 5. Strongly Agree

Finally, I am going to ask you some questions related to your household:

36. Is there anybody in your family whose educational level is lower than primary school?

a. Yes, please let me know the number _____

b. No

37. In the last 5 years, which of the following large expense(s) has your household incurred?

a. No large expenses b. Marriage c. House construction

d. Serious medical conditions e. Other, please explain:_________

38. What is the main source of your household income?

a. Wage b. Agricultural income c. Non-agricultural income d. Asset income

e. Support from children working outside of the county f. Government subsidies

g. Other, please explain: _________________

39. The net income per capita in your household last year was ___________yuan.