Irrigation's Roles and a Type of Sustainable Agricultural Development in Arid Areas of Northwest China

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Abstract

China has been experiencing rapid transitions during the fast process of development since XiaoPing DENG launched economic reform in 1978. However, after 30 years of development, China is being challenged by two typical problems: one is the concentration of the remaining rural poverty in some areas, which are identified as less developed areas; and the other is the degradation of environment. These two problems are more serious in the northwest than in other areas since the northwest is the droughtiest inland area in China. Both the incidence of rural poverty and the incidence of rural low-income are much higher in the northwest than in other areas of China. For China, the increasing income gap among regions is a profound social problem. Meanwhile, water scarcity is the cause of ecological deterioration and desertification of farmlands. All of the problems reported above have a close relationship with agricultural development. In this less developed area, agriculture is still the main source of income for most farmers. However, this sector consumes almost 90% of the total water resources; thus, its water consumption is the main obstacle to sustainable development. The patterns of agricultural development with limited water resources that can reduce rural poverty and halt desertification of arable lands must be identified and studied. In other words, the sustainable agricultural development in the northwest has to meet three conditions simultaneously: improving or maintaining farm income, reducing water consumption to a low level, and preventing the abandonment of arable lands.

Therefore, the objective of this study is to identify patterns of sustainable agricultural development with limited water consumption in the droughty northwest. In order to achieve this objective, this study is divided into three parts: (1) the role of irrigation in rural poverty reduction; (2) the role of irrigation in

primary crop production and improvement of technical efficiencies; (3) limitation of water consumption and implementation of sustainable agricultural practices.

It has been demonstrated in developing countries that agricultural development, as opposed to development in other sectors, is effective for reducing rural poverty. By dividing a long period into two sub-periods, the estimation results demonstrate that irrigation played an important role increasingly in rural poverty reduction among the detailed factors of agricultural development. Considering the droughty climate of the northwest, the improvement of irrigation ratio of farm land can be expected to contribute significantly to the rural poverty reduction, however, it is unlikely to occur without changes in the agricultural practices involving water-intensive cropping. The northwest must substantially reduce its agricultural water consumption to support sustainable development. Following this, the farmers would be able to switch to high value-added water-saving agricultural practices.

The next part of this study focuses on Minqin County to study the role of irrigation on crop production and improvements in technical efficiency with the introduction of a stochastic frontier production function and the simulation of sustainable agricultural development with the use of a linear programming model. In Minqin County, the main water resource for agriculture is groundwater, which decreases from the south to the north.

Cotton is cultivated in Minqin County because it is a high value-added and water-saving cash crop; however, there is plenty of opportunity to expand its scale of cultivation. Based on the plot-level survey data, the estimation results show that the expenditure on irrigation played a very important role in cotton production. There is also no significant difference in average technical efficiency between the south and the north. These results show that cotton cultivation can be expanded throughout Minqin County. Meanwhile, the characteristics of the plots themselves were the main reasons for the variation in technical efficiency. It is especially noteworthy that technical efficiency was lower in sandy plots than in normal plots. However, the characteristics of the farm managers did not appear to have an impact on the variation in the technical efficiency. The above estimation results show that in Minqin County, the differences in the farmers' management, which is explained by the characteristics of the farm managers, do not seem so important on cotton production comparing with the differences in the environment.

To improve the productivity of the land, wheat is intercropped with corn, and wheat monocultivation is avoided; however, this is dependent on the availability of sufficient groundwater in Minqin County. Household survey data from two sites show that the expenditures for irrigation outweigh other inputs. Moreover, the same expenditure for intercropping is more effective than that for mono-cultivation. The survey results show that irrigation groundwater is efficiently utilized. Since the groundwater decreases from the south to the north of Minqin, the availability of groundwater at the two survey sites is unequal. As a result, the farmers in the north are at a disadvantage. Reasons of technical efficiency variation are also different between intercropping in the south and mono-cultivation in the north. Intercropping is more complex than monocultivation and requires that its practitioners have a higher level of education. In addition, any distractions, such as part-time jobs, could affect their technical efficiencies. In contrast, distractions such as part-time jobs did not have any effect on the productivity from mono-cultivation. However, the younger farm managers can have higher technical efficiency. Ultimately, the use of groundwater will have to be sustainable, and guidelines for all farmers will be necessary to achieve this goal.

The results of this study demonstrate that the consumption of water for agriculture cannot be reduced by limiting irrigation volume alone. Moreover, water scarcity has a significant impact on agricultural practices. Increasing the growth of crops that require less water could ameliorate the negative effect of water scarcity since their growers can get the same technical efficiencies although some of them are limited by the problem of water scarcity more seriously.

Because of water scarcity, the consumption of water for agriculture must be limited to the maximum available level which is permitted to utilize in the future. With a linear programming model, the simulated results show that it is difficult to limit the water consumption of agriculture to the above level because the problems of desertification and poverty will increase. However, if limitations were placed on water-intensive food crops, the available water would support all arable lands. To achieve sustainable agricultural development with the available water resources would require that the droughty northwest area in China switch from food-crop-oriented planting to water-saving and high-value-added agricultural practices. Therefore, the Chinese government must guarantee the farmers' food securities who give up food crop cultivation and to establish new programs that would stabilize their farm income.

In conclusion, irrigation contributes significantly to the sustainable development of the droughty northwest by reducing rural poverty and increasing crop production. Droughty areas, such as Minqin County, will have to change their water-intensive food-crop-oriented planting patterns to water-saving, high-value-added practices. Otherwise, it would be difficult to achieve sustainable agricultural development for such droughty areas. To this end, the Chinese government would need to guarantee food security for the local communities by transferring food commodities from water-rich areas. Therefore, the results of this study suggest that the Chinese government should, as soon as possible, plan an agricultural system that serves a larger area or even one that serves the entire country. In addition, the Chinese

Agricultural Insurance Programs and National Farmers' Association could contribute to these country-wide changes.

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Chapter 1
General Introduction

1 Introduction

China has experienced rapid transitions since XiaoPing Deng launched economic reform in 1978. One type of reform is from a state-controlled economic system to a market-driven economic system, and another, from an agricultural society to an urban, industrial society. From 1978 to 2006, the annual average growth rate of the real gross domestic product (GDP) had been increasing at a high rate of 9.8%; the personal annual average GDP growth rate has also been increasing at a high rate of 8.6% (NBSC, 2007). See Table 1.1. This remarkable economic growth has benefited many rural people whose living standards have been increasing significantly since the reform and opening of the country that began in 1978. As a result, many rural poor people escaped poverty from 1978 to 2006. The number of rural poor people was reduced from 250 to 21.5 million, and, correspondingly, the incidence of poverty also decreased from 30.7% to 2.3% (RSDNBS, 2004 and 2007; see Table 1.2). However, because of voluminous consumption of resources and excessive population growth, China's developmental sustainability is being challenged by many problems. They include the exploitation of natural resources, ecological deterioration, widening disparities (NERC, 2007), the marginalization of rural poverty, diminishing groundwater, and the expansion of desertification.

Although the above problems are common throughout China, the various areas differ. China is divided into three areas: east, middle, and west, according to their economic levels. The economic level gradually decreases from east to west. On the basis of this division, there are also some additional regions: according to the geographical characteristics and climate, there are also the northeast and the northwest. The northwest is the driest hinterland in China. It includes the Xingjiang Uygur and

Ningxia Hui autonomous regions and Gansu, Shaanxi, and Qinghai Provinces (see Fig. 1.1). The total area of the northwest is about 3,080 thousand km^2, which is 32.1% of China's landmass; its arable lands are 11,400 ha, or 12% of China's arable lands (The Ministry of Water Resources of China, 1999). Most of the northwest is in the arid and half-arid zones, where the evaporation rate is very high, 4~10 times of the precipitation.

In such a droughty area, the concentration of rural poor people, water scarcity, and desertification challenge sustainable development. In 2006, about 64% of the remaining rural poor people and about 62% of the low-income rural people were concentrated in the west, which includes the five provinces of the northwest (RSDNBS, 2007). In addition, the ecological and environmental problems are also much more serious than those of other areas. One of the typical problems is desertification, which has been expanding in the northwest for many decades. In China, most of the deserts are located in the Xinjiang Uygur autonomous region and Gansu and Qinghai Provinces (Wang et al., 2003). The interaction of the droughty climate and the desertification intensifies the problem of water scarcity in the northwest. Over its long history, the droughty northwest is one of China's food bases because the farmers had to guarantee food securities by themselves. Several kinds of water-intensive food crops, such as wheat and corn, are still cultivated on a large scale. Thus, about 90% of water resources are consumed by the agricultural sector, and 80% of agricultural water consumption is taken up by irrigation (Jia and Liu, 2004).

All of these problems have a close relationship with the development of agriculture. In the northwest, as the main income source of the farmers, agriculture plays important roles in not only reducing rural poverty but also preventing the desertification of arable lands. However, the present rate of water consumption for agriculture is not sustainable. It is necessary to discuss what kind of agricultural practices can reduce the remaining rural poverty and prevent the arable lands from desertification under the limitation of water resources. In other words, the sustainable agricultural development in the northwest has to meet three conditions simultaneously: improving or maintaining farm income, reducing water consumption to a low level, and preventing the abandonment of arable lands.

2 Literature Reviews

2.1 Definition of Sustainable Development

The concept of sustainable development was recently proposed as a guiding principle for economic development planning. It is applicable in both developed and developing countries. This idea grew from numerous environmental movements in earlier decades and was defined by the Brundtland Commission in 1987 as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). The essence of this form of development is a stable relationship between human activities and the natural world, which does not diminish the prospects for future generations to enjoy a quality of life at least as good as our own. This contributed to the understanding that sustainable development encompasses a number of areas and highlights sustainability as the idea of environmental, economic, and social progress and equity, all within the limits of the world's natural resources.

Several years latter, participants of Earth Summit attempted to highlight the importance of sustainability during the summer of 1992 at a United Nations meeting (UNCED, 1992). One hundred and fifty-two government leaders from the world attended this Summit and enshrined sustainability in Agenda 21, a plan of action and recommendation that all countries should produce national sustainable development strategies. Despite the bound conventions and numerous detailed reports, there seems to have been little known about the details by the ordinary citizens around the world.

In the more than 10 years since Rio Summit, there has been little change in poverty levels, inequality, or sustainable development in the world. This is in an age of immense wealth in increasingly fewer hands. The inequality of consumption (and, therefore, use of resources, which affects the environment) is terribly skewed: "Twenty percent of the world's people in the highest-income countries account for 86% of total private consumption expenditures, the poorest 20% a minuscule 1.3%," according to the 1998 United Nations Human Development Report (UNHDR, 1998).

On 8 Sep. 2000, following a three-day Millennium Summit of world leaders at the headquarters of the United Nations, the General Assembly adopted the Millennium Declaration (UN, 2000). In this declaration, poverty eradication is addressed. The General Assembly declared their intent to halve, by the year 2015, the proportion of the world's people whose income is less than one dollar a day, that of those who suffer from hunger, and that of those who lack access or money to pay for safe drinking water.

With the development, many people recognize that sustainable development does not focus solely on environmental issues. The United Nations World Summit Outcome Document (UN, 2005) refers to "interdependent and mutually reinforcing pillars" of sustainable development as economic development, social development, and environmental protection. Poverty eradication, changing unsustainable patterns of production and consumption, and protecting and managing the natural resource base of economic and social development are overarching objectives and essential requirements for sustainable development.

Following all the conferences from 1987 to 2005, it is evident that there was a shift in emphasis on environmental issues at the 1987 Brundtland Commission from a focus on environmental, social, and economic development at the Rio Summit in 1992 to the eradication of poverty and the change of unsustainable patterns of production and consumption at the United Nations World Summit Outcome Document in 2005.

However, the record on moving towards sustainability so far appears to have been quite poor (Global Issues, 2005). Although we might not always hear about it, sustainable development and all the inter-related issues associated with it are urgent issues and have been for many years, though political will has been slow-paced at best.

2.2 Agricultural Development and Rural Poverty Reduction

2.2.1 Poverty Reduction in Rural China

In China, poverty is primarily a rural problem. Both the poverty scale and incidence are much higher in rural than in urban areas. About one-third of the rural population lived in poverty before China's reform and opening up. However, many of the rural poor benefited from the rapid economic growth, and the population living in poverty diminished from 250 million in 1978 to 21.5 million in 2006. The rural poverty rate also dropped, correspondingly, from 30.7% to 2.3% (RSDNBS, 2007).

From 1978 to 2000, China had experienced three phases in the reduction of rural poverty according to the different policies issued by the Chinese central government. The first phase was from 1978 to 1985; the second phase, from 1986 to 1993; and the third phase, from 1994 to 2000 (see Table 1.3). In the first phase, rural poverty decreased sharply due to the issue of the Household Contract Responsibility System (HCRS), which significantly improved agricultural productivity (Ravallion and Chen, 2007). In the second phase, programs were created to reduce rural poverty, since the HCRS could not effectively reduce rural poverty any further. In the third phase, the government invested money and provided supplies a lot in the regions identified as poverty-stricken counties. However, the government's activities had little effect on rural poverty reduction. The above results are supported by the data in Table 1.3, which shows that rural poverty decreased quickly in the first phase but slowed down in the second and third phases. In the first phase, the average annual poverty reduction incidence was as high as 2.28%; in the second phase, the average annual poverty reduction incidence was about 1.14%; and, in the third phase, the average annual poverty reduction incidence was only about 0.83%.

From 2000 to 2004, the rural poverty head-count ratio remained at around 3%, although the economic growth stayed at a high level (RSDNBS, 2007). It seems difficult for China to further reduce rural poverty after a long period of sustained reduction. In 2004, the Chinese government substituted a new policy of Rural Tax Reform for Agricultural Tax that had been the farmers' main burden for several decades. It is precisely because of eliminating the farmers' burden that the rural poverty incidence decreased from 2.8% in 2004 to 2.3% in 2006 after several years of staying at the same level (RSDNBS, 2007). Now, in some areas of China, such as the east, rural poverty is no longer a serious social problem. However, in recent years, the high speed of economic development in China is being accompanied by increasing income inequality. He (2007) presented the Gini coefficients of China. The coefficient had increased from 0.371 to 0.439 during the period of 1997 to 2004 (see Fig. 1.2). The trend of the Gini coefficients also shows that some poor people might not benefit from this development. Nowadays, most of the rural poor people are in the west, especially, in the northwest. Thus, to further reduce rural poverty is still a very difficult but important task for the northwest of China.

2.2.2 Agricultural Development and Rural Poverty Reduction

It is not an exaggeration to say that the battle to achieve the global society's stated objectives on hunger and poverty reduction will be won or lost in the rural areas of developing countries. Globally, extreme poverty continues to be a rural phenomenon despite the increase of urbanization. Of all poor people in the world, 75% live in rural areas, and, for the most part, they depend on agriculture, forestry, fisheries, and related activities for survival (Anríquez and Stamoulis, 2007).

Economic development, particularly agricultural development, is thought to greatly benefit rural poverty reduction when the national average income is at a low level (Pinstrup and Pandya, 2001; Hossain and Marciano, 2000). When the national average income is at a low level, many people live in rural areas and depend more on agricultural sector than on other sectors. History also shows that different rates of poverty reduction over the past 40 years have been closely related to differences in agricultural performance in many underdeveloped countries. Growth in agriculture has been consistently shown to be more beneficial than growth in other sectors to the poor. Kakwani (1993) used the additive property of the most popular poverty indicators, the FGT (Foster, Greer, Thorbecke) class, and decomposed the effects of sectoral growth on poverty. Using the data of the Côte d'Ivoire Living Standards Survey conducted in 1985 about the living standards of the Ivorian population, she showed that the elasticity of poverty with respect to agricultural output is much larger than it is in other sectors. Ravallion and Datt (1996) used a long-time series data of India to explain poverty with the output from the different sectors of the economy. They found a large elasticity of poverty with respect to the primary output. The primary sector was more effective at poverty alleviation than industry. Thorbecke and Jung (1996) also used the additive property of the FGT poverty measures and a Social Accounting Matrix (SAM) to decompose the contribution of each sector to poverty alleviation. The authors applied this methodology to Indonesia and found that the primary sector had a larger contribution to poverty alleviation than the industrial sector and a slightly larger one than the service sector. Khan (1999) applied the same methodology with data from South Africa and reported similar evidence. Warr (2001) also provided evidence that the growth of agriculture in a number of South East Asian countries significantly reduced poverty but this was not matched by the growth in manufacturing. Gallup et al. (1997) showed that every 1% growth in per capita agricultural Gross Domestic Product (GDP) led to 1.61% growth in the incomes of the poorest 20% of the population. The agricultural role was much greater than the impact of similar increases in the manufacturing or service sectors.

In China, the role of agriculture in rural poverty reduction was also estimated by Ravallion and Chen (2007). A detailed discussion about the relationship between economic progress and rural poverty reduction was presented by them. They adjusted the rural poverty lines according to the cost of living by region and found that the agricultural sector played a far more important role in rural poverty reduction than the secondary or tertiary sources of GDP from 1980 to 2001 using the model of the impact of the output composition of growth on poverty presented by Ravallion and Datt (1996). Numerous other studies have also revealed similar results but emphasize the important qualification that the degree to which agricultural growth reduces poverty is usually conditional upon the initial level of inequality (Bourguignon and Morrison, 1998; Timmer, 1997; de Janvry and Saddoulet, 1996; Anríquez and Stamoulis, 2007). Using household data of 60 rural villages in six provinces, Huang et al. (2005b) studied the impact of irrigation on rural incomes, poverty, and the income distribution in rural China. Their results demonstrate that irrigation increases income and reduces poverty and inequality. However, they also indicated that their policy recommendation does not support the increase of irrigation at any cost.

Since many poor people depend deeply on the agricultural sector, this might be the reason that agricultural development plays a more pro-poor role than other sectors. However, under certain conditions, migration from rural to urban areas may be more important to poverty reduction than rural economic growth (Fields, 1980; Anand and Kanbur, 1985). During the process of development, the secondary and the tertiary industries need more labors than before; thus, they can provide many non-agricultural job chances for the rural people. As a result, many poor people can escape the poverty trap. According to a study on Vietnam (Van De Walle and Cratty, 2004), the determinants of both poverty incidence and participation in rural off-farm activities are modeled as functions of household and community characteristics using comprehensive national household surveys for 1993 and 1998. They insist that participation in the emerging rural non-farm market economy will be the route out of poverty for some, but certainly not all. By using cross-sectional data from Ethiopia, Kenya, and Uganda, Matsumoto et al. (2006) estimate the determinants of the participation in local non-farm activities and migration at the individual level and then the determinants of farm and nonfarm income. Their results suggest that local non-farm activities and migration offer employment opportunities for workers from low-potential agricultural areas. Indeed, non-farm activities and migration are likely to provide an important pathway to reduce poverty in low-potential agricultural areas in East Africa.

From the above studies, it is a fact that agricultural growth is more pro-poor than that of other sectors. This seems to be substantiated in poor countries such as India, as well as in middle-income countries such as South Africa and China. However, considering the slowed-down speed of rural poverty reduction in recent years, it is essential to study the effective factors of agricultural development in rural poverty reduction.

2.3 Influences of Resource Scarcity on Sustainable Development

2.3.1 General Theories about Resources, Development, and Poverty

By combining the definition of sustainable development with the problem of water scarcity in northwest China, the concept of sustainable agricultural development includes the protection of the environment, the improvement or maintenance of farm income, the reduction of rural poverty, and the reduction of agricultural water consumption during development.

Recent literature (World Bank, 1992; Grossman and Krueger, 1995; Arrow et al., 1996) demonstrates another kind of nonlinearity for countries that do not avoid a U-shaped curve relating to economic growth and environmental quality on the basis of cross-sectional data. As income per capita rises, environmental quality gets worse and then improves. This may be due to the fact that the income elasticity of demand for a better environment is positive, partly because the pollution intensity of production changes as a country's output composition shifts from agriculture to manufacturing and then to services and partly because the technological and organization capacity for the abatement of pollution improves as a country becomes richer to offset the increasing pollution attendant on the growth process.

This U-shaped relationship, however, does not warrant complacency on environmental matters in poor countries (Grossman and Krueger, 1995). First of all, the relationship has been shown only for emissions of a few air and water pollutants, not generally for resource stocks or stocks of waste. Second, a relationship observed in cross-country data does not imply that, for a given poor country, the environment will automatically improve with income over time. Third, some resources will never recover.

Similar to the theory of U-shaped curve, another useful set of environmental theories that serves to explain the aspects of the relationship between environmental resources and economic development is that known as the Karshenas Curve (Allan and Karshenas, 1996). Allan and Karshenas isolated what they considered to be two key variables. The independent variable consists of the stock of environmental resources, such as water that is available to a political economy. This variable is plotted on the horizontal axis, with a critical threshold being the minimum beyond which development would become unsustainable. This is evident as the vertical dotted line on Figure 1.3, with the area to the left of that representing ecological catastrophe. The dependent variable is the standard of living, and this is plotted on the vertical axis. A critical threshold in this regard being the minimum standard of living is shown as a horizontal dotted line in Figure 1.3, with the area beneath that representing a Malthusian catastrophe. The concept of water and sustainable development can thus be represented graphically as coinciding with the area on the graph above these two minimum threshold points. In other words, sustainable development would exist in the upper right-hand portion of the graph.

The Karshenas curve shows that, in theory, as a political economy starts to develop, it initially reduces its stock of environmental capital (water). This developmental trajectory may cross the threshold into un-sustainability, but then, through a series of policy interventions, the government can change this trajectory sufficiently to bring the curve back into the area of sustainability. This is shown in the left-hand graph of Figure 1.3. In reality, the political economy concerned may not show evidence of crossing the threshold that is represented in the left-hand graph. The graph on the right-hand side shows what happens in reality in many developing countries found in sub-Saharan Africa. As the country tries to develop, it consumes its stock of environmental resources, such as water, but fails to translate this into an improvement in the standard of living for its citizens. These theories provide a theoretical basis for the government's interventions.

Bardhan and Udry (1999) described the two-way relationship between poverty and environment degradation. For their daily livelihood, the poor, particularly in rural areas, depend on local environment resources, such as forests, fisheries, grazing lands, and irrigation water. The local commons also provide some insurance for the poor as a fallback source of food and fodder in bad crop years. With the erosion of the local commons, the decimation of forests and grazing lands, the silting and increasing toxicity of rivers and ponds, the depletion of aquifers, and soil erosion and desertification, the life of the rural poor has become more insecure and impoverished in many parts of Africa and South Asia. In many countries, such depreciation of the environmental resource base has been disproportionately costly for the poor. The other side of the relationship between poverty and environmental degradation is that poverty in turn drives people to desperate short-run mining of land and water and to other intensive resource extraction, straining the already fragile and limited environmental base sometimes beyond the possibility for repair and renewal. This two-way relationship suggests yet another way in which it is difficult to escape from the vicious circle of poverty.

There is also an inverted-U-shape hypothesis to explain the relationship between income inequality and development. Based on available data, Kuznets concluded that inequality in income distribution in advanced economies decreased from the 1920s, especially with large reductions before and after World War II (Kuznets, 1955). Furthermore, in the absence of reliable data, he considered it possible that inequality increased in the earlier period. According to his conjecture, if historical data are available to draw the measure of inequality, such as the Gini coefficient, in the vertical axis in association with average income per capita in the horizontal axis, the relationship would be curved in an inverted-U shape with an initial phase of increasing inequality succeeded by a phase of decreasing inequality. This is the famous Kuznets inverted U-shape curve theory.

If the water resource is taken as an example, the above theories describe the relationship between water consumption and development as well as the relationship between water consumption and poverty. General views present the idea that water resources per capita will improve with development. However, such improvement will not be achieved in all cases. So far, there is no evidence to show that all of the natural resources per capita decrease first and then increase during the process of development for developed countries. In the droughty northwest, since the subsistence agriculture consumes most of the water, there should be some measures to switch the present water consumption pattern to a water-saving one.

2.3.2 Water Scarcity and Its Influences on Poverty and Agriculture

Now, many arid countries and regions are confronting the problem of water shortage, and they are failing to mobilize sufficient social resources to make the adaptation effectively. The water crisis in China is more serve and urgent than that in most countries worldwide. Its water availability per capita is only about a quarter of the world average and is expected to get worse in the near future.

China's mean annual precipitation is 648 mm (FAO, 1999). The scarce amount of this resource is unevenly distributed throughout the country. In the coastal areas of the southeast and some regions of the southwest, the mean annual precipitation exceeds 2,000 mm. It exceeds 1,000 mm in the south of the middle and lower reaches of the Yangtze River; it is between 400 and 800 mm in the Huaihe River basin, the northern plains, and northeast and central China; it is less than 400 mm in parts of northeast China and most of the hinterland in the northwest; and it is even less than 25 mm in the Tarim and the Qaidam basins. Precipitation is one of the most important ways to form the runoff and to supply the groundwater. Thus, low precipitation produces arid areas in northwest China. Based on the data of NBSC (2007), the annual precipitation of the provincial main cities is described by Fig 1.4. It shows that the precipitation in the five provinces in the northwest is very low and none of them is above the average precipitation for all of China.

From the 1940s, population increase and social economic development increased large-scale water consumption and caused significant hydrologic and eco-environmental changes in northwest China. Now, in the Hexi Corridor, the Junggar Basin, and the Tarim Basin, the utilization of water resources already exceeds 65%, which is much higher than 30%, the world's average in arid regions (Wang and Cheng, 2004). As a result, rural poverty incidence is much higher in the northwest, and its agricultural sustainable development has been threatened for many years.

Water shortage is always accompanied by the problem of poverty in the world. Barker, van Koppen, and Shah (2000) demonstrate that poverty persists in many of the rain-fed and upland areas, the so-called marginal areas, most of which can be described as water-scarce. Much of sub-Saharan Africa, with its lack of developed water resources, fits this category. Despite the apparently wide range of potentially useful technologies, efforts to increase productivity and alleviate poverty have thus far met with limited success. They also show that irrigation has played a major role historically in poverty alleviation by providing food security, protection against famine, and expanded opportunities for employment both on and off the farm. The development of irrigated agriculture has been a major engine for economic growth and poverty reduction.

Now about 21.5 million people were still classified as living in absolute rural poverty (annual income less than 693 Yuan) and 35.5 million people as having low income (annual income less than 958 Yuan) in rural China in 2006 (RSDNBS, 2007). See Table 1.4. Some researchers (Han and Zhao, 2005) argue that the essence of rural income poverty in the western region is water poverty. About 64% of the remaining rural poor (13.7 billion) and 62% of the low-income rural people (21.0 billion) are concentrated in west China; thus, the incidence of rural poverty is much higher than that of other areas. In Qinhai Province, the rural incidence of absolute poverty is still high, being above 10%. In Inner Mongolia, Guizhou, Yunnan, Shaanxi, and Xingjiang, the rural incidence of absolute poverty is also high ranging between 5%-10%. With regard to low-income people, the incidence is high, being above 10% in Guizhou, Yunnan, Shaanxi, Gansu, and Xingjiang Provinces. However, in east China, the incidence of rural poverty decreased to 0.3%, and the incidence of low-income individuals decreased to 0.7%.

It is not surprising that the poorest regions are always those with low precipitations. As the most effective sector in reducing rural poverty, agricultural development shows regional characteristics mostly because of differences in water resources. In the past, since the areas of transportation and information technology were underdevelopment, subsistence farming was the main agricultural development form in the whole China. As a result, the food crop share of crop cultivation areas does not differ significantly (see Table 1.5). This table shows that the food crop share of crop cultivation areas in the west was 5% higher than that in the east, where the water resources are rich, and only slightly lower than that in the middle. Although there are no great differences in the food crop shares in different areas, the yields differ significantly (see Table 1.6). In this table, it is evident that the food yields in the west are much lower than those in other areas. On the contrary, the cash crop yields, such as that from cotton, are much higher in the west. According to the comparative advantage theories, the west should produce cash crops other than food crops. However, the west cultivates as many food crops as other areas, and it does so mainly because of food security. Clearly, the high food crop share in the west contributes to the high incidence of rural poverty.

Due to over-exploitation of groundwater, food production will be adversely affected in the arid areas (Barker, van Koppen, and Shah, 2000). With rapid increase in water demands, the competition among household, industrial, environmental, and agricultural water consumption has been escalating in many regions in China (Rosegrant and Cai, 2002). These developments raise the question of whether water scarcity will constrain sustainable agricultural development in the arid regions.

3 Hypotheses, Objectives, and Outline

3.1 Hypotheses and Objectives

The studies referenced above show that the range of sustainable development is very wide. It not only means to improve the standard of living to alleviate rural poverty but also to protect the environment to produce developmental, societal, and environmental harmony. In China, agricultural development can be expected to be an important way of reducing rural poverty, since it is still the main income source for most farmers in poor areas. Improving the technical efficiencies of the farmers can also ameliorate farm income. In addition, the agricultural sector also plays an important role in protecting the arable lands from desertification in some droughty marginal areas. However, this sector consumes most of the water resources; thus, the latent water resource cannot support the present agricultural practices in a sustainable way.

According to the economic theories that have been introduced about the relationship between development and environment, development trumps environment in the early stage of development. However, we expect that development can be consistent with environment if the developing areas implement acceptable management methods of agriculture. This is the hypothesis of this study.

In this study, it is assumed that, to prevent the droughty areas from falling into the two-way relationship between poverty and environmental degradation, technical efficiency should be improved on the farm, and subsistence farming should be converted to water-saving commercial farming. Therefore, for the droughty northwest, sustainable agricultural development should meet the three following conditions: reducing the remaining rural poverty by improving farm income, reducing agricultural water consumption to a feasible level, and protecting the arable lands from desertification.

Although much of the literature has shown that irrigation is important to reduce rural poverty, none of the studies focused on its dynamic role. In addition, there has been no research to show the different roles of irrigation on different crops and how to obtain a sustainable agricultural development model with limited water resources in droughty areas. Therefore, the overall objective of this study is to identify a type of sustainable agricultural development that is suitable for the droughty northwest China. Specific objectives addressed in this study are as follows: (1) to analyze the relationship between agricultural development and the reduction of rural poverty and to measure the role of irrigation in the reduction of rural poverty from a dynamic view; (2) to study the role of irrigation in crop production and ways to improve the technical efficiency on the farm; (3) to simulate ways to achieve sustainable agricultural development under the limitation of available agricultural water consumption.

However, Northwest China is an enormous area. Its farming structure varies in accordance with the resource distribution in different areas. This study examines Minqin County of Gansu Province as a case study for ways to obtain sustainable agricultural development with limited water consumption. Minqin County is a typical droughty area of Northwest China (see Fig. 1.5). It is surrounded by deserts on three sides, and its groundwater level decreases from the south to north. The available water resources cannot meet the needs of agricultural development over a long time. Minqin County is a good example to demonstrate the main objective of this study. The details supporting this idea are introduced in the next chapter.

3.2 The Outline of This Study

This dissertation has 7 chapters (see Fig. 1.6).

The background, literature reviews of the theories and past studies, and the hypothesis and objectives of this study are introduced in Chapter 1. This chapter shows that, in the droughty northwest, sustainable agricultural development has to meet three conditions: to improve or at least to maintain farm income, to sufficiently reduce agricultural water consumption, and to protect arable lands from desolation.

The experience of poverty reduction in rural China from 1988 to 1998 is measured in Chapter 2, and its implications about how to improve the irrigation ratio to reduce the remaining rural poverty in the droughty northwest is also discussed in this chapter.

Since the droughty northwest is very large, it is difficult to obtain a general type of sustainable agricultural development. Therefore, Minqin County of Gansu Province will be used as a case to study for methods to obtain a sustainable agricultural development with limited agricultural water consumption in the droughty marginal area. The problem of serious water scarcity will be introduced, and ways to obtain sustainable agricultural development with limited water resources will also be discussed. Before the detailed analyses, the case study site of Minqin County will be introduced in Chapter 3. In this Chapter, the reasons for selecting Minqin as a case study site, its subsistence-oriented farming, its water scarcity, and the way in which farmers share groundwater are introduced. The studies of Chapters 4, 5, and 6 are based on the data of field surveys that were conducted in Minqin County in 2005 and 2006.

Chapters 4 and 5 explain the role of irrigation on cotton and wheat production and provide an analysis of the reasons for the variation in technical efficiency. In Minqin County, cotton is the commonest water-saving cash crop, and wheat is the commonest water-intensive food crop. Improving technical efficiency not only helps improve farm income but also contributes to the change from the present subsistence-oriented farming to water-saving commercial farming. Chapter 4 is an analysis of ways to improve the technical efficiency of cotton farmers. This study has the potential to assist farmers who want to increase their farm income and their scale of cotton cultivation.

Chapter 5 will assess the roles of irrigation on different patterns of wheat production in two survey plots that have different groundwater levels but share the same groundwater resource. This study can serve as a guide for wheat farmers who want to improve their technical efficiency and practice a sustainable use of groundwater.

By comparing the influence of water scarcity on different crops, we hope to identify methods for adjusting farming practices. Methods for developing sustainable agricultural practices with limited water consumption are discussed in Chapter 6, along with estimates from a linear programming model.

Finally, Chapter 7 includes the following: the summaries of the roles of irrigation on rural poverty reduction and main production; the reasons for the technical efficiency of farming two main crops; and a discussion of sustainable agricultural development in a case study of Minqin County. Some implications from this study and the remaining subjects are also presented in the last chapter.

Tables and Figures

Table 1.1 Real Economy Annual Growth Rates of China from 1978 to 2006

Index of last year =100.

Year	Gross Domestic Product	Agricultural Sector	Industry Sector	Tertiary Sector	Per Capita GDP
1978	111.7	104.1	115.0	113.8	110.2
1979	107.6	106.1	108.2	107.9	106.1
1980	107.8	98.5	113.6	106.0	106.5
1981	105.2	107.0	101.9	110.4	103.9
1982	109.1	111.5	105.6	113.0	107.5
1983	110.9	108.3	110.4	115.2	109.3
1984	115.2	112.9	114.5	119.3	113.7
1985	113.5	101.8	118.6	118.2	111.9
1986	108.8	103.3	110.2	112.0	107.2
1987	111.6	104.7	113.7	114.4	109.8
1988	111.3	102.5	114.5	113.2	109.5
1989	104.1	103.1	103.8	105.4	102.5
1990	103.8	107.3	103.2	102.3	102.3
1991	109.2	102.4	113.9	108.9	107.7
1992	114.2	104.7	121.2	112.4	112.8
1993	114.0	104.7	119.9	112.2	112.7
1994	113.1	104.0	118.4	111.1	111.8
1995	110.9	105.0	113.9	109.8	109.7
1996	110.0	105.1	112.1	109.4	108.9
1997	109.3	103.5	110.5	110.7	108.2
1998	107.8	103.5	108.9	108.4	106.8
1999	107.6	102.8	108.1	109.3	106.7
2000	108.4	102.4	109.4	109.7	107.6
2001	108.3	102.8	108.4	110.3	107.5
2002	109.1	102.9	109.8	110.4	108.4
2003	110.0	102.5	112.7	109.5	109.3
2004	110.1	106.3	111.1	110.1	109.4
2005	110.4	105.2	111.7	110.5	109.8
2006	111.1	105.0	113.0	110.8	110.5
Average	109.8	104.6	111.6	110.8	108.6

Data Source: NBSC (National Bureau of Statistics of China), 2007.

Table 1.2 Absolute Rural Poverty Line and Rural Poverty of China

Year	Poverty Line (Yuan/Person/Year)	Numbers of Rural Poor People (Million)	Share of Rural Population (%)
1978	100	250.0	30.7
1985	206	125.0	14.8
1986	213	131.0	15.5
1987	227	122.0	14.3
1988	236	97.0	11.1
1989	259	102.0	11.6
1990	300	85.0	9.4
1991	304	94.0	10.4
1992	317	80.0	8.8
1993	350	75.0	8.2
1994	440	70.0	7.7
1995	530	65.0	7.1
1996	580	58.0	6.3
1997	640	50.0	5.4
1998	635	42.0	4.6
1999	625	34.0	3.7
2000	625	32.0	3.5
2001	630	29.3	3.2
2002	627	28.2	3.0
2003	637	29.0	3.1
2004	668	26.1	2.8
2005	683	23.7	2.5
2006	683	21.5	2.3

Data Source: RSDNBS (Rural Survey Department of National Bureau of Statistics), 2004 and 2007.

Table 1.3 China's Rural Poverty Incidences and Scales in the past Three Phases

Phases	Poverty Incidences	Poverty Scales	Annual Reduction Rates
1st Phase (1978-1985)	31%-15%	250-125 million	2.29%
2nd Phase (1986-1993)	16%-8%	131-75 million	1.14%
3rd Phase (1994-2000)	8%-3%	70-32 million	0.83%

Data source: Poverty Incidences and Poverty Scales are from RSDNBS (2001) and Annual Reduction Rates are calculated by the author according the corresponding data.

Table 1.4 Distributions of Rural Poor and Low Income People by Areas in 2006

Unit: 10 thousands; %

Areas	Absolute Poor People		Low-Income People	
	Population	Incidence	Population	Incidence
The whole China	2,148	2.3	3,550	3.7
East	112	0.3	226	0.7
Middle	560	2.0	1,041	3.7
West	1,370	4.8	2,196	7.7
Northeast	107	1.9	87	1.8

Data Source: RSDNBS (Rural Survey Department of National Bureau of Statistics), 2007.

Table 1.5 Food Crops Cultivation Areas' Shares by Areas

Unit: %

Regions	2002	2003	2004	2005	2006
East	63.1	60.5	61.2	63.0	63.1
Middle	69.2	67.9	69.4	70.1	65.3
West	69.2	66.8	66.8	66.9	65.0
Northeast	-	-	-	-	85.9

Data source: Ministry of Agriculture of China, 2007.

Note: food crops include rice, wheat, maize, soybean and potato.

Table 1.6 Yields of Main Crops by Areas in China

tons/ha

2006	Food Crops	Cereal	Wheat	Corn	Cotton
East	3.39	4.92	5.10	5.53	1.08
Middle	3.28	4.65	4.93	5.25	1.11
West	2.56	3.26	3.35	4.80	1.66
Northeast	4.05	4.11	3.75	6.07	1.50
2002					
East	3.03	4.34	4.31	4.82	1.09
Middle	3.06	3.85	3.84	5.22	1.03
West	2.67	3.16	3.05	4.51	1.52

Note: the yields are calculated by the author. The original data are from Ministry of Agriculture of China, 2003 and 2007.

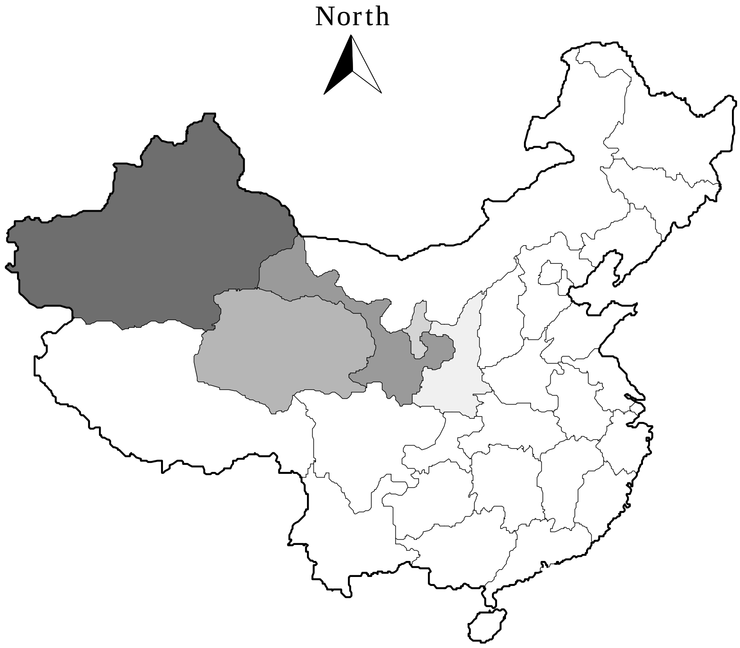


Fig. 1.1 The Position of Northwest China

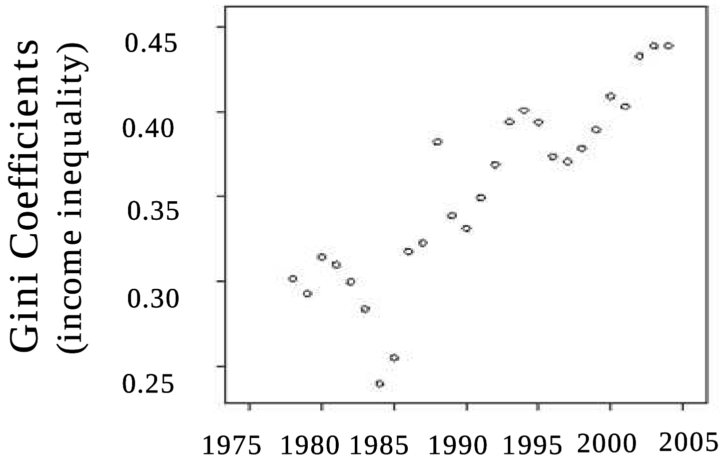


Fig. 1.2 Changes of China's Gini Coefficients

Data source: Ya HE, 2007.

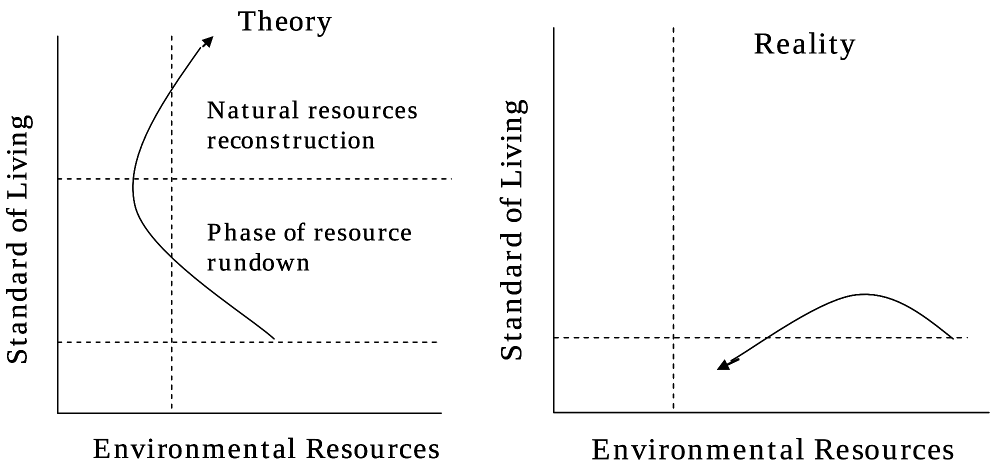


Fig. 1.3 Karshenas's U-Curve of Environmental Resources and Economic Development

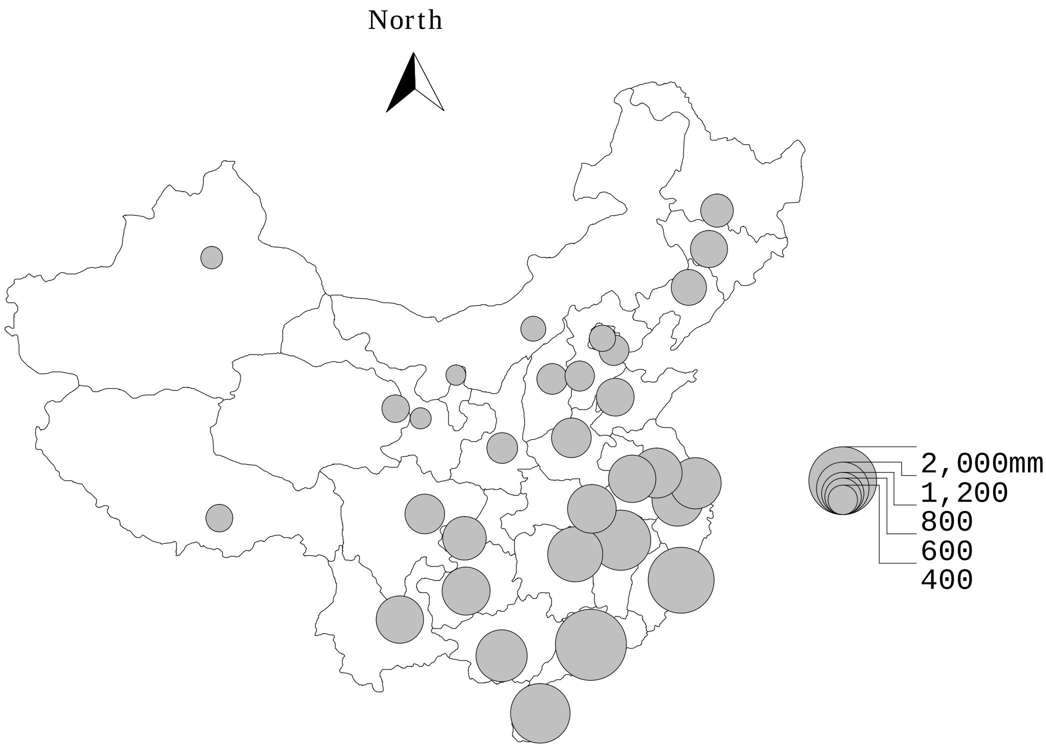


Fig. 1.4 Annual Precipitation in China by Regions

Data Source: NBSC, 2007.

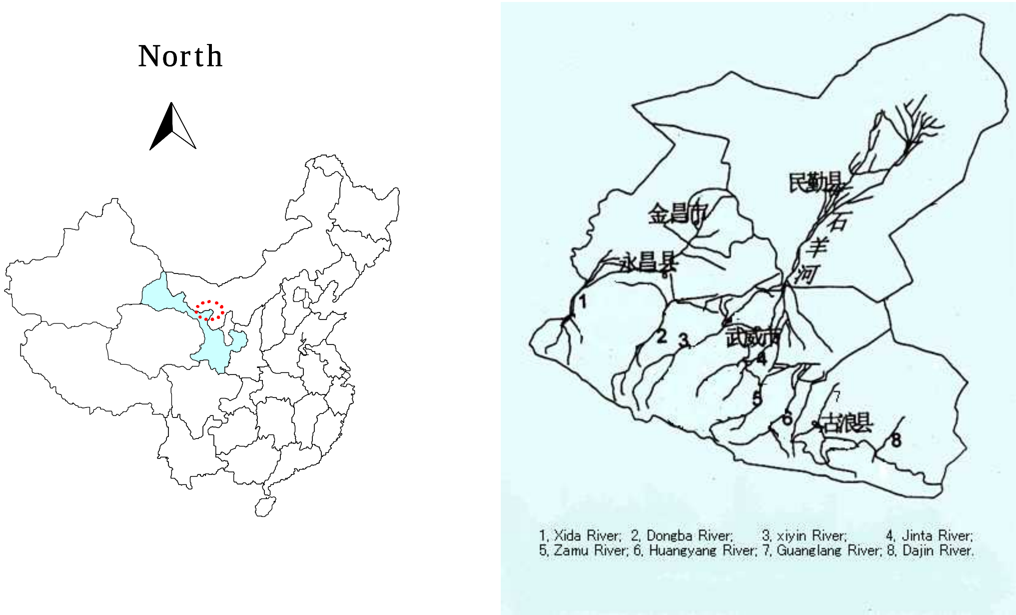


Fig. 1.5 The Position of Minqin County, Gansu Province

Data Source: The author finished the right figure based on the map of Shiyang River Valley provided by Bureau of Water Resources of Minqin County in 2005.

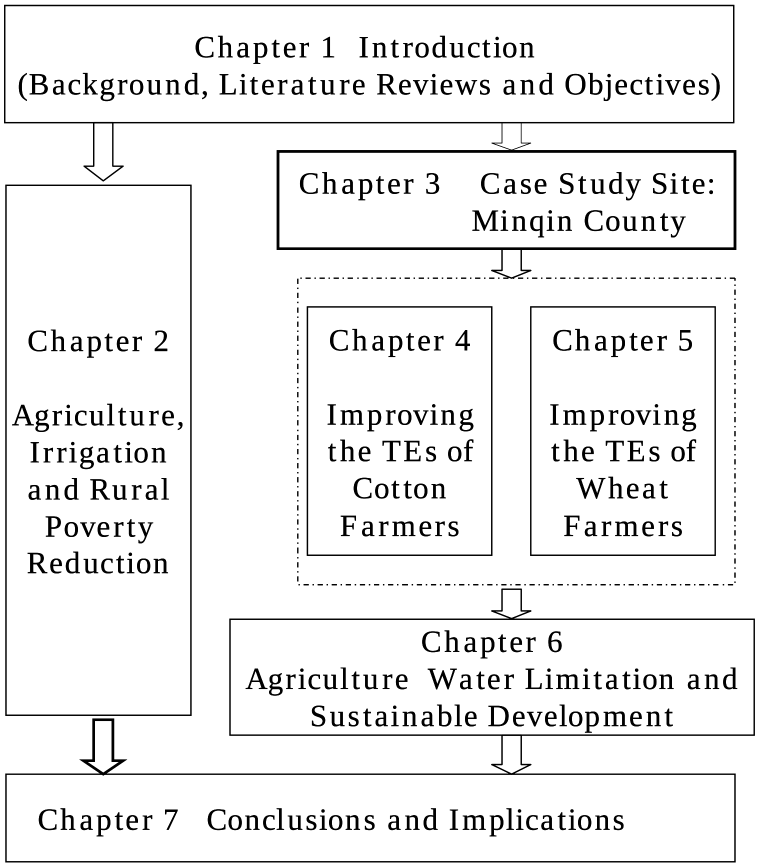


Fig. 1.6 The Outline of the Dissertation

Chapter 2
Agricultural Development and Factors Contributing to Rural Poverty Reduction in China: 1988 to 1998

1 Introduction

De-collectivization of the agricultural land system, which transferred the ownership of farm goods to the farmers directly, benefited a bulk of rural poverty, whose livelihoods were closely linked to small-scale subsistence agriculture in the rural China. Since agriculture was the primary income source for most farmers, it played a greater role in reducing rural poverty than either the secondary or the tertiary sectors (Ravallion and Chen, 2007). In many areas of densely populated countries, land parcels are small and fragmented. This is detrimental to agricultural development. Although opportunities for productivity gains still exist, there is a general pessimism emerging for the role of agricultural growth in rural poverty reduction. There is a concern that agriculture will not be sufficient for sustaining the rapid populations increase in the future. Currently in China, the distribution of rural poverty has a very close relation to the economic levels after a period of development. Many researchers like to divide China into three groups: the east, middle and west according to the economic levels of these areas. Now the rural poor people mainly concentrate in Western China, where the economy, especially the secondary and the tertiary industries, are less developed. The most droughty five provinces-Shaanxi, Gansu, and Qinghai provinces, Xingjiang•Uygur and Ningxia Hui autonomous regions-are defined as the northwest which is included by the west of China. In the droughty northwest, its rural poverty incidence is even much higher comparing to other areas in the west of China. It is said that the droughty climate is very un-benefit not only for agricultural development but also for the rural people to run from poverty.

By 2000, China had experienced three phases in the reduction of rural poverty according to the differences in policies issued by the Chinese central government. The first phase was from 1978 to 1985; the second phase, from 1986 to 1993; and the third phase, from 1994 to 2000 (see Table 1.3). In the first phase, rural poverty decreased sharply due to the issue of the Household Contract Responsibility System (HCRS) which significantly improved agricultural productivity (Ravallion and Chen, 2007). In the second phase, programs were created to reduce rural poverty, since the HCRS could not effectively reduce rural poverty any further. In the third phase, the geo-typical rural poverty arose. During the phase, most rural poverty concentrated in the areas identified as mountains and droughty areas. The government invested money and provided supplies in the regions identified as national poverty-stricken counties. However, the government's activities contributed little to rural poverty reduction. The above results are supported by the data in Table 1.3, which shows that rural poverty decreased sharply in the first phase but slowed down from the second phase to the third phase. From 2000 to 2004, the rural poverty head-count ratio remained at around 3% (RSDNBS, 2007) although the economic growth stayed at a high rate (NBSC, 2005). For China to further reduce rural poverty after a long period of sustained reduction seems a difficult proposition.

After a period of reduction, in the east of China, rural poverty is no longer a serious social problem. Currently, around half of the rural poverty concentrates in the west, where the economic is less developed and the environment is also harder. For China, to reduce the remaining rural poverty mainly means to reduce the poor in the less developed regions. To combine past experiences of rural poverty reduction with the present situations is thought to be a better method to obtain the objective. However, the collected provincial data, which fixed the research period of this study, were only from 1988 to 1998, lacking the years of 1990 and 1993. According to the Developmental Stage Theory, the past experiences of rural poverty reduction of the whole China still deserve it especially the less developed west regions to learn how to reduce its poor people.

The following section 2 will introduce some literatures about the relationship between poverty reduction and economic growth, especially agricultural growth; section 3 will analyze and measure some detailed factors contributing to rural poverty reduction; section 4 presents the estimation results and discussions; the final section 5 offers conclusions and likely implications.

2 Rural Poverty Reduction and Agricultural Development

Since the beginning of practicing the HCRS and the Reform and Opening up Policy from 1978, China achieved markedly in rural poverty reduction. Economic growth, particularly agricultural growth, is reported to greatly benefit rural poverty reduction when the national average income is at a low level (Hossian, Gascon, and Marciano, 2000; and NBSC, 2004). In China, agriculture grew fast in the first phase of rural poverty reduction when the new farmland policy-HCRS-markedly reduced rural poverty. Half of the decline in numbers of rural poor people occurred from the late 1970s to the early 1980s. According to the China's poverty standard, the numbers of rural poverty reduced from 250 millions to 125 millions (see Table 1.3) and the poverty incidence also decreased from 30.7% to 15.1% respectively (see Figure 2.1) from 1978 to 1985. Past experiences showed that different rates of poverty reduction had been closely related to the differences in agricultural performance not only in China but also in many less developed countries. The growth in agriculture has been consistently shown to be more beneficial to the poor than the growths in other sectors (Hossian, 2001; Ravallion and Datt, 1996;

Ravallion and Chen, 2007). Ravallion and Chen (2007) showed that rural sector growth reduced poverty in both rural and urban areas in India. They also presented a detailed discussion about the relationship between economic growth and rural poverty reduction in China. They adjusted the rural poverty lines according to the cost of living and found that agriculture played a more significant role in rural poverty reduction than the secondary or tertiary sources of GDP from 1980 to 2001. Numerous other studies have also revealed similar results but emphasize the important qualification that the degree to which agricultural growth reduce poverty is usually conditional upon the initial level of inequality (Bourguignon and Morrison, 1998; Timmer, 1997; de Janvry and Saddoulet, 1996; Anríquez and Stamoulis, 2007).

The close relationship between rural people and agriculture makes agriculture play a great role in rural poverty reduction. Many experiences show that the secondary and the tertiary industries cannot decrease rural poverty like agricultural sector (Ravallion and Chen, 2007). But under certain conditions, migration from rural to urban may be more important to poverty reduction than rural economic growth (Fields, 1980; Sudhir and Kanbur, 1985). During the process of development, the secondary and tertiary sectors also provided rural people with non-farm jobs; thus, many rural poor people benefited from the development of these sectors.

Recently, both agricultural growth and rural poverty reduction have slowed in China. Although China succeeded in rural poverty reduction, there are still 26.1 millions, who are classified as the absolute rural poverty with annual income less than 650 Yuan, and 60 millions, who are classified as low income people with annual income less than 800 Yuan, in rural China in 2004 (RDSNBS, 2007). Poverty is an economic problem, but the distribution of the current rural poverty shows a very close relationship to the environmental conditions. Most remaining rural poverty concentrates in the west where the economic activity level is low and the environment is unhealthier. Currently, in the east rural poverty is not a serious social problem any more. Table 2.1 compares the differences in rural poverty situations among the three areas and shows that both poverty scale and poverty ratio are much higher in the west of rural China. Further reduction in the rural poor people, who concentrate in the west, is a tougher task for China.

Most past studies about poverty reduction concentrate on the contributions of the three sectors growths. To our knowledge, there is no a researcher to study poverty reduction from the dynamic point of view. The following study is the first time to estimate and compare rural poverty reduction in China in two sub-phases. China has no possibility to issue an effective policy like HCRS, which improved agricultural development greatly, to reduce the remaining rural poverty any more. Learning experiences of rural poverty reduction from the second and third phases will contribute to providing some valuable suggestions of reducing rural poverty.

3 Model

3.1 Identify the Routes of Rural Poverty Reduction

Ravallion and Datt (1996) and Ravallion and Chen (2007) split the economy (Y) into three sectors (the primary (Y_1), secondary (Y_2), and tertiary (Y_3) components) so that $Y = Y_1 + Y_2 + Y_3$ and noted that the rate of growth in Y could be approximated by the sum of the share-weighted growth rates of the three sectors. And then they estimated the roles of each sectors in poverty reduction. However, they did not analyze what kinds of detailed factors contributed to poverty reduction from the dynamic point of view. Their models also could not identify the routes of non-farm sectors benefiting rural poverty reduction. Based on their theory of economic development contributing to poverty reduction, a model is constructed not only to indentify the route of economic growth benefiting rural poor people but also to confirm the detailed factors, which contribute to rural poverty reduction, using provincial pooled data from the dynamic point of view.

China's economic development, particularly agricultural development, has clearly played an important role in the country's long-term success against rural absolute poverty. However, economic development cannot do all things to rural poverty reduction. Some factors, such as the fluctuation of rural consumer price and the unhealthy environment might also affect the process of rural poverty reduction. Based on the experiences of many countries that economic growth contributed significantly to poverty reduction and the analyses in section 2, the routes of rural poverty reduction can be concluded as: 1) agricultural development, which is the primary income source of farmers, 2) non-farm sectors development, which provide employees to rural migrants, and 3) others. The following function (1) is constructed to identify the relationship between rural poverty (p) and agricultural production (Y_1), non-farm sectors' development (Y_2) and other factors (O).

$$p = f(Y_1, Y_2, O) \tag{1}$$

3.2 Detailed Factors Connecting with Rural Poverty Reduction

There are several poverty indicators, such as head-count ratio (HCR), poverty gap ratio (PGR) and income gap ratio (IGR) and so on. Since HCR data are easy to understand and obtain, it is taken as the indicator of rural poverty in this study.

Agriculture is different from other sectors since its development is not only affected by traditional inputs but also population variation and damage of natural disaster. Usually, labor is an important traditional input for agriculture. However, since there were two many rural people but per capita arable land was very small, many rural labors stayed in villages and depended on agriculture but could not work as effectively as they could; thus, there were lots of surplus laborers in rural China. The surplus rural labors could not contribute anything to agricultural development and postponed the process of rural poverty reduction. From the middle of 1980s, many farmers went to work in non-farm sectors to improve their families' livings. Providing migrant farmers with non-farm jobs was the main route that the development of the secondary and the tertiary sectors benefited rural people. No or low school education is the obstacle for the migrant farmers to get non-farm jobs and also is difficult for them to master the advanced agricultural production technology.

The factors connecting with agricultural development are identified as vector X and the factors connecting with the non-farm sectors to benefit rural poor people as L. Then, function (1) can be rewritten as the following function (2):

$$p = f(Y_1(X), Y_2(L), O) = f(X, L, O) \tag{2}$$

Vector X includes irrigation ratio of farm land, fertilizer consumption, the damage of natural disaster and rural population variation. Irrigation should play a great positive role in agricultural development since the increase of the irrigated land is a main method of improving land productivity and achieving stable yields, especially for the droughty areas. With the globe warming and growth in demand for farm goods, agriculture will depend on the increase of irrigation ratio more and more deeply. Irrigation ratio is taken as an important variable to measure its role in rural poverty reduction. Hossain et al. (2000) and Huang et al. (2005a) also reported the positive impact of irrigation on rural household income. Fertilizer, the indispensable input of agriculture, should also play the positive role in rural poverty reduction. However, its role should gradually decrease with development since there is a law of diminishing marginal benefit between fertilizer increase and yields. In this way, it cannot support agriculture to grow at a high rate for a long period if the agricultural production technology is not improved much. During the study period, rural population markedly increased in China. The increased rural people decreased per capita agricultural outputs and job chances. Therefore, a large rural population should slow down the process of rural poverty reduction. Another factor, natural disaster, which negative damage to agriculture production cannot be completely prevented by farmers, damaged agriculture production frequently and in wide range. Floods, drought, desertification, and storms are the main types of natural disaster in rural China. Natural disaster is also the reason for low-income farm earners returning to poverty (Pinstrup and Pandya, 1995). In 2003, the natural disaster damaged agriculture production heavily so that rural poverty incidence increased for the first time in recent years. In this study, only the land output decreased over 30% by natural disaster was defined as the damaged areas. The share of damaged areas was taken as the variable to measure the damage of natural disaster to rural poverty reduction. Since agriculture was the primary income source for most poor farmers, natural disaster should have had a serious negative effect on rural poverty reduction.

The rural labors employed in non-farm sectors could significantly accelerate the process of rural poverty reduction, since the migrated farmers could get higher income from non-farm jobs. With the development, the role of non-farm jobs on rural poverty reduction should increase since migrated farmers can get increasing income from non-farm jobs; thus, their families could more easily escape from poverty. In addition to the rural labors employed in non-farm sectors, another variable connecting with rural labors, their school education level should likely affect the process of rural poverty reduction, too. The school education level can closely determine if the migrated farmers can get non-farm jobs. In this study, the ratio of educated rural labors whose school education levels were higher than illiterate and semi-literate was taken as a variable to measure the role of school education on rural poverty reduction.

Vector O includes two kinds of factors: rural price indexes (P) and the special characteristic of the droughty areas (D). Generally speaking, the increase in agricultural prices should improve the farmers' farm income and contribute to rural poverty reduction. In contrast, the increase in cost of agricultural production should play the negative role. However, their comprehensive role depends on the differences of their increase range and also the self-consumption part of farm goods by the farmers. If 1) the differences are not big enough and 2) the poor farmers consumed most of produced farm goods, the rural poor people might not benefit much from the increases in agricultural goods. For the low income poor people, another variable, rural inflation level which was explained by rural consumer price index, should impact the farmers' production activities and slow down the steps of the poor getting out of poverty trap. China is usually divided into three parts: the east, middle and west (see Chapter 1). However, the droughty climate of the northwest (see Fig. 1.1) discriminates itself from other areas. Lacking water and desertification make this area be difficult to develop agriculture and also other sectors; thus, the droughty climate should postpone the process of rural poverty reduction in the northwest. Therefore, instead of applying a dummy variable of the west to the poverty reduction model, a dummy variable of the northwest (the five provinces in northwest are given "1", otherwise "0") was applied into the model to measure the effect of the droughty climatic on the process of rural poverty reduction. If the dummy variable of the west is applied to the model, the role of irrigation on rural poverty reduction might not be measured correctly.

All the introduced detailed factors are presented in Table 2.2.

In addition to the dummy variable of the northwest, the following linear logarithm function (3) was applied to measure the roles of the detailed factors in the process of rural poverty reduction:

$$\ln(p) = A + \alpha * \ln(X) + \beta * \ln(L) + \gamma * \ln(P) + \delta * D + \varepsilon \quad (3)$$

where ε is the error term.

4 Estimation Results and Discussions

The HCR data are from Anti-Poverty Office of China's State Council and other data are from official yearbooks, including China Statistical Yearbook, China Agricultural Statistical Yearbook and China Rural Statistical Yearbook, issued by China's National Bureau of Statistics. The rural poverty was no longer a serious problem in Beijing, Shanghai and Tianjin municipalities. Their economic structures are also different from other provinces. In the three municipalities, their shares of agriculture in GDP are lower than 5%, which is much lower than 16.5%, the average share of the whole country (NBSC, 1999). In addition, there are no statistical data about the corresponding price indexes in HaiNan Provinces and Tibet autonomous district. Heilongjiang Province had very low irrigation ratio but Tibet autonomous district had very high irrigation ratio. Therefore, these seven regions are excluded from the estimation in this study.

With the help of estimation software EVIEWS 3.0, the function (3) is estimated by the method of Ordinary Least Squares (OLS). Since some variables, such as the irrigation ratio and per unit area fertilizer usage, might vary in the same trend, the correlation coefficients of four variables (see Note 1), among which the multi-collinearity might occur the most possibly, were measured. The estimation results show that the highest one, 0.70, is still in the allowable limit of no multi-collinearity. Then, the provincial pooled data in the whole period from 1988 to 1998 were estimated. Since the primary objective of this study is to measure the trend of the roles of the detailed factors, Chow-test is applied to judge if it is reasonable to divide the long phase into two sub-phases. The Chow-test shows that it is reasonable to separately estimate the function of rural poverty reduction in the second phase and the third phase. Then, the two phases are estimated separately: the second phase is from 1988 to 1992, and the third phase is from 1994 to 1998. To achieve the most effective factors contributing to rural poverty reduction, the most reasonable results were selected after trying on several occasions (see Table 2.3). The ratio of the sales price index of farm goods to agricultural production cost index did not show any effect on rural poverty reduction; thus, this index ratio variable was dropped from the estimation. This result might be caused by the two reasons which had been explained in the above section. One of the reasons was confirmed by comparing the two price indices of the whole China. During the study period, the above index ratio did not fluctuate much. However, the second possible reason, that the poor consumed most of their produced goods, needs further confirmation. The final estimation results are presented in Table 2.3. The adjusted-R^2 values and F-values are large enough and most of the t-test values are also significant in both results. Since the dependent variable is HCR, the minus coefficient means positive role on rural poverty reduction; and plus coefficient means negative role on rural poverty reduction. Most of the estimated coefficients are consistent with the above analyses. However, White Heteroskedasticity Test reported that the problem of heteroskedasticity existed in the third phase of rural poverty reduction. In order to exclude this problem, Weighted Least Squares (WLS) was applied to estimate the function of rural poverty reduction in the third phase again. There are no great differences between the result estimated by WLS and the result estimated by OLS (see Table 2.3). As a better selection, the result estimated by WLS is finally applied to explain rural poverty reduction in the third phase in this study.

The estimation results presented in Table 2.3 suggest that both the two important factors of agriculture production, irrigation and fertilizer, significantly played positive roles in rural poverty reduction during the two phases. However, the role of the increase in irrigation ratio increased but that of fertilizer decreased by analyzing the coefficients in the two phases. The coefficient of the role of irrigation ratio increased from 0.39 in the second phase to 0.59 in the third phase. But the coefficient of the variable of fertilizer declined from 1.09 in the second phase to 0.70 in the third phase. The improvement in agriculture productivity increasingly depends on the increase in irrigation ratio rather than the increase in traditional inputs, such as fertilizer and labor. Therefore, the increase in irrigation ratio contributed better than that of fertilizer to the process of rural poverty reduction. Huang et al. (2005b) also found that irrigation greatly benefited rural poverty reduction by plot-level data in China. Han and Zhao (2005) presented that the rural income poverty in the west was water poverty and irrigated agriculture had played and also will play a critical positive role in alleviating poverty; however, other inputs such as fertilizer cannot play the same role. Therefore, it was not difficult to understand that the increase in irrigation ratio did an increasing positive role in rural poverty reduction from the second phase to the third phase but the increase in fertilizer usage did not do so.

According to the estimation results, the other two factors connecting with agricultural development: the increase in rural population and the damage of natural disaster had negative effects to rural poverty reduction. The negative role of the increase in rural population increased but that of the damage of natural disaster decreased. In China, with the increase in rural population, the arable lands per capita declined gradually so that the increase imposed great pressure on rural poverty reduction. After a period of development, the rural people should become stronger in preventing the damage of natural disaster. This was confirmed by the estimation results that the negative coefficient of the damage of natural disaster decreased from 0.36% in the second phase to 0.20% in the third phase. Although the negative role of the damage of natural disaster decreased, it still should effectively slow down the process of rural poverty reduction in the near future.

From the middle of 1980s, many town entrepreneurs have appeared in rural China. Thus, the rural labors had two ways to get non-farm jobs: from migrating into the urban or staying in the town entrepreneurs run by the farmers themselves. However, both of them should play an bigger positive role in rural poverty reduction. Some researchers (Sudhir and Kanbur, 1985; Fields, 1980; Ravallion and Chen, 2007) reported that the non-farm jobs significantly contributed to rural poverty reduction. Our estimation results also confirmed that the increase in share of non-farm employment of rural labor had a positive effect on rural poverty reduction. From the second phase to the third phase, the corresponding coefficient increased from 0.50% to 1.43%. In other words, non-farm jobs increasingly contributed to rural poverty reduction. This might be caused by the increasing income that other sectors provided to the non-farm rural labors. Currently, with the increased non-farm income, a whole poor family could get out of poverty much easier than before. Non-farm jobs are still hoped to play an important positive role in reducing rural poverty in the near future. At another hand, the results showed that the share of the educated rural residents played positive role in rural poverty reduction in the second phase but it was played nothing in the third phase (This variable was dropped from the estimation because of the no statistical significance). This can be explained by that rural people could achieve knowledge from production experiences.

Currently, most of the rural poor people concentrate in the areas where the economic levels are low and the environments are harder for development. The estimation results also confirmed the above facts that the droughty northwest was more disadvantage in reduction of rural poverty than other areas. Water scarcity slowed down economic development; thus, the areas with the problem of water scarcity were not benefit for the reduction in rural poverty. However, in the droughty areas, some water-intensive but low-value added crops, such as wheat and corn, were cultivated in large scales because the farmers had to guarantee their food availabilities by themselves. This subsistence-oriented farming limited the farmers' farm income to a low level. Switching the present farming practices to a more water-saving one should result in the increase in irrigation ratio. Thus, water-saving farming practices will contribute to the process of rural poverty reduction. In addition, lacking water resource also limited the development of the secondary and the tertiary sectors so that the rural people in these areas could not get non-farm jobs as many as those in other areas. At another hand, the negative role of the increase in rural consumer price on rural poverty reduction came out in the third phase (1994~1998).

5 Conclusions and Implications

5.1 Conclusions

From the Reform and Opening up began in 1978, it is undeniable that China has gotten great success in rural poverty reduction. However, there are still 26.1 million absolute poor and 60 million low-income people in rural China. Most of them concentrate in the regions with low economic levels and unhealthy environments. Since the effect of de-collection on rural poverty reduction in the first phase of rural poverty reduction is a one-off gain and currently, most of the rural poor people concentrate in the less developed regions, China should learn from the experiences of the reduction in rural poverty after the first phase. This study analyzed and measured the experiences of the reduction of rural poverty in the period of 1988 to 1998 because the availability of the provincial data of HCR was limited to this period. However, according to the development stage theory, the experiences about the reduction in rural poverty in this the studied period still deserve China, especially the droughty northwest to learn. According to our knowledge, the existing studies mainly concentrate on the roles of the three sector growths in poverty reduction from a static point of view. This study is the first time to study the experiences of the reduction in rural poverty in China by dividing the long period into two sub-phases to grasp the possible changing effects of the detailed factors, which might contribute to the reduction in rural poverty, from a dynamic point of view.

Based on the literatures of agricultural sector and other sectors against rural poverty, this study analyzed the detailed factors connecting with agricultural development and identified the route of the secondary and tertiary sectors benefiting rural poor people in China. Their roles were separately estimated during the period of 1988 to 1992 and the period of 1994 to 1998, which were covered by the second and the third phases of rural poverty reduction. The estimation results presented: (1) with the development, the increase in irrigation ratio increasingly played a positive role in rural poverty reduction but the increase in fertilizer usage played a declining positive role; (2) the increase in the share of non-farm rural labors increasingly contributed to the reduction in rural poverty; (3) rural population increase, the damage of natural disaster on agriculture, and rural price inflation disturbed the process of rural poverty reduction; (4) comparing to other regions, the droughty northwest was at a comparative disadvantage in reducing its poor rural people.

5.2 Implications

1) If the reduction in rural poverty is expected to depend on agricultural development, increasing irrigation ratio might help to get this objective. However, increasing irrigation ratio will cost a lot of money and also need a lot of water resource according to the traditional method. This is no an easy work. For example, lacking money and water resource in the northwest make it be very difficult to increase irrigation ratio if the farming practices did not do any change. By introducing water-saving crops or land-saving crops (water-saving farming practices) instead of the prevailing water-intensive subsistence-oriented farming practices, the decrease in water consumption for agriculture can contribute to the increase in irrigation ratio. Thus, how to develop water-saving farming practices is the author's next study subject.
2) The objective of reducing all rural poor people cannot be achieved only by agricultural development. The government should increase non-farm jobs to the poor rural people by creating labor-intensive industries in the less developed droughty areas. It also needs the government to establish agricultural insurance program to compensate the farmers' farm losses from natural disaster.
3) The Chinese government should control the rapid increase in rural consumer price, and also pay attention to the negative influences from population increase on rural poverty reduction.

Note 1: For the second phase, $r_{x_1,x_2} = 0.68$; $r_{x_1,L_1} = 0.44$; $r_{x_1,L_2} = 0.37$; $r_{x_2,L_1} = 0.64$; $r_{x_2,L_2} = 0.54$; $r_{L_1,L_2} = 0.46$. For the third phase, $r_{x_1,x_2} = 0.63$; $r_{x_1,L_1} = 0.58$; $r_{x_1,L_2} = 0.43$; $r_{x_2,L_1} = 0.70$; $r_{x_2,L_2} = 0.62$; $r_{L_1,L_2} = 0.57$. Where x_1 is the irrigation ratio; x_2 is per unit area fertilizer input; L_1 is the share of non-farm rural labors; and L_2 is the percentage of educated rural laborers.

Tables and Figures

Table 2.1 Poverty Incidence and Poverty Scales in the Three Areas in rural China

Areas	1998 ('0000, %)		2004('0000, %)	
	Poverty population	Poverty rate	Poverty population	Poverty rate
East	622.1	1.7	374	1.0
Middle	1558.8	4.8	931	2.8
West	2029.5	9.1	1305	5.7
Whole China	4210.4	4.6	2610	2.8

Data source: RDSBNS, 2001 and 2005.

Table 2.2 Detailed Descriptions of the Variables in Model (4)

Variable	Description
p (Head-count ratio, %)	Percentage of rural people under China's poverty line to rural population
X Vector (Connecting with agricultural productivity or development)	
Irrigation Ratio (%)	Percentage of irrigated areas to arable lands' areas
Fertilizer (kg/ha)	Input of fertilizer per unit area
Population	Rural residents (10,000 people)
Damage of Natural Disaster (%)	Percentage of the arable lands' areas, whose output decreased over 30% by disaster, to the areas of the total arable lands
L Vector (Connecting to rural labors)	
Non-agricultural share (%)	Percentage of rural labors employed in the secondary and tertiary sectors
Educated labors' share (%)	Percentage of non illiterate & semi-literate rural laborers to total labors
O Vector	
Consumer's Price Index (%)	Rural consumer's price indices (last year=100)
Price Index Ratio (%)	Price index ratio of rural consumption price index to production cost
Northwest dummy	Dummy variable: 1 for provinces in the northeast otherwise 0. Northwest includes 3 provinces Shanxi, Ningxia, and Gansu in this study.

Table 2.3 Roles of the detailed Factors Contributing to Rural Poverty Reduction in China

	Dependents	(1) 1988-1992	(2) 1994-1998	
Sample size and Estimation Method		92/OLS	115/OLS	115/WLS
X Vector	Irrigation	-0.39(-2.47***)	-0.59 (-2.82***)	-0.59 (-11.04***)
	Fertilizer	-1.09(-4.38**)	-0.67 (-2.78***)	-0.70 (-10.21***)
	Population	0.31(3.12**)	0.34 (3.18***)	0.34 (16.67***)
	Outside shock	0.36(3.08***)	0.19 (1.70*)	0.20 (7.73***)
L (Labor)	Non-agricultural share	-0.50(-2.89***)	-1.45 (-6.49***)	-1.43 (-41.29***)
	Educated labors' share	-0.42(-0.77)	---	---
O Vector	Northwest dummy	0.73(3.19***)	0.87 (4.24***)	0.82 (14.90***)
	Consumption Price Indices	---	0.90 (1.19)	1.02 (8.84***)
Constant		6.81(2.82***)	5.79 (3.87***)	5.84 (15.72***)
	R^2	0.72	0.73	0.998
	Adjusted-R^2	0.70	0.72	0.998
	F-test	30.79	41.92	2639.81

Notes: (1) The results are estimated by Eviews Software and the data in the parentheses are the t-statistics;

(2) ***, **, and * asterisks on the value of the parameters indicate they are at 1, 5 and 10% significant level, respectively;

(3) Data of head-count ratio (HCR) were from the China Help Poverty Office, lacking data in 1990 and 1993; other data are from China's Statistic Yearbook (1988 to 1999), China Agricultural Yearbook and China Rural Statistic Yearbook (1988 to 1999) provided by National Bureau of Statistics of China.

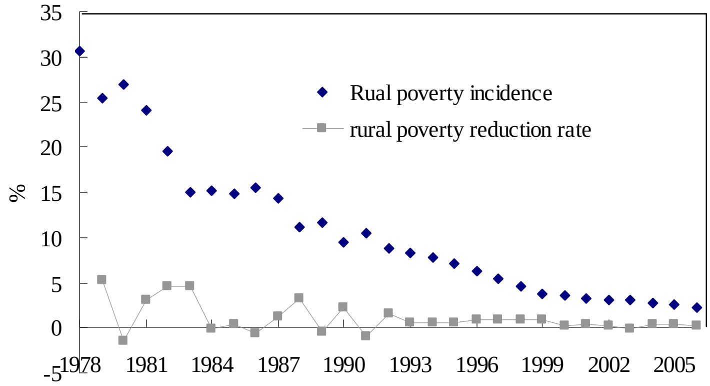


Fig. 2.1 Poverty Incidence and Poverty Reduction Rates in Rural China

Data source: RDSNBS, 2006.

Chapter 3
Case Study Site: Minqin County

1 Reasons for Selecting Minqin as the Case Study Site

Desert, sandy land, and Gobi are about 166.9 km^2, and they make up about 17% of China's landmass (Wang et al., 2003). In the 1960s and 1970s, the speed of desertification was about 1,560 km^2/a; in the 1980s, it was about 2,100 km^2/a; and in the 1990s, it increased to 2,460 km^2/a (Wang et al., 2003). It is obvious that China is undergoing the most serious desertification in the world. If desertification cannot be effectively controlled, the attempt to implement sustainable development in western China will fail. In recent years, severe sandstorms have been appearing more frequently and severely on an expanding scale. This is closely related to human activities and the changing global climate. The northwest covers a large area where sandstorms occur frequently and result in natural disasters. Strong sandstorms occur suddenly and disastrously, and they often result in losses to the national economy and damage to individual lives. In the past two years, very strong sandstorms afflicted northern China several times. They even reached the lower reaches of the Yangtze River.

The causes and expansion of desertification mainly result from natural factors, but irrational human activities also have a significant impact. These include the inappropriate use of land, increasing pressure on the presently productive land brought about by population growth, and undue expansion of urbanization, faulty government policies, and poverty. China is endeavoring to stop desertification by returning farmlands to grasslands or forest. However, this is not reasonable in some of the more marginal regions. Keeping these marginal regions in balance environmentally and developmentally is very important if sustainable development is to be achieved. Minqin

County of Gansu Province is a typical marginal region that borders on deserts on three sides. The deserts are encroaching on Minqin at a rate of 10-20 m/year (Li et al., 2005). The problem of desertification is mainly caused by water scarcity in Minqin County.

Minqin County is in the middle of Gansu Province. More than 94% of the County is desert (Bureau of Statistics of Minqin County, 2007). It is bordered by the Badain Jaran Desert and the Tengger Desert to the west, north, and east, and it borders Wuwei City to the south. The Badain Jaran Desert is the second largest desert in China, with an area of 49.2 thousand km^2 (Wang et al., 2003). It is located to the west and north of Minqin County. The Tengger Desert is the fourth largest desert, with an area of 42.7 thousand km^2 (Wang et al., 2003). It is located to the east of Minqin County and the west of Inner Mongolia. Since Minqin County is surrounded by desert on three sides, it is likened to a green wedge separating the two deserts and protecting them from merging into a larger one. If the Minqin oasis were to disappear, the two deserts would merge into a large one so that the environment of Gansu Province and the entire Northwest China would change from bad to worse. If this were to occur, it would be very costly for China to restore the sandy lands to vegetation. With regard to sustainable development of the northwest and the entire China, Minqin plays a critical role in protecting the environment from desertification.

The annual precipitation of Minqin is 113 mm, but evaporation is high at 2,646 mm (Li et al., 2005). With the development of economic activities from the 1950s, the scarcity of water worsened, and the ecological environment has been severely degraded. The surface water from the Shiyang River has decreased from 542 million m^3 to 80 million m^3 in recent years. Therefore, the consumption of agricultural water depends primarily on groundwater. As a result, the groundwater level is decreasing at a rate of 1 m/3years, and its salinity has been increasing at a rate of 0.02-0.35 g/year from the south to the north. From the 1980s, 135 thousands Mu *Elaeagnus multiflora* forests declined, 350 thousands Mu vegetation disappeared, 200 thousands Mu arable lands became deserts, and 3,950 thousands Mu natural grass lands degenerated. Currently, about 94% of Minqin County is desert. Minqin County, once a beautiful oasis, is now one of desert sources in China. Desertification of Minqin is primarily caused by a water shortage. To prevent the expansion of the desert, reducing water consumption is necessary.

In this marginal Minqin County, agriculture remains very importantly not only as the primary income source for most farmers but also as the territory protecting the two deserts from merging into a bigger one. With the absence of agriculture as a result of drought, the farmers will be forced to leave this area. The farmers are the last holdouts in Minqin County; once they depart, nothing will remain but the desert. Therefore, the continuance of agriculture provides some protection to Minqin, so long as it is sustainable. However, agriculture requires more water consumption than any other sector of society. According to the average water consumption data from 2002 to 2006, agricultural irrigation accounts for approximately 82% of the total water consumption (Bureau of Statistics of Minqin County, 2007). The conservation of water for agriculture would contribute significantly to preserving the arable lands. Since Minqin is a typical droughty area of northwest China, a study of sustainable agriculture there should produce knowledge that would be applicable to similar areas.

2 The Water Resources of Minqin County

2.1 The History of Water Resources in Minqin County

Minqin County is in the lowest reach of the Shiyang River Valley, and it is bordered by deserts on three sides. The only source of surface water is the Shiyang River. Approximately 100 years ago, in northern Minqin County, Qing'tu Lake covered 100 km^2 (Li et al., 2005). At that time, Minqin had very rich water resources, which, along with the widespread arable lands, attracted many people to the area. However, with the development and the population increase in the upper reaches of the Shiyang River Valley, the surface water to Minqin diminished considerably, and, as a result, the last drop of water of Qing'tu Lake disappeared 30 years ago. The residual shells in the sand are the only evidence that there ever was a large lake there.

Eight rivers empty into the Shiyand River Valley. From the west to the east, they are the Xida, Dongba, Xiyin, Jinta, Zamu, Huangyang, Gulang, and Dajin Rivers (see Fig. 1.5). With the climate variation, the water from the main rivers decreased gradually (see Table 3.1). In the 1950s, the total water volume was as high as 1,744.2 million m^3. However, it decreased from 1,418.4 million m^3 in the 1960s to 1,220.9 million m^3 in the 1990s. Compared with this reduction, the surface water to Minqin decreased much more sharply (see Fig. 3.1). In the 1950s, the surface water volume to Minqin was 542 million m^3. However, it decreased sharply to 131 million m^3 in the 1990s. In addition, there is evidence showing that the current trend will be curtailed anytime soon because of the increasing demand for water with the development and population increases along the upper reaches of the Shiyang River Valley.

The desertification of Minqin County has been attributed partially to the construction of the Hongya Mountain Reservoir in the late 1950s (Li et al., 2005). The disappearance of surface water in Minqin County diminished the capacity for agriculture. In order to utilize the surface water efficiently, Hongya Mountain Reservoir, which locates at the front part of Minqin County, was built in 1958. The surface water from the Shiyang River flowed into the reservoir, where it remained until it was needed for irrigation. This reduced the flow of water into the lowest parts of Minqin County. As a result, Qing'tu Lake could not be supplied with new surface water and disappeared in 10 years. The farmers downstream began to pump groundwater for irrigation. Because of the low precipitation and the high evaporation, there is no surface water to supplement the diminishing groundwater. As a result, the groundwater level has decreased sharply, and the mineral content of the water from the upper to the lower reaches of Minqin at a rate of 0.02-0.35 g/l per year. The groundwater in the lowest levels was not potable for people and animals because of the high mineral content; furthermore, it could not be used for irrigation before the germination of crops any more.

Sustainable agricultural development in Minqin County is being challenged by water scarcity. Without any adjustment, the available water resources cannot support development in Minqin County for a long time. To reduce agricultural water consumption and to prevent any enlargement of the desert, it will be necessary to practice water-saving agriculture.

2.2 Future Water Supplies and Agricultural Water Demand

Since the sustainable development of Minqin County has been challenging by the water scarcity, China's Prime Minister JiaBao WEN advised that Minqin County should not become another Lop Nur, which had been the second largest in China and is currently a droughty area (Li et al., 2005). However, water scarcity will not be overcome without the cooperation of the people of Minqin County and water consumers throughout the Shiyang River Valley. The surface water consumption of Minqin County is entirely determined by the water consumption along the upper reaches of Shiyang River Valley. At present, it is very difficult to increase the surface water to Minqin County by decreasing the volume of surface water consumption along the upper reaches of the Shiyang River Valley.

To solve the problems related to water scarcity, the Department of Water Resource and the Development and Reform Commission of Gansu Province drafted a document title Focus Management Planning of the Shiyang River Valley in 2006 (Department of Water Resources of Gansu Province et al., 2006). According to the Eleventh Five Year Planning of Minqin County, the difference between water demand and water supply was about 532 million m^3 in 2005 (The People's Government of Minqin County, 2006). Even though planning was undertaken, the difference between water demand and water supply could still be as large as 221 million m^3. One of the objectives of the planning was to increase the surface water to Minqin County and to decrease the exploitation of the groundwater so that a balance between the exploitation and the supplement of the groundwater could be maintained. To attain this objective, the first step is to increase the surface water to Minqin County from 98 million m^3 to 250 million m^3 at least and to decrease the exploitation of groundwater from 517 million m^3 to 89 million m^3 until the year 2010 (Department of Water Resources of Gansu Province et al., 2006). The groundwater level can be expected to stop decreasing, and the environmental deterioration can be expected to diminish. The second step is to continue to increase the surface water to Minqin County and to decrease the exploitation of groundwater until 2020.

However, it is not easy to achieve such an objective since there is no safe system to guarantee the necessary surface water to run into Minqin County. To decrease agricultural water consumption, the government plans to cut down the effective irrigation areas per farmer from 4.5-5 mu to 2.5 mu in Minqin County (Department of Water Resources of Gansu Province et al., 2006). The reductions in the irrigation areas amount to more than 44% of the total. Since Minqin County is bordered by desert on three sides, any abandoned arable land will soon become desert. In this way, the deserts will encroach upon it even faster.

3 Groundwater Resource Utilization and Subsistence-oriented Farming

3.1 Farmers Corporate to Utilize the Groundwater Resource

There are 232.1 thousand farmers in Minqin County and 69.3 thousand urban residents (Bureau of Statistics of Minqin County, 2007). The average arable area per farmer is about 4.5~5 mu, which is much higher than the average 2.6 mu per capita throughout the Shiyang River Valley (Department of Water Resources of Gansu Province et al., 2006). Minqin County has approximately 2.385 million mu areas, but the arable land amounts to about 0.97 million mu. The droughty climate causes most of Minqin County to be covered with sand. In addition, little surface water runs into Minqin County since it is located on the lowest reach of the Shiyang River Valley. As a result, the source of agricultural irrigation is primarily groundwater.

In Minqin County, the distribution of arable land determines the utilization of groundwater by farmers. At the initial stage of the distribution of arable land, all arable plots were categorized according to their characteristics to protect farmers and to distribute the land fairly. As a result, several plots were assigned to one household; however, they varied in quality and were not located in the same area. Because of this, local farmers have to share wells cooperatively, since one household is difficult to own several deep wells. The schematic, shown in Fig. 3.2, shows the plot distribution and the manner in which the wells are shared. For example, it is assumed that there are 9 households identified as 1, 2, ⋯ and 9 in a group within a village. They share 4 wells indentified as A, B, C, and D. In Fig. 3.2, it is evident that each household can utilize any of the 4 wells. This mechanism requires that all of the farmers share the wells.

During the field surveys, it was found that the village collective owned most of the wells. The farmers share the maintenance costs according to the amount arable land each holds. With the exception of the maintenance costs, the farmers have to pay for the electric power required for irrigation. Since there is no other limitation on the groundwater consumption, the farmers are concerned solely with the price of electricity when they pump the groundwater.

3.2 Subsistence-oriented Farming

The agricultural sector is the most important income source for most of the farmers, and it is the largest water consumer. In the entire Shiyang River Valley, agricultural irrigation water accounts for about 86% of the total water consumption (Department of Water Resources of Gansu Province et al., 2006). However, the utilization coefficient of irrigation water is between 0.46 and 0.61. The planting method is not reasonable since the ratio of revaccination or inter-planting is approximately 22%, and this ratio is as high as 60% in some groundwater-rich areas. The traditional irrigation way in Minqin County is intensively water-consumptive so that the irrigation quota is very high and varies between 370m^3/mu to 399m^3/mu.

Since Minqin County is remote from urban areas and bordered by desert on three sides, the local farmers are not likely to obtain non-farm work. Agriculture is the most important sector for most of the farmers because it furnishes food security. As a result, food crops are cultivated on a large scale, although they are more water-intensive and have less value-added than most of the cash crops, such as cotton and caraway (see Table 3.2). In Minqin County, the top three crops on the cultivation scale are wheat, cotton, and green feed. Compared to wheat, the latter two produces higher income and requires less water. In the past 15 years, the planting pattern has changed (see Table 3.2). First, the share of food crops decreased by about 30%, and the wheat cultivation scale also decreased from 398,382 mu in 1992 to 350,646 mu in 2006, although the total cultivation areas have been increasing. In contrast, the cultivation areas of cotton and green feed have been increasing quickly. Their shares increased from 3.38% and 3.30%

in 1992 to 25.89% and 16.65% in 2006, respectively. The main reason for these significant changes is the decrease in water resources. To adapt to this change, the farmers substitute water-saving cash crops for water-intensive food crops (see Table 3.2). However, the water-intensive food crops are still cultivated on a large scale because what is most important for farmers is to guarantee food security for their families through the agricultural sector. In addition, the total arable lands increased on a large scale over the past 15 years (see Table 3.2). In 1992, the area of arable land was only 593,352 mu, but, in 2006, the area of arable land increased to 945,818 mu. The fast increase of arable land accelerated the decline of groundwater levels. Now, the remaining groundwater resources can support Minqin County for about 17 years, according to an officer who worked in the Water Resource Department of Wuwei City when the survey team visited Minqin in 2005. However, if the arable lands are not irrigated, they will soon become desert since no water can be used to support these abandoned lands to recover vegetation.

Switching to water-saving farming seems to be the only way of achieving sustainable agricultural development for droughty areas, such as Minqin County.

Tables and Figures

Table 3.1 Runoff Volumes of the Main Branches of Shiyang Rivier Valley

Unit: 100 million m^3

Year	Xida	Dongda	Xiyin	Jinta	Zamu	Huangyang	Gulang	Dajin	Total
1951-1960	1.824	3.639	4.245	1.774	3.121	1.629	0.992	0.218	17.442
1961-1970	1.499	2.998	3.828	1.393	2.188	1.439	0.629	0.129	13.508
1971-1980	1.486	2.898	3.566	1.281	2.310	1.203	0.680	0.124	13.548
1981-1990	1.745	3.214	3.693	1.350	2.443	1.462	0.749	0.117	14.773
1991	1.089	2.346	2.123	0.797	1.570	0.675	0.366	0.053	9.019
1992	1.491	2.401	2.552	1.235	2.167	1.257	0.555	0.119	11.777
1993	2.229	3.406	3.665	1.739	2.918	1.908	0.918	0.198	16.981
1994	1.353	2.725	2.498	1.336	2.101	1.286	0.691	0.145	12.135
1995	1.732	2.884	2.864	1.262	2.002	1.001	0.558	0.157	12.460
1996	1.452	2.664	2.454	1.322	2.019	1.153	0.609	0.110	11.783
1997	1.609	2.732	2.703	1.376	1.980	1.005	0.577	0.110	12.092
1998	1.671	2.675	2.695	1.116	2.088	0.984	0.570	0.239	12.038
1999	1.673	2.715	2.455	1.072	1.677	0.797	0.669	0.107	11.155
2000	1.427	2.762	3.149	1.280	2.265	1.176	0.457	0.111	12.627
1991-2000	1.573	2.731	2.716	1.254	2.079	1.124	0.597	0.135	12.209

Data source: Bureau of Water Resources of Wuwei City, 2004

Table 3.2 Changes of the Agricultural Planting Structures of Minqin County

Crops	1992		2005		2006	
	Areas	Shares	Areas	Shares	Areas	Shares
	mu	%	mu	%	mu	%
Total Broadcast Area:	593,352	100.00	949,136	100.00	945,818	100.00
1 Food Crops	398,382	67.14	349,867	36.86	350,646	37.07
#wheat	**305,078**	**51.42**	**234,484**	**24.70**	**246,880**	**26.10**
#maize	62,136	10.47	90,831	9.57	89,258	9.44
2 Cash Crops	148,522	25.03	343,269	36.17	367,590	38.86
#cotton	**20,030**	**3.38**	**190,053**	**20.02**	**244,906**	**25.89**
#sun flower	4,611	0.78	35,508	3.74	30,156	3.19
#water-melon seed	78,300	13.20	73,950	7.79	44,483	4.70
#caraway seed	14,237	2.40	28,490	3.00	24,102	2.55
#white-melon seed	--	--	8,017	--	6,728	--
#other	10,415	1.76	5,136	0.54	15,297	1.62
3 Others	46,447	7.83	254,000	26.76	227,582	24.06
#vegatable	8,222	1.39	58,161	6.13	50,114	5.30
#melons	16,930	2.85	26,290	2.77	19,998	2.11
#green feed	**19,606**	**3.30**	**169,549**	**17.86**	**157,470**	**16.65**

Data source: Bureau of Statistics of Minqin County, 1993, 2006 and 2007.

Table 3.3 The Fixed Water Consumption and The Profit Coefficients of Main Crops in Minqin County

PC=Profit Coefficients

			2003	2004	2005	2006
No.	CROPS	Irrigation Water (m3)	Profit (Yuan/mu)	Profit (Yuan/mu)	Profit (Yuan/mu)	Profit (Yuan/mu)
1	Wheat	423	194	454	392	316
2	Corn	455	394	214	316	542
3	Wheat+Corn	715	522	630	640	640
4	Cotton	228	1,406	527	932	638
5	Caraway Seeds	293	1,016	919	682	902
6	Melon Seeds	300	355	540	653	422
7	Melon's Seed without Pee	300	513	481	739	624
8	Sunflower Seeds	293	366	513	793	456
9	Melon	300	1,104	757	818	931
10	Pumpkin	300	593	512	619	720
11	Green House Vegetable	360	6,666	4,712	8,219	7,135
12	Multifilm Pepper	410	1,054	1,284	674	1,331
13	Onion	400	--	2,621	947	5,206

Data source: the data are based on Bureau of Statistics of Minqin County (2005 and 2007).

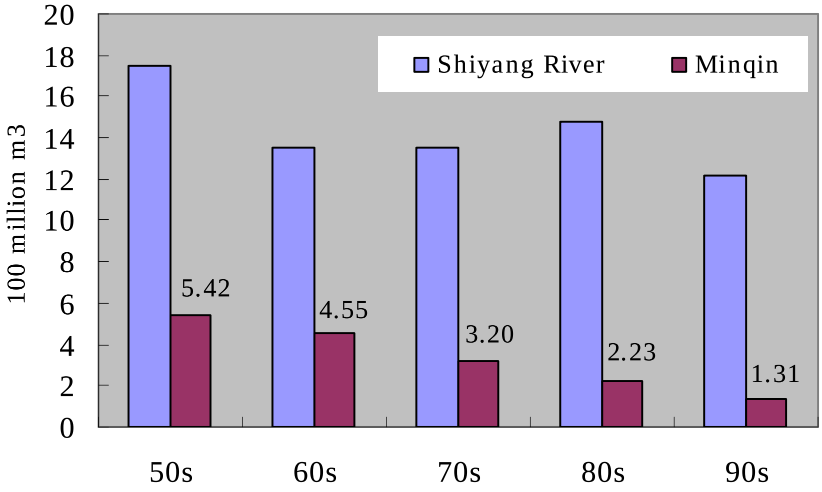


Fig. 3. 1 Runoff Volumes of Shiyang River and Minqin County

Data source: Bureau of Water Resources of Wuwei City, 2004.

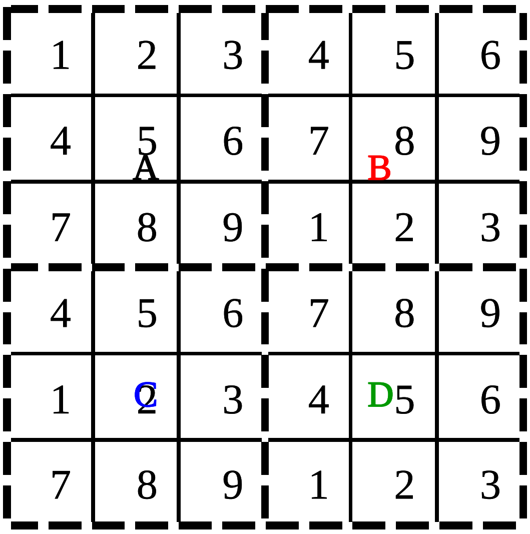


Fig. 3.2 A Schematic about the Plots' Distribution around the Wells in Minqin

Note: The authors described this figure according to the field surveys;

1,2,…,9 means the numbers of 9 different farmers;

A, B, C, D means different 4 wells.

Chapter 4
Technical Efficiencies of Cotton Farmers and Sources of Technical Inefficiency

1 Introduction

Northwest China is a large droughty area which includes Xingjiang•Uygur and Ningxia Hui autonomous regions and Gangsu, Shaanxi, and Qinghai provinces (see Fig. 1.1). About 90% of its water resources are consumed by the agricultural sector, and it is said that the remaining available water resources cannot support this area to develop in a sustainable way (Jia and Liu, 2004). The stress of water scarcity has prompted researches involving water-saving crop production. Because of the arid climate and sufficient sunlight, cotton is one of the most important farm commodities in terms of high value-added and water-saving crops for the Northwest China. However, because of subsistence-oriented agriculture, in the northwest the 2.9% proportion of the cotton is lower than those 4.0% in the middle and 5.1% in the east although the northwest has great comparative advantages in cotton production (Ministry of Agriculture of China, 2008). With the increasing demand for cotton, it seems reasonable to expand cotton cultivation to substitute for part of water-intensive but low value-added crops, such as wheat, in droughty areas of Northwest China. This production activity is expected to be beneficial to agricultural sustainability in arid areas. Although cotton is a traditional and common crop in Northwest China, there are many factors affecting its production. Thus, the yields are different among different farmers, even among different plots. If cotton farmers can increase their technical efficiencies (TEs), it can be forecasted that cotton cultivation will increase. Therefore, measuring the TEs of cotton farmers and seeking the factors of technical inefficiency (TIE) could contribute cotton to become a staple cash crop in these arid areas. This is important not only for improving the farmers' farm income but also for saving agricultural water consumption to support the sustainable agricultural development in the arid areas.

Compared with the studies devoted to measuring the technical efficiencies of other crops' farmers, such as wheat and rice farmers, those about cotton farmers in the arid areas are still limited. Brooks (2001) studied the characteristics and the cost of cotton production of United States. Chakraborty et al. (2002) examined technical efficiencies of cotton growers both by stochastic and non-stochastic production function approaches in Texas. They found that irrigated farms are 80% and non-irrigated farms are 70% efficient on average. Mohammad-Yusuf (2005) estimated the effects of market reform on cotton production efficiency by a case study of Tajikistan. However, it is still necessary to conduct researches of cotton production in arid areas since there the cultivation technical skills and the climate are different from other regions. Minqin County is a typical arid region in Gansu province of Northwest China with only 110mm annual precipitation but 2,664mm annual evaporation (Chang, 1994). In this area, cotton is cultivated not only as the most important cash crop but also as a strategic crop for saving agricultural water consumption to support Minqin's sustainable development. In this chapter, Minqin County will be taken as a case to study irrigation's role in cotton production and to identify the factors of technical inefficiency of cotton farmers by plot-level data. Based on the estimation results, how to improve the TEs of cotton farmers and enlarging cotton cultivation in the arid areas of Northwest China will be discussed.

The outline of this chapter is as follows. Section 2 starts with a review of previous studies on the theoretical framework of Stochastic Frontier Production Function and some empirical works. Section 3 provides the variables, model specification, and the data applied in this study. Section 4 discusses the estimated empirical results. Section 5 suggests conclusions and implications.

2 Literature Reviews about Stochastic Frontier Production Function

In this study stochastic frontier production function will be applied to measure technical efficiency of production. It has been acknowledged that, in reality, a gap normally exists between a firm's actual and potential levels of technical performance. Technical efficiency is defined as the capacity and willingness of an economic unit to produce the maximum possible output from a given bundle of inputs and a fixed technology (Kalirajan and Shand, 1999). The literatures on efficiency analysis are broadly divided into programming or deterministic methods, statistical or stochastic frontier methodologies, and Bayesian methods. The deterministic, nonparametric approach that developed out of mathematical programming to measure efficiency is known as data envelopment analysis (DEA), while the parametric approach which uses a stochastic production, cost, or profit function to estimate efficiency is called the stochastic frontier approach (SFA). And the Bayesian approach to measuring technical efficiency was discussed by van den Broeck et al. in 1994.

And for almost as long, econometricians have been estimating average production functions. It has only been since the pioneering work of Farrell (1957) that serious consideration has been given to the possibility of estimating so-called frontier production functions, in an effort to bridge the gap between theory and empirical work. For a variety of reasons these efforts had not been completely successful. In 1977, the stochastic frontier production function was independently proposed by Aigner et al. and Meeusen and Broeck in 1977. Since then, the stochastic frontier production function has been a significant contribution to the econometric modeling of production and the estimation of technical efficiency of firms. Their specifications were to introduce a non-negative random component in the error term of the production function to generate a measure of technical inefficiency effect, or the ratio of actual to the expected maximum output, given inputs and the production technology. Mathematically, the stochastic production function and the error structure can be expressed as follows:

$$Y_i = f(x_i, \beta)e^{\varepsilon_i} \tag{1}$$

$$\varepsilon_i = v_i + u_i, \quad i = 1, \bullet\bullet\bullet N. \tag{2}$$

where i indicates regions (farms), Y_i denotes output, X_i indicates a vector of inputs, β is a vector of parameters to be estimated; and ε_i is the disturbance term. Function (1) is a production function and function (2) is a technical inefficiency function. As usual, in terms of error, v_i represents the symmetric disturbance and is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$. It takes random variation in output due to the factors outside the control of the region (farm), such as seasonal weather. $u_i s$ are non-negative random variables, associated with technical inefficiency of production, which are assumed to be independently distributed, such that u_i is obtained by truncation (at zero) of the normal distribution $N(z_i\delta, \sigma^2)$.

The basic case of technical efficiency of i-firm in the t-period can be specified as:

$$TE_i = \frac{E(Y_i \mid u_i, X_i)}{E(Y_i \mid u_{i=} 0, X_i)} = e^{-u_i} \tag{3}$$

The technical efficiency measure depends on the conditional expectations, which are shown in formula (3), where the values are assessed at the maximum likelihood estimates of all parameters in this model and the expected maximum value of output depends on the error term (that is $u_i = 0$).

The economic logic behind this specification is that the production process is subject to two economically distinguishable random disturbances, with different characteristics. It involved two random components, one associated with a traditional random error and the other being the presence of technical inefficiency. The first one is due to external random factors. And the non-positive disturbance u_i reflects the fact that each firm's output must lie on or below its frontier (Aigner et al., 1977). Greene (1980) insists that a stochastic frontier with gamma-distributed errors should be estimated by the maximum-likelihood estimation.

Furthermore, the parameterization of Battese and Corra (1977) is employed: $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$. As recently emphasized by Coelli et al. (1998) the γ-parameterization has an advantage in seeking to obtain the maximum likelihood estimates because the parameter space for γ can be defined for an appropriate starting value for the iterative maximization algorithm involved. Thus, a value of γ close to zero denotes that the deviations from the frontier are due entirely to noise, while a value of gamma close to one would indicate that all deviations are due to the inefficiency.

After Aigner et al. (1977), the stochastic frontier production function has been accepted for many decades. The theoretical studies mainly concentrate on u_i's distribution when the data are based on cross-section or panel. Estimation for a single cross-section of firms requires the explicit specification of distribution of statistical noise and inefficiency variable terms. However, the strong assumptions about the error's distributions of cross-sectional data are not required when panel data are available (Schmidt and Sickles, 1984). Battese and Coelli (1995) applied a panel data model that the inefficiency effects are assumed to be independently distributed as truncations of normal distribution with constant variance, but with means which are a linear function of observable variables. Their model is applied popularly in empirical works.

Comparing to other models, stochastic frontier production function has itself advantages. Quantification of technical efficiency is useful in three ways: 1) it facilitates comparisons across similar economic units, i.e. it indicates relative efficiency; 2) where measurement reveals variations in efficiencies among economic units, further analysis can be undertaken to identify the factors causing such variations; 3) such analysis bears policy implications for the improvement of efficiencies (Kalirajan and Shand, 1999).

3 Data, Variables and Model Specification

3.1 Data and Variables

A plot-level field survey about cotton production was issued in July, 2006. Two towns of Minqin, where cotton was the commonest cash crop, were chosen as the survey points. Before the survey, it was planed to do the survey by random sampling. However, since some farmers were not at home during the survey, it was difficult to issue this plan perfectly. As the sub-optimal selection, the field survey was conducted by visiting the households stochastically. One cotton plot each household was surveyed and a total of 86 plot-level samples with detailed information about cotton production in 2005 were obtained. Xiqu Town, one of the survey points, is at the lowest part of Minqin and connects with deserts; Dongba Town, the other survey point, is in the upper Minqin. The mineral level of the groundwater increase from Dongba to Xiqu, but the groundwater level is reversing itself. Forty-two plot-level samples were obtained in Xiqu, and forty-four plot level samples were obtained in Dongba.

For cotton production, the necessary inputs include seed, water resource for irrigation, labor, fertilizer, and machines for plowing and broadcasting. However, according to the survey, the purchase price of cotton seed varied in a large range among the households according to the purchase time and the purchase places. And the amount of seed cannot reflect the difference in quality. Thus, the variable of seed was dropped from the estimation model. Because of little surface water, most of the farmlands were irrigated by groundwater. The differences in irrigation cost are only from the expenditures of electricity powers on pumping the groundwater. For the farmers, it is difficult for them to calculate exactly how much water they pumped but they remembered clearly how many electricity powers they consumed in irrigation since they had the correlative memo pads. Therefore, the electric powers on irrigation were substituted for the consumption of groundwater in this study. Except for the necessary inputs, disaster was the biggest factor leading to the reduction in yield because of the poor environment. Finally, the variable of the negative effect of disaster was also put into the production function.

Since the data are based on the plot-level, the variation of technical inefficiency should mainly be from two kinds of factors: the plot characteristics and the attributes of farm managers. The characteristics of the plots include their sizes, sandy or non-sandy lands, and their locations, whether near or far from a town. Their locations contain the difficulties in the groundwater quality. For example, the groundwater of Dongba, which is near to Minqin, has a lower mineral content level than that of Xiqu, which is far from Minqin city. The attributes of the farm managers include full-time or part-time farmer, age, and school education level. As Minqin is a marginal oasis connected with deserts, the effects of environment on cotton production should be great. Therefore, the characteristics of the plots should have greater influences on the technical efficiency variance than those of the farm managers. In this study, these two kinds of factors are taken as the main reasons of the TIE.

All of the statistics about the data are shown in Table 4.1.

3.2 Model Specification

Based on the above analyses and following the stochastic frontier production function (Meeusen and Broeck, 1977; Battese and Coelli, 1995), the empirically estimated double-logged form model is defined by the following production function (4) and technical inefficiency function (5) in this study:

$$\ln Y_i = a + \sum_{j=1}^{4} b_j * \ln X_{ij} + b_5 * X_{i5} + (v_i - u_i) \quad (4)$$

$$u_i = \delta_0 + \sum_{k=1}^{6} \delta_i * z_{ik} + W_i \quad (5)$$

where i is the i-th plot, Y, the yield per mu (500 g/mu), α, the constant or intercept, X_{i1}, the expenditure on machinery before harvest (yuan/mu); X_{i2}, the expenditure on fertilizer (yuan/mu); X_{i3}, the labor input before harvest (hours/mu); X_{i4}, the electricity consumption on irrigation (kw/mu); X_{i5}, the dummy of the level of natural disaster damage on cotton yield (0 for no damage; 1 for damage between 1%-15%; 2 for damage over 15% but lower 30%; 3 for damage above 30%); δ_0, the constant or intercept; z_{i1}, the sandy land dummy (sandy plot is given 1 or otherwise 0); z_{i2}, the area of the plot (mu); z_{i3}, the town dummy (Dongba near Minqin city is given as 1 and Xiqu far away from Minqin City is given 0); z_{i4}, the part-time farm manager is given as 1 and otherwise 0; z_{i5}, the farm manager's age (year); and z_{i6}, the farm manager's education level (years). $b_1 \ldots b_6$ and $\delta_1 \ldots \delta_6$ are the corresponding coefficients to be estimated.

The method of maximum likelihood is proposed for the simultaneous estimation of the parameters. The likelihood function is expressed in terms of the variance parameters, $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma_s^2$. The hypotheses can be tested by the generalized likelihood-ratio statistic, λ, given by $\lambda = -2[L(H_0) - L(H_1)]$. $L(H_0)$ and $L(H_1)$ denote the values of the likelihood function under the null (H_0) hypothesis and the alternative (H_1) hypothesis separately. If the given null hypothesis is true, λ has an approximate Chi-square distribution or a mixed Chi-square distribution when the null hypothesis involves $\gamma = 0$.

4 Estimation Results and Discussions

The software Frontier 4.1 (Coelli, 1996) was applied to estimate functions (4) and (5) at the same time. By showing the most reasonable result, the estimation has to try several times. Firstly, the estimation results presented that the coefficient of the fertilizer variable was not significant either by the Ordinary Least Square Estimation (OLSE) or the Maximum Likelihood Estimation (MLE) and was also very small. This showed that increasing fertilizer input had no significant effect on increasing cotton yield. Therefore, the variable of the expenditures on fertilizer was dropped from the function, and the model was estimated again. This is the first estimation result presented in Table 4.2.

In order to test whether or not the Z vector was the main factors affecting the technical inefficiency, λ test was conducted. The generalized likelihood-ratio tests of various null hypotheses are presented in Table 4.3. The first null hypothesis, which specifies that all of the inefficiency effects are absent from the model, is rejected. The second hypothesis, which specifies that the variables of z_4, z_5, and z_6 should be eliminated from the technical inefficiency function, is accepted. Therefore, the variables of z_4, z_5, and z_6 were dropped from the technical inefficiency function and the model was estimated again. Based on the new estimation result, the third null hypothesis was continued. The third null hypothesis, which specifies that the inefficiency effects (only three factors) are eliminated from the model, is rejected. The forth-null hypothesis, which specifies that the inefficiency effects are not stochastic, is also refused. At last, the result (2) estimated by MLE is accepted as the most profitable result and is also shown in Table 4.2. The estimated value of gamma (γ) is about 0.9 in the result (2) and significant at the 1% level with a t-value of 14.13. This estimation result showed that about 90% of the technical inefficiency could be explained by the former three variables.

There were no great differences between the coefficients estimated by the OLSE method and the coefficients estimated by the MLE method. All of the inputs had positive effects on cotton production.

The coefficient of labor input is 0.260 when estimated by OLSE and 0.156 when estimated by MLE. Both of the two coefficients are large and at highly significant levels. The coefficients of other inputs are relatively smaller. If the marginal production cost is not considered, labor input has the largest elasticity of production. However, farmers make their decisions by comparing the marginal revenue with marginal cost. Therefore, if the marginal costs are considered, the situation might be different. In Minqin County, the electricity's price of pumping the groundwater for irrigation is only 0.30 yuan/kw, and the price of labor is about 2.5 yuan/hour according to our field survey. Increasing the unit yuan on labor input can improve the cotton yield by 0.06% (see the calculations in the Appendix), but increasing the unit yuan on pumping the groundwater can improve cotton yield by 0.34% according to the estimation result (2). This shows that increasing the same marginal cost on pumping the groundwater will have the largest effect on increasing cotton yield. Since the cost differences in irrigation are only from the expenditures of electricity powers on pumping the groundwater, the highest elasticity of production unit yuan on pumping groundwater will encourage the farmers to pump groundwater. However, this elasticity of production has a close relationship with the prices of inputs. If the electricity price of pumping the groundwater increased, the role of unit yuan on it will decrease. On the other hand, the coefficient of disaster, a negative 0.161 with a high significant t-statistic level, shows that the disaster was an important negative factor of cotton production.

The estimated coefficients in the inefficiency function are also of interest. The estimation results denied that the differences in the farm manager attributes were the reasons of the TIE but accepted the differences in the plot characteristics as the main reasons. This result is consistent with the hypothesis that, in marginal places, the unhealthy environment should have a greater influence on the variance of the TE than the farm managers. Among the characteristics of the plots, sandy land was the main reason for the variance of the TE. In fact, among the 86 plot-field samples, there are 40 sandy plots, but 28 of them are in Xiqu Town which is in the lowest part of Shiyang River Valley and near the desert. This showed that desertification affected cotton yield more seriously in the lower part of the Shiyang River Valley than in the upper part. On the other hand, in Minqin, the land sizes are very different. According to our field survey, cotton land varied from 0.5 mu to 3 mu (see Table 4.1). The TIE showed a negative relationship with the size of the plots. This might be caused by the fact that smaller plots could lead to sub-optimal usage of factor inputs and, thus, to lower overall returns to land. The factors contributing to this result could also be due to extra labor input, wasted space along borders, inadequate monitoring, and the inability to use certain types of machinery, such as plowing. Except for the negative effects from disaster and sandy plots, however, Dongba Town near Minqin did not show a positive effect on improving the TE. This result showed that, at present, the difference in groundwater quality had little influence on cotton yield. However, the test did not prove that the attributes of the farm managers influenced the variance of the TE. This could be explained by the position of Minqin County. As noted in the above, Minqin is a marginal place bordering by deserts. Compared to the effects from unhealthy environment on cotton production, the effects from the attributes of the farm managers did not seem important. Therefore, this study did not find any effect from the attributes of the farm managers on cotton yield. However, their effects cannot be denied only by our estimation results.

The TE distribution is shown by Fig. 4.1. The average TE of cotton farmers is about 85% in the whole Minqin. There is still a room to improve the TE for many cotton farmers since 57.7% of them got a TE lower than 90%. In order to get a higher TE, the farmers should select the plots with less sand and larger size to plant cotton. Although the numbers of sandy plots and the plots affected by natural disaster in Xiqu were more than those in Dongba, the average TE of cotton farmers (84.8%) in Xiqu Town was not much lower than that (85.1%) in Dongba Town.

5 Conclusions and Implications

As the commonest cash crop, cotton is very important in the arid areas of Northwest China since it is not only high value-added but also water-saving. In this paper, SFPF is applied to measure the factors of TE and TIE of cotton farmers by a case study of Minqin County, a typical arid area surrounded by deserts in Gansu Province of Northwest China.

The estimation results show that both irrigation and labor input, the two key factors of cotton cultivation, had significantly positive effects on yield increase. The elasticity of production of labor input was the biggest if attention was limited to the estimation coefficients only. However, after the marginal effect of one Yuan input was considered, increasing the same cash expenditure of electricity powers on pumping the groundwater would be the best choice for the farmers. This presents that water, as the scarce resource, played its proper role in cotton cultivation in the arid Minqin County. However, this effect had a strong connection with the prices of inputs. Since Minqin County is a marginal region, except the damage from natural disaster, the variances of the technical efficiencies were mainly from the differences of the plots' characteristics, such as whether or not sandy plots and their sizes. Except the influences from desertification and disaster, the town near Minqin city did not show any superiority in cotton cultivation. The attributes of the farm managers also did not influence the technical efficiency variance. However, although the town near the desert had more plots affected by desertification and natural disaster than the town near Minqin, there was no big difference in their average technical efficiencies.

According to the significant elasticity of production of several inputs and the slight influence from the towns' positions, the cotton farmers still can improve their technical efficiencies and enlarge cotton cultivation scale in the whole Minqin. This will be helpful to introduce cotton to take the place of the water-intensive food crops, such as wheat and cotton, and then be benefit of developing water-saving planting patterns to support the sustainable development. Improving the cotton farmers' abilities and agricultural infrastructure to lessen disaster's damage is also important for the farmers to improve their technical efficiencies. However, without an agricultural insurance policy to stable the farmers' cotton income, it is still difficult to enlarge the cotton cultivation areas to substitute for water-intensive food crop cultivation. Land fragmentation should also be avoided. Since it is very difficult to improve the lands that are already full of sand, the important thing for the marginal arid areas, such as Minqin, is to protect the normal arable lands from any further desertification.

Tables and Figures

Table 4.1 Summary Statistics of the 86 Cotton Production Plots in 2005

Variables	Sample Mean	CV	Std. Dev	Maximum	Minimum
Yield (500g/mu)	479	0.21	101	650	240
Expenditures on machine (yuan/mu)	43	0.30	13	60	20
Fertilizer expenditures(yuan/mu)	121	0.19	23	188	66
Labor's inputs before harvest (hours/mu)	103	0.02	2.3	17.4	6.7
Electricity for irrigation (kw/mu)	88	0.31	27	152	35
Plot areas (mu)	1.5	0.33	0.5	3	0.4
Age of the farm manager	45	0.19	8.6	60	27
Education years of the farm manager	8	0.33	2.6	12	0
Numbers of the plots damaged by disaster	13 (11 samples belong to Xiqu; 2 samples beong to Dongba)				
Numbers of sandy plots	40 (28 samples belong to Xiqu; 12 samples belong to Dongba)				
Part-time farm managers	40 (19 samples belong to Xiqu; 21 samples belong to Dongba)				

Note: CV means coefficient of variation and Std. Dev means standard deviation.

Table 4. 2 Estimation Parameters of Stochastic Frontier Production Models

	Coefficient by OLSE	(1)Coefficient by MLE	(2)Coefficient by MLE
Stochastic frontier production			
a	4.325(8.56***)	5.029(10.68***)	4.511(10.55***)
X_1	0.091(1.74*)	0.062(1.24)	0.067(1.45)
X_3	0.260(3.07***)	0.159(1.98*)	0.156(2.01*)
X_4	0.079(1.38)	0.089(1.97*)	0.090(2.02*)
X_5	-0.166(-8.63***)	0.161(-9.47***)	-0.161(-9.52***)
Technical inefficiency model			
Z_1	---	0.251(1.53)	0.303(2.51**)
Z_2	---	-0.191(-1.28)	-0.201(-1.28)
Z_3	---	0.112(0.81)	0.142(1.20)
Z_4	---	0.027(0.25)	---
Z_5	---	0.002(0.10)	---
Z_6	---	0.001(0.33)	---
σ^2	0.273	0.056(1.92*)	0.064(2.37)
r	---	.905(13.48***)	0.911(14.13***)
Log-likelihood value	35.32	44.52	44.43

Note: ***, ** and * mean that t-values are significant at 1%, 5%, and 10% level respectively.

Table 4. 3 Tests of Hypotheses for Parameters of the Technical Inefficiency Model

Null Hypotheses	Log- Likelihoods	$X_{0.95}^2$-Values	Test Statistics	Results
If H_1=44.52				
(1) H_0: $\gamma=\delta_1=\cdots=\delta_6=0$	35.32	12.59	18.39	Refuse H_0
(2) H_0: $\delta_3=\cdots=\delta_6=0$	44.43	7.81	0.2	Accept H_0
If H_1=44.43				
(3) H_0: $\gamma=\delta_1=\cdots=\delta_3=0$	35.32	7.81	18.22	Refuse H_0
(4) H_0: $\gamma=0$	39.85	7.81	9.16	Refuse H_0

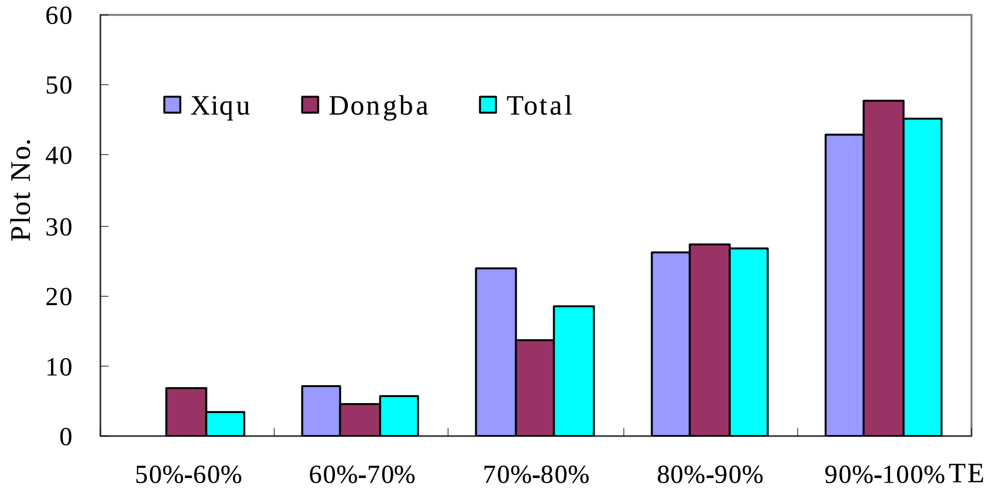


Fig. 4.1 Distribution of the Technical Efficiencies of Cotton Farmers

Appendix

Calculation about the Output Elasticity of Unit Yuan on Cotton Production

$b_i = \frac{\Delta y / y}{\Delta x_i / x_i} = \frac{\varepsilon_i}{(1 yuan/mu)/x'_i} \Rightarrow \varepsilon_i = \frac{b_i * (1 yuan/mu)}{x'_i}$. Here, y is the average output; x_i is the average i-th input; $x'_i = x_i$ *(price of x_i); b_i is the corresponding elasticity of production; ε_i is defined as the elasticity of production caused by increasing the unit *yuan* on x_i. For example, since the price of labor input is 2.5 yuan/hour, then $\varepsilon_3 = \frac{b_3 * 1 yuan/mu}{x_3 * 2.5 yuan/hour} = \frac{0.156 yuan/mu}{103 hour/mu * 2.5 yuan/hour} = 0.06$. The following 0.34% is calculated by the same method.

Appendix –Table

Output Elasticity of Unit yuan i th Input (ε_i) on Cotton Production

ε_1 (input: machine)	0.16
ε_3 (input: labor)	0.06
ε_4 (input: irrigation)	0.34

Chapter 5
Role of Irrigation in Wheat Production And Improving the Technical Efficiency

1 Introduction

Northwest China is a huge droughty region as the former introduction. Here rainfall is very little but the evaporation is very high. The rainfall cannot match the need of agricultural water consumption not only in quantity but also in terms of the temporal distribution. Little surface water and the low precipitation result in the decrease of the groundwater and cannot contribute to compensate for this decrease any more. Over consumption of groundwater has caused its level to decrease sharply in recent years. The great stress of water scarcity in Northwest China has promoted the study of saving agricultural water consumption. At present, this seems to be the most effective way of supporting the sustainable agricultural development for the arid areas of Northwest China.

In the Northwest China, wheat is the commonest water-intensive crop in the term of the main staple food. Saving its water consumption can contribute to save agricultural water consumption since it is planted in a large scale and consumes a large volume of water. Generally speaking, there are two ways to save wheat water consumption without decreasing the food security: restricting wheat water consumption and/or decreasing the cultivation areas by improving the technical efficiencies (TEs) of wheat farmers at the same time. As a result, part of the saved water can be distributed to other water-saving and higher value-added cash crops. Therefore, 1) the information about the role of groundwater irrigation on wheat production and its different effects in different areas are very important to guarantee the farmers, who live in the neighbor areas where the groundwater consumption of one area affects the groundwater level of another area, to use the groundwater in a sustainable way; 2) meanwhile, since wheat is cultivated as the main staple food, the information of how to improve the TEs of wheat farmers will be very valuable for improving the food security and saving agricultural water consumption.

Comparing with the number of studies devoted to measuring TEs of other crops farmers, studies on wheat farmers in arid areas are limited. Wilson and Asby (2001) analyzed the objectives of maximizing annual profits and maintaining the environment are positively correlated with, and have the largest influence on technical efficiency in eastern England. Hassan and Ahmad (2001) analyzed the TEs of mixed wheat production in Punjab and Pakistan. Croppenstedt (2005) found that 1) no factor affected the technical efficiencies of wheat farmers and 2) technical efficiencies did not vary with farm sizes in Egypt by estimating stochastic frontier production model. However, there has been no study about how to improve the TEs of wheat farmers in the arid areas of Northwest China. In this study I will take an arid area, Minqin County which is in the middle of Gansu province, as a case to estimate the role of groundwater irrigation on wheat production and how to improve the TEs by estimating a stochastic frontier production function (Battese and Coelli, 1995).

If Minqin becomes a desert, the sustainable development of the northwest and the whole China will be challenged by the serious environment. It is not difficult to forecast the fate of the whole Northwest China from Minqin. Like most of areas in Northwest China, farming is still a critical production activity for the farmers in Minqin. Here, wheat, as the main staple food crop, is cultivated in largest scale. It is a water-intensive but low value-added crop comparing with many other crops, such as cotton and caraway. By order of water consumption, wheat production per unit is the fifth; but by order of profit, it is only the eleventh among the 15 main crops in 2004 (Statistical Bureau of Minqin County, 2005).

2 Model Specification and Data

2.1 Model Specification

In this study it is presumed that only the inputs before harvest, such as seed, expenditure on machine, and fertilizer, electricity for pumping the groundwater and labor input, affected wheat yield because some parts of inputs when and after the harvest activity, such as labor, do not play great influences on the yield. Another explanatory variable, disaster also associates with the fluctuation of the yields. During the field survey, it was found that there was no great difference in seed consumption among the households. As a result, the variable of seeds was dropped from the estimation model in this study. In the northwest of China, the environment is fragile so that many kinds of disasters, such as drought, sand-dust storm, and hailstone, always occur. One of the results of disasters is the yield's decrease. Minqin County is a marginal area near to the deserts, the damage of sandstorm is the most common and serious one for wheat production. The dummy variable of disaster (D) is put into the production function to reflect its negative effect on wheat production. The detailed meanings of the inputs are showed in Table 5.1.

The SFPF (Battese and Coelli, 1995) is applied popularly in empirical studies. Based on this model and the above analyses, the empirical SFPF of this study follows as:

$$\ln Y_i = a + b_1 \ln X_{1i} + b_2 \ln X_{2i} + b_3 \ln X_{3i} + b_4 \ln X_{4i} + b_5 \ln X_{5i} + b_6 D_i + (v_i - u_i) \quad (1)$$

$$u_i = \delta_0 + \sum_{k=1} \delta_k * z_{ki} + w_i \quad (2)$$

where, Y_i is the total wheat yield for i th household and X_{ji} is a vector of inputs for i -th household. X_{5i} is wheat cultivation area for i -th household. The detailed meanings of all of the variables are shown in Table 5.1. $\ln$ represents the natural logarithm. v_i is an independently and identically distributed $N(0, \sigma_v^2)$ random error. It represents the errors in measurement of the farmer's output and other events. And u_i is a non-negative random error associated with technical inefficiency of wheat production, which is assumed to be independently and identically distributed with truncations (at zero) of the normal distribution with mean μ_i and variance σ_u^2. It measures in terms of forgone output, that is, by how much the farmer's output falls short of the maximum possible output obtainable given the technology and the quantities of inputs available. z_{ki} is supposed to be the vector of various farm-specific characters including the age of the farm manager, his education level, whether or not he is a part-time farmer, and the family size. They are expected to the reasons of technical efficiency variance. They are defined in Table 5.1 and summarized in Table 5.2. δ_{ki} s are the corresponding unknown parameters to be estimated. The independent variable in function (2) defined in terms of technical efficiency variation associated with the negative (positive) coefficient will have a positive (negative) impact on TE. In this study, it is supposed that the technical efficiency variance is mainly from the attributes of the farm manager and his family. The experience of wheat cultivation, which is indicated by the age of the farm manager, should do help to improve the TE. However, the technologies of wheat cultivation were improved fast, especially in seeds and fertilizers. The younger farm manager should be more emotional in mastering the new technologies and can be expected to get a higher TE. Another variable, whether or not the farm manager was a part-time farmer, is expected to play different roles in wheat mono-cultivation and wheat intercropping because of the difference in labor intensities. So a part-time job should affect the farmer when the production activity is labor-intensive. Higher education level could help the farmer to manage the production activity more effectively. Meanwhile, a larger family should help the family labors to work more efficiently when the production activity is labor-intensive. The differences of the wells' depths may be a proper measure of TE's variation. However, one household usually utilize several wells and there are also no great difference in well's depth according to the introduction in Chapter 3. Thus, the differences in the depths of wells were dropped to analyze in this study.

Maximum likelihood estimates of the parameters are obtained by the computer program FRONTIER 4.1 (Coelli, 1996). The variance parameters are estimated in terms of $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$. γ varies between 0 and 1. If γ is near to 1, it means that much of the technical efficiency variance can be explained by the given factors; if the γ is near to 0, it means that the TIE cannot be explained well by the given factors. Besides the magnitude and significance of the variance parameter, γ, it is also of interest to examine various null hypotheses, such as technical inefficiency effects are not present, i.e., $\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$; technical inefficiency effects follow a standard truncated-normal distribution, suggested by Stevenson (1980), i.e., $\delta_1 = ... = \delta_4 = 0$. These null hypotheses can be tested by the generalized likelihood-ratio statistic, λ, given by $\lambda = -2\{L(H_0) - L(H_1)\}$. $L(H_0)$ and $L(H_1)$ denote the values of likelihood function under the null (H_0) and the alternative (H_1) hypothesis respectively. If the given null hypothesis is true, λ has approximately Chi-square distribution or mixed Chi-square distribution.

Function (1) is a double log production function which can measure the variable return to scale. However, there might be the phenomena of multi-collinearity among the inputs, such as labor input and fertilizer input, since most of them vary in the same trend with the cultivation areas. In order to avoid this risk, function (1) was transformed into the following function (3) by subtracting $\ln X_{5i}$ to each member corresponding to yield and inputs from function (1) (William and Christopher, 2005).

$$\ln \frac{Y_i}{X_{5i}} = a + \sum_{j=1}^{4} b_j \ln \frac{X_{ji}}{X_{5i}} + (\sum_{j=1}^{5} b_j - 1) \ln X_{5i} + b_6 D_i + (v_i - u_i) \tag{3}$$

Then, if y_i and x_{ji} are substituted for Y_i / X_{5i} and X_{ji} / X_{5i} , function (3) can be rewritten as the following function (4):

$$\ln y_i = a + \sum_{j=1}^{4} b_j \ln x_{ji} + (\sum_{j=1}^{5} b_j - 1)\ln X_{5i} + b_6 D_i + (v_i - u_i) \tag{4}$$

where, y_i and x_{ji} are the corresponding yield and the vector of inputs measured by unit per mu (15mu=1ha). After transformed, function (4) eliminates the risk of multi-collinearity but still can estimate the return to scale by the coefficient $\sum_{j=1}^{5} b_j - 1$. If $\sum_{j=1}^{5} b_j - 1 > 0$ at significant level, there is a return to scale; if $\sum_{j=1}^{5} b_j - 1 \leq 0$ at significant level, there is no return to scale. The technical efficiency of the i-th farmer is defined by equation (5):

$$TE_i = \frac{\exp(x_{ji}b + v_i - u_i)}{\exp(x_{ji}b + v_i)} = \exp(-u_i) = \exp(-\delta_i z_i - w_i) \tag{5}$$

Finally, the stochastic frontier production model of this study is made from function (4) and function (2).

2.2 Data

The present study is based on the data collected by the field surveys conducted both in the south and the north of Minqin County, Gansu Province in 2005 and 2006. In the both survey plots, clusters of households were randomly selected according to the name lists and the household heads were interviewed by structured questionnaires. However, during the survey, some of the selected farmers were not at home. As second best option, their neighbors were visited so that the samples can be kept the representativeness. In Minqin, the groundwater level decreases from the south to the north. As a result, there are some differences in crops' planting pattern. The north has already connected with the deserts in three sides and there the groundwater level is very low. Here mono-cultivation is the main type of wheat cultivation. However, in the south, the groundwater can be pumped easily at present time and intercropping is the main type of wheat cultivation. Their groundwater consumption impacts mutually between the south and the north. The substantial groundwater consumption by the south will accelerate the groundwater of the north to decrease. If the north cannot pump the groundwater again, this area will become desert. Therefore, it is necessary to keep all of the farmers to use the groundwater fairly in a sustainable way. As the results of the field surveys, 45 household samples about mono-cultivation in the north and 51 household samples about intercropping in the south were gotten. In order to do the estimations, it is needed to transfer the intercropping yields of wheat and maize into a single reference yield. The ray production function model[1] of Chris and Heidi (2003) can help to meet the target in a simple way which can avoid the bias of the reference yield from the unstable prices. The transformation of the yields implies that the production of the two intercropped crops is viewed as inseparable one production process (with only one residual or disturbance) resulting in two outputs. The descriptions of the data are summarized in Table 5.2.

According to the field surveys, the consumption difference in irrigation water resource among the farmers was only from how much groundwater they pumped. When the farmers pump water, they only concern about how many electric powers they consumed without considering the fixed expenditures on well, maintenance etc.. Therefore, this study only paid attention to the role of water resource pumped without considering the expenditures correlating with water conservancy facilities. It is better to take the pumped groundwater as the variable to estimate the role of water resource on wheat production. However, during the survey, it was found that the farmers could

[1] $\|y\| = \sqrt{y_1^2 + y_2^2}$, y_1 is the yield of wheat per mu, y_2 is the yield of maize per mu, y is the reference yield.

not calculate and remember how much water they pumped from the well for irrigation but remembered how many electric powers for pumping they consumed clearly. As the substitute for the consumption of water resource, the consumption of electric powers for pumping was applied in this study. Comparing to wheat mono-cultivation, wheat intercropping with maize is more input-intensive, such as fertilizer, labors and water resource. After wheat harvested, maize still needs to be irrigated about 4-7 times. However, only by Table 5.2, it cannot be found that there is great difference in the consumption of electric powers for pumping between intercropping and mono-cultivation. The main reason is that the groundwater levels are different in the two survey plots. In the north where wheat mono-cultivation is the main type, the groundwater level is already very low so that the tube wells are much deeper than those in the south. It costs the north more electric powers to pump the same volume of groundwater. As a result, there are no great consumption differences in electricity powers for pumping between wheat mono-cultivation and wheat intercropping with maize. Considering the groundwater differences of the two areas, it cannot say the role of pumped groundwater on wheat production in the whole Minqin by detailed index. Thus, the role of the consumption of electric powers on wheat production will be analyzed case by case. Table 5.2 also shows that there are no great differences of the job opportunity numbers gotten by the farm managers in the north and in the south. The north survey plot is about 65km far away from Minqin city. Here the off-farm job opportunities were less than those in the south. However, according to our field surveys, in the north many farmers worked on farming for other farms or farmers. In this study, the two kinds of part-time jobs were not differenced since both of them should affect labor-intensive production activities of the farmers. This is the reason that why the part-time job opportunities of the farm managers in the two areas had no great differences.

3 Estimation Results and Discussions

By the software FRONTIER 4.1 (Coelli, 1996), the maximum likelihood estimates of the parameters about wheat mono-cultivation and wheat intercropping with maize production are presented in Table 5.3. Both of the two results are the most acceptable estimation results after several tries. The variables of the education level and family size did not show any relationship with the technical efficiency variation of wheat mono-cultivation farmers so that they were not estimated in the final model of wheat mono-cultivation. All the slope coefficients or the output elasticity of inputs show the expected signs in the production function. According to the t-statistics and the coefficients $(\sum_{i=1}^{5} b_i - 1)$ in the two models, there were no returns to scale either for wheat mono-cultivation or wheat intercropping with maize.

The variance parameters, γ, in the two models, are almost close to 1 with highly significant t-statistics. Those results suggest that the combination effects of the factors in function (2) are significant enough in explaining the technical efficiency variance of wheat production.

Generalized likelihood-ratios of the null hypotheses test are presented in Table 5.4. The first null hypothesis, which specifies that all of the inefficiency effects are absent from the model of wheat mono-cultivation, is strongly rejected. The second null hypothesis, which specifies that the inefficiency effects are not a linear function of the ages and part-time farmers, is also rejected. The third null hypothesis, which specifies that the inefficiency effects caused by the four factors are absent from the model of wheat intercropping with maize, is also strongly rejected. Since the two variables: the education levels of the farm managers and family sizes did not have effects on the technical efficiency variation of mono-cultivation, we also checked if they had no effect on the technical efficiency variation of intercropping by the forth hypothesis. However, this hypothesis is rejected. These estimation results indicate that the joint effects of these explanatory variables of technical efficiency variance are significant although individual of them does not mean anything.

It is expected that the rarest resource, groundwater, should play the biggest role in wheat yield. That means the variable of the electric powers consumption should have the biggest slope coefficient. However, among all of the inputs' slope coefficients, that of the electric powers consumption is not the biggest both for mono-cultivation and intercropping. For mono-cultivation, it is the smallest with the value of only 0.131; for intercropping, it is 0.208, smaller than those of the expenditure on machine and the cultivation areas. Only by analyzing these coefficients, they cannot show that irrigation played more importantly although groundwater was the rarest resource in arid areas. It seems that the farmers would like to increase some other inputs rather than to increase pumping the groundwater to improve wheat yield when they do their decision of increasing expenditures. However, in fact, the farmers do their decision of increasing expenditures on what kind of inputs by comparing the coefficients of output elasticity (slope coefficient) calculated by the same cost. Now in Minqin County, agricultural labor cost is about 2.5yuan/hour and the price of electric power is about 0.3yuan/kw according to our survey. Unit yuan expenditure on different inputs will bring different output elasticity. The corresponding coefficients of output elasticity of unit yuan were calculated and showed in Table 5.5. From Table 5.5, it was easy to find that the coefficient of output elasticity of unit yuan on electric powers for pumping increased. It increased to the second biggest for wheat mono-cultivation and it increased to the top biggest for wheat intercropping with maize. These results indicate that the farmers more likely tend to increase expenditure on pumping the groundwater to irrigate. Meanwhile, the coefficient of output elasticity of unit yuan on electric powers to pump groundwater for wheat mono-cultivation (0.31%) is smaller than that for intercropping (0.45%). This result shows that if the farmers can pump water as much as they need without much difficulty, they like to cultivate intercropping other than mono-cultivation because the same cost of pumping on intercropping can bring them higher output elasticity. Thus groundwater as a communal resource will be over pumped and the groundwater consumption by the farmers in the north should be affected a lot by the farmers in the south. As a result of these, saving the groundwater becomes a difficult thing.

On the other hand, the results show that the combination of the attributes of the farm managers explained most of the technical efficiency variation although single of them was not at significant level. These estimation results were similar to that of Battese and Coelli (1995). In this study among the factors in function (2), a common factor: the age of the farm manager had negative effect (positive coefficient) on wheat production. This shows that the younger farm mangers got a higher TE than the older. The reason to explain this is that the younger can master the new production technology faster. Another variable, a part-time farm manager had negative role in wheat intercropping with maize in the south but had no same role in wheat mono-cultivation in the south. This might be caused by the differences in labor intensities of the cultivation types. It needs more labor inputs to plant intercropping than mono-cultivation so that the part-time jobs of the farm managers affected their production activities. Higher education level benefited intercropping in the south but did nothing to mono-cultivation in the north. The most possible reason is that mono-cultivation is a knowledge-saving production activity so that education level of the farm manager does not seem important. Meanwhile, a larger family played different roles on intercropping and mono-cultivation. Other family members can support the labors to work more effectively when the production activity needs a lot of labor inputs. As a result, a larger family helped more labor-intensive intercropping but did nothing to labor-saving mono-cultivation in the north.

4 Conclusions and Implications

As the main staple food, wheat is cultivated in large scale although it is a water-intensive but low value-added crop for the arid areas of Northwest China. The SFPF is applied to measure the role of groundwater irrigation on wheat production and to identify the factors of technical efficiency variation by case studies both in the north and the south of Minqin County, Gansu Province. Because of the difficulty in collecting the real consumption volume data of groundwater irrigation, the consumption of electric powers was substituted for it. Considering the mutual impacts of groundwater consumption in the south and the north, this paper analyzed wheat production in the two survey plots.

The results indicate that among all of the inputs, the expenditure on electric powers of pumping the groundwater played more important role. In other words, the farmers are more likely to increase expenditure on pumping the groundwater. Meanwhile, the same expenditure on pumping the groundwater played more important role in wheat intercropping with maize in the south. Elsewhere, the effects of some salient factors of technical efficiency variation are assessed. Although single of them was not at significant level, their combination explained most of the technical efficiency variation. Younger farm managers can achieve a higher TE both in the north and south. For the more input-intensive wheat intercropping farmers in the south, higher education levels and larger families can help them to get higher TEs. Meanwhile, part-time jobs impeded the wheat intercropping farmers to get higher TEs in the south.

According to economics theory, it is more appropriate for the farmers in the south to consume much groundwater than the farmers in the north. However, facing the desertification risk of some lands in the north, the farmers both in the south and the north should be guaranteed to use the water resource fairly in a sustainable way. Therefore, groundwater scarcity and the mutual impact need the government to take some new programs to save agricultural water consumption. One of the possible methods is to distribute the same given amount of available groundwater resource to all of the farmers to clear the negative impact of the south water consumption upon the north. Thus facing the limited water resource, the farmers should adjust their present planting patterns to more water-saving type to improve their living standards. Behind this, it needs the government to guarantee the farmers' food security to support them to adjust their planting decisions. Meanwhile, encouraging the younger farmers to manage production will improve the TEs in the whole Minqin. For the more labor / knowledge-intensive wheat intercropping pattern in the south, improving the farm managers' education and coordinating their part-time jobs with agricultural production activities also can help to achieve higher TEs.

Tables and Figures

Table 5. 1 Description of the Variables Involved in Wheat Production in Minqin County

Variables		Description
Output (y)		Aggregated quantity of wheat or preference output each household (500g/mu)
Inputs		
Machine	(x_1)	The expenditures on machine for cultivating and sowing (yuan/mu)
Fertilizer	(x_2)	The expenditures on fertilizer (yuan/mu)
Irrigation	(x_3)	The consumption of electricity powers for pumping before harvest (kw/mu)
Labor	(x_4)	Labor input engaged before harvest (hours/mu)
Areas	(X_5)	Wheat cultivation areas of the household (mu)
Disaster Dummy	(D)	It is given 1 if the yield is affected by disaster or otherwise 0 (1,0)
Farm-specific Variables		
Ages	(z_1)	The age of the farm manager (years)
Education Levels	(z_2)	School education years of the farm manager (years)
Family size	(z_3)	The number of the family members
Part-time dummy	(z_4)	If the farm manager got part-time job, it is given 1 or otherwise 0.

Table 5. 2 Summary Statistics of Variables involved in Wheat Production in Minqin

Variables	Mono-cultivation (45)		Intercropping with Maize (51)	
	Mean	S. D.	Mean	S. D.
Output (500g/mu)	700.0	116.0	1019.0	147.2
Machine (yuan/mu)	53.7	11.3	52.9	5.1
Fertilizer (yuan/mu)	136.6	30.1	203.0	27.5
Irrigation (kw/mu)	141.1	33.0	153.5	20.0
Labor (hours/mu)	45.7	8.8	66.0	1.4
Areas (mu)	3.3	1.5	3.5	1.4
Disaster dummy	12		14	
Ages (years)	42.8	8.7	46.4	9.6
Edu. levels (years)	8.4	2.9	7.9	2.5
Family size (No.)	4.2	1.2	4	1.5
Part-time dummy	21		20	

Data Source: Authors' field surveys.

Note: S.D. means standard deviation.

Table 5.3 Maximum-Likelihood Estimates of SFPF for Wheat Production in Minqin

Variables	Parameters	Wheat mono-cultivation	Wheat intercropping with maize
Stochastic frontier production function			
Constant	b_0	3.176 (5.5***)	3.508(4.81***)
x_1	b_1	0.189(2.02*)	0.218(1.32)
x_2	b_2	0.309 (5.23***)	0.198 (1.88*)
x_3	b_3	0.131(2.37**)	0.208 (2.07**)
x_4	b_4	0.170(1.76*)	0.154(1.90*)
X_5	$\sum_{i=1}^{5} b_i - 1$	-0.011(-0.28)	-0.004 (-1.12)
D	b_6	-0.042(-1.27)	-0.080(-1.82*)
Technical inefficiency function			
Constant	δ_0	-0.289(-1.06)	0.302(1.00)
Z_1	δ_1	0.008(1.35)	0.001(0.22)
Z_2	δ_2	---	-0.013(-1.30)
Z_3	δ_3	---	-0.033(-1.41)
Z_4	δ_4	-0.032(-0.36)	0.025(0.33)
σ^2	σ^2	0.034(3.72***)	0.016(3.12***)
γ	γ	0.999(782697.65***)	0.999(920.84***)
Log likelihood		37.64	49.96

Note: 1) the data in ( ) are t-statistics; *, ** and *** are significant especially at 10%, 5% and 1% levels; 2) the symbol "---" means that the corresponding variable does not enter the estimation.

Table 5.4 Tests of Hypotheses for Parameters of the Inefficiency Frontier Model

Null hypothesis(H_0)	Log(Likelihood)	Test statistic	$\chi^2_{0.95}$-value	Decision
Mono-cultivation				
(1) $H_0 : \gamma = \delta_0 = \delta_1 = \delta_4 = 0$	30.91	13.46*	9.48	Rejected
(2) $H_0 : \delta_1 = \delta_4 = 0$	33.35	8.58*	5.99	Rejected
Intercropping				
(3) $H_0 : \gamma = \delta_0 = \delta_1 = ... = \delta_4 = 0$	41.76	16.4*	12.59	Rejected
(4) $H_0 : \delta_2 = \delta_3 = 0$	45.45	9*	5.99	Rejected

Note: An asterisk on the value of the test statistic indicates that it exceeds the 95th percentile for the corresponding $\chi^2_{0.95}$-distribution and so the null hypothesis is rejected.

Table 5.5 Output Elasticity of unit Yuan Input on Wheat Production

ε_i Output elasticity of unit yuan i th input	Wheat mono-cultivation	Wheat intercropping with maize
ε_1 (input: machine)	0.35%	0.41%
ε_2 (input: fertilizer)	0.23%	0.10%
ε_3 (input: Irrigation)	0.31%	0.45%
ε_4 (input: labor)	0.15%	0.09%

Note: For example, $b_i = \frac{\Delta y / y}{\Delta x_i / x_i} = \frac{\varepsilon_i}{(yuan/mu)/x'_i}$ so $\varepsilon_i = \frac{b_i(yuan/mu)}{x'_i}$. Here y is the average output (500g/mu); x_i is the average i-th input; $x'_i = x_i * price_i$; b_i is the corresponding output elasticity; ε_i is the output elasticity of unit yuan i-th input.

Appendix

Estimation Results by Mixing Mono-cultivation with Intercropping

Here the author presents another estimation result for the readers to discuss by mixing wheat mono-cultivation with intercropping in the same estimation model. The summary statistics of the mixed data are showed in Appendix-Table 5.1; the estimation results are presented in Appendix-Table 5.2; and the distribution of the TEs are drawn in Appendix-Fig. 5.1.

By mixing, the total samples for estimation increased to 96. Since the groundwater levels are different between the north and the south, an area dummy is applied to the north. It means that if the sample belongs to the north, it is given 1; otherwise it is given 0. The Software Frontier 4.1 is applied to do the estimation. As the estimation result, the coefficient of irrigation of the north equals to 0.14 (α_4-D*α_4=0.18-0.04=0.14) which is smaller than that of the south, 0.18(α_4). Like the estimation results in the body of Chapter 5, the coefficient of irrigation is not the biggest both for wheat mono-cultivation and wheat intercropping with corn. But, by comparing the output elasticity coefficients of the same expenditure on inputs, the inputs' roles will change. The output elasticity coefficients of unit yuan are also presented in the Appendix-Table 5.2. The re-calculation results show that the coefficients of one yuan extra expenditure of irrigation on wheat production increase to the highest both for wheat mono-cultivation and wheat intercropping with corn. These results are similar to the estimation results in the body of Chapter 5.

The things which are different from the estimation results in the body of Chapter 5 are the reasons of technical efficiency variation. Here the results show that the technical efficiency variation is mainly from the differences of school education levels of the farm managers and the family sizes.

Appendix-Table 5.1

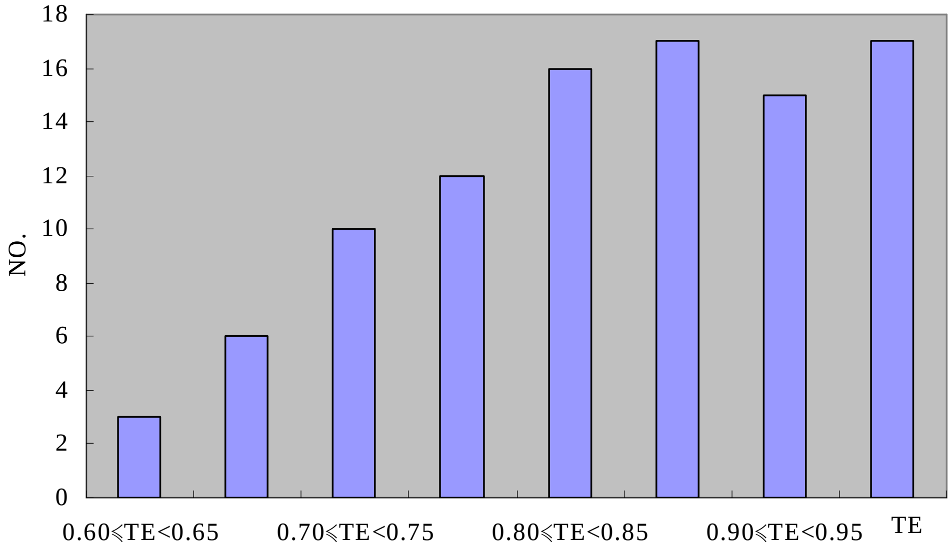
Summary Statistics of Wheat Production by Household in Minqin County

	Mean	Max.	Mini.	Dev.	CV
Y	869.08	1281.00	400.00	208.25	0.24
x_1	83.24	78.00	32.00	8.55	0.10
x_2	171.85	254.00	60.00	43.94	0.26
x_3	56.43	69.00	27.30	14.30	0.25
x_4	147.65	209.50	68.00	27.46	0.19
X_5	3.39	8.00	1.00	1.40	0.41
x_6			Total 26		
z_1	7.93	12.00	0.00	2.92	0.37
z_2	4.10	6.00	2.00	1.33	0.32
z_3	44.63	65.00	27.00	9.06	0.20
z_4			Total 41		

Appendix-Table 5.2 Parameter Estimates of Stochastic Frontier Production Model

Variables	Coefficients	T-statistics	Output Elasticity	Unit Yuan
		Stochastic Frontier Production Function		
α_0	(α_0) 3.33	4.66***		
x_1 (machine)	(α_1) 0.17	2.09**	ε_1	0.20
x_2 (Fertilizer)	(α_2) 0.30	6.20***	ε_2	0.17
x_3 (Labors)	(α_3) 0.16	2.10**	ε_3	0.11
x_4 (Irrigation)	(α_4) 0.18	3.24***	ε_4 (Intercropping)	0.41
D*x_4	-0.04	-3.86***	ε_4 (mono-cultivation)	0.32
X_5 (Areas)	(α_5) -0.02	-0.67		
x_6 (Disaster)	(α_6)-0.05	-1.89*		
		Technical Inefficiency Model		
z_0	0.42	4.81***		
z_1(education)	-0.01	-1.01		
z_2 (family size)	-0.05	-1.82*		
σ	0.02	3.09***		
λ	1.00	2381.85***		

Note: D is the area dummy. Here wheat mono-cultivation in the north is given 1 and wheat intercropping in the south in given 0.



Appendix-Fig. 5.1 Distribution of Technical Efficiencies of Wheat Farmers

Chapter 6
Water Consumption Limitation and Sustainable Agricultural Development

1 Background

Northwest China, which includes the Xingjiang Uygur and Ningxia Hui Autonomous Regions and Gansu, Shaanxi, and Qinghai Provinces, is an enormous droughty area (See Fig. 1.1). Here, rural poverty and water scarcity are serious obstacles to sustainable agricultural development. Water scarcity contributes to desertification in these regions. It is anticipated that, with development, the problem of water scarcity will worsen in the coming decades. This obstacle influences the development of the agricultural sector as well as the regional economy.

In Northwest China, the agricultural sector accounts for approximately 90% of the society's water resources (Jia and Liu, 2004). For such a droughty area with low precipitation and high evaporation, the available water resources cannot support agricultural development over a long period. Limiting agricultural water consumption is a strategic way to achieve sustainable agricultural development for droughty areas. Facing such limitations, the farmers adjust their farming and animal husbandry to improve their farm income. However, some negative effects, such as a reduction in farm income, which in turn is related to rural poverty, and the desolation of the abandoned farmlands, will occur if tight restrictions are placed on agricultural water consumption. Therefore, the present and future generations of the droughty northwest will need to meet three conditions simultaneously for sustainable agricultural development: reduce water consumption to a level that will permit the agricultural sector to exist, improve farm income, and prevent the desertification of arable land. Under limited agricultural water consumption, it is important to understand the manner in which sustainable agricultural development can be achieved. This study will address these issues by presenting a case study of Minqin County of Gansu Province.

2 Case Study Site: Minqin County

Minqin County is a poor and arid area in the middle of Gansu Province. In this arid area, non-farm sectors have not developed well, and there are thousands of poor people in the villages. Minqin County is bordered on three sides by the Badain Jaran desert, the second largest desert in China, with an area of 49,200 km^2, and the Tengger desert, the forth largest desert with an area of 42,700 km^2 (Wang et al., 2003). The oasis of Wuwei City is on the southern border, and it is the only site where surface water enters the county from the Shiyang River.

Historically, the annual rainfall in Minqin County is 110 mm, but its evaporation rate is as high as 2,650 mm (Chang et al., 1994). Little surface water from the Shiyang River limits agricultural irrigation and makes it primarily dependent on groundwater (see Chapter 3). In Minqin County, about 91% of the water is consumed by the agricultural sector (Bureau of Statistics of Minqin County, 2006). As a result, the level of groundwater has been decreasing at a rate of 1m /3years (Li et al., 2005). The reduction in the groundwater accelerates the process of desertification. Now, about 94% of Minqin County is sandy wasteland. The desert has been encroaching at a rate of 20m/year in recent years (Li et al., 2005). If nothing is changed, the groundwater will only be able to support Minqin County development for approximately 17 years, according to reports by a government officer in 2005. If the government is correct, by 2022, the Minqin oasis will disappear, and the bordering deserts will merge. The current conditions make it clear that the environment of northwest China and even though the entire China is under a severe threat. Protecting Minqin County from desertification is very important for China. On the other hand, if nothing is changed, water scarcity will result in a reduction in farm income and an increase in rural poverty.

The implementation of sustainable development in Minqin County has great value. In Minqin County, agriculture is the main source of income. Furthermore, it plays a very important role in preventing desertification of the remaining arable lands. Because of water scarcity, it is likely that the farmers will abandon arable lands. However, since Minqin County is bordered by desert on three sides, no surface water will flow to the abandoned arable lands, and low-level groundwater is not easily accessible due to surface grasses. Abandoned arable land is not as easily recoverable for vegetation as other lands. As a result, the abandoned arable land will become desert in a short period. Therefore, one of conditions for the sustainable agricultural development of Minqin County is to protect the arable lands from abandonment. Since the groundwater level decreases from the south of Minqin County to the north, water scarcity in the north is much more serious. Currently, in the north, the farmers cannot pump as much groundwater as they need; however, in the south, they can. The excessive pumping in the south will accelerate the depletion of groundwater in the north, since all areas in Minqin County share the same groundwater. Success depends on the cooperation of all farmers in Minqin County to share the groundwater in a sustainable way. However, farmers are primarily motivated by the need to provide food for their families and maximize their income. Therefore, in the relatively groundwater-rich south, high-value-added water-intensive crops, such as onions and red peppers, as well as low-value-added food crops, such as wheat and corn, are cultivated on a large scale. In the absolutely groundwater-poor north, few water-intensive food crops are cultivated to ensure the availability of food. In addition, as a way of withstanding the risk from disaster and utilizing the byproducts to maximum the farm income, sheep are traditionally reared in pens. In recent years, alfalfa has been cultivated as feed for sheep to conserve consumption of water for agriculture and protect the land from desertification. The government supports this tactic. The local government compensates the farmers for their arable lands converted to grasslands or woods with 100 kg wheat per mu.

Currently, the available groundwater cannot support the present subsistence farming for a long time. The local government will coordinate the distribution of surface water from the upstream of the Shiyang River Valley to increase the flow of surface water to Minqin County. However, the total amounts of available surface water and groundwater are still insufficient for the cultivation of all arable lands in Minqin County. As a result, arable land will have to be limited to 60% (see Note 1) of the present arable land (Water Resources Department of Gansu Province et al., 2006). However, the remaining 40% of non-irrigated arable land will soon become desert, since there is no longer any possibility for it to obtain water. It is a high priority to adjust farming practices in Minqin County to retain the remaining 40% of arable land. However, it is not known whether the 60% of the normal irrigation quota would be enough for Minqin to irrigate all of the arable lands if the farmers use reasonable planting patterns. We will examine changes that occur in farm income as a result of limitations on water consumption. The policies and government action that will be required to irrigate the arable lands and prevent poverty will be investigated. Study of the methods for providing support to the agricultural sector for the development of sustainable agriculture is important and urgent. According to the analysis above, sustainable agricultural development in Minqin County should meet three conditions simultaneously: (1) reducing agricultural water consumption to a rate below 60% of the normal irrigation quota; (2) cultivating all arable land; and (3) improving or maintaining farm income. Determining steps to achieve sustainable agricultural development in Minqin County is the objective of this study. In the following study, a linear programming model will be applied to study the minimum agricultural water consumption and methods for achieving sustainable agricultural development.

3 Linear Programming Model and Data

3.1 Linear Programming Model

Linear programming falls under the convex optimization theory and is considered to be an important part of operational research. Its standard form (Hazel and Norton, 1986) can be expressed as follows:

Max $$Z = \sum_{j=1}^{n} c_j X_j ;$$

Subject to $$\sum_{j=1}^{n} a_{ij} X_j \le b_i , \text{ all } i = 1 \text{ to } m ;$$

And $$X_j \ge 0, \quad \text{all } j = 1 \text{ to } n ,$$

where Z is the maximum total gross margin; X_j is a set of the activity level, $j = 1$ to n; c_j = the forecasted gross margin of a unit of the j th activity; and a_{ij} = the quantity of the i th resource required to produce one unit of the j th activity. Let m denote the number of resources; then $i = 1$ to m; b_i = the amount of the i th resource available.

Since this study focuses on the achievement of sustainable agricultural development in Minqin County, the analysis is based on farming practices in the county and the behavioral responses of the farmers to them. To simplify the analysis, two assumptions are made: (1) the study is based on a farm household model (Vakis et al., 2004) in which the farmers value income above such things as leisure and their objective is thus to maximize income by working on the farm; (2) this study is based on a typical household of four individuals, including two laborers, 18.6 mu of arable land, and farmers who have to ensure the availability of food for themselves and their families. However, the farmers can adjust their cropping patterns and the number of sheep to maximize their income.

The typical farm household has two main production activities: farming crops and rearing sheep in pens. Many kinds of crops are cultivated in Minqin County. However, several types of crops need to be grown near urban centers and cannot be depended on for stable income. In addition, surveys show that households cultivate no more than seven kinds of crops. Therefore, six main crops and alfalfa were selected for an analysis of how to achieve the sustainable agricultural development with the limited agricultural water consumption. The six main crops include wheat, corn, cotton, caraway, seed-watermelon, and sunflowers. To rear sheep, the farmers utilize the byproducts of corn and caraway, and they plant alfalfa. Therefore, in the model, farmers can choose from the six crops, alfalfa, and rearing sheep as their agricultural production activities. However, they encounter four constraints: limited acreage, food and feed insurance, water consumption, and limited working hours.

First, farmers are limited to the use of 18.6 mu of farmland. Second, the farmers have to face the constraint of ensuring the availability of food. For the purposes of this study, a family keeps the equivalent of 115% of its annual wheat consumption, which is based on a standardized per capita consumption. The additional 15% is considered to be insurance in case of a shortfall. The farmers have two ways to get their main grain: cultivating wheat by themselves or receiving a wheat subsidy of 100kg/mu from the local government if they switch crops to cultivate alfalfa. In addition, the farmers can also plant feed for rearing sheep. In the traditional method of rearing sheep, sheep have to be fed two kinds of feed each day: corn and grasses (alfalfa) or byproducts of some crops (corn stalk or caraway stalk). The third constraint is the limitation on water for agriculture. Fulfilling the limitations placed on water use is one of the most important objectives according to this study. The water limitations will be changed at intervals of 5% to determine the minimum amount of water suitable for agriculture and to predict the responses of farmers. The last constraint concerns the available work hours each month. In Minqin County, farming occurs from March to October. The available work hours differ monthly depending on the weather. July and August, the hottest months in Minqin County, require that the farmers reduce their normal work time from 10 hours/day to 8 hours/day. According to surveys, days of rest increase from 4 to 5 days a month. For the farmers, the two busiest activities are broadcasting seed in April and picking cotton from the end of September to October. During these activities, production cannot be postponed. Therefore, April and September are considered to be two distinct times that require the full attention of the farmer.

At last, the linear programming model in this study is composed of one objective function and 15 detailed constraints. The combination of these terms and the data introduced in the following are used to compose a simplex table.

3.2 Data

Since this study is based on a typical household model, the data applied should be from the household level. However, the production yields and profits fluctuated over the years. Stable data obtained over a period of years would provide the best information. A field survey, however, does not provide the kind of data needed. Statistical data provide the costs and profits for each crop from 2003 and 2006, and the data applied in this study are obtained from governmental statistical yearbooks and a field survey.

However, since the sale prices and the production costs of most of the crops increased in recent years, only the average data of the net profits in the years of 2005 and 2006 are applied in this study. The crop yields are four-year-averaged data, since longer time-serious data can show more stable expected yields. In detailed, the applied statistical data are divided into two groups. One deals with the net profit coefficients of wheat, corn, and cotton, caraway seed, sunflower, and seed melon, and the other, with the volume of water consumption for each crop. Since alfalfa is cultivated not for sale but as feed for sheep, there is no corresponding statistical data about alfalfa production. The profit coefficient of alfalfa is calculated according to the subsidies from the government. The profit coefficient of alfalfa and that from sheep are calculated according to the supplemental survey conducted in 2007. Here there are two kinds of profit coefficients concerning cotton production. One is based on data from self-employed individuals, and the other, on data from farms employing wage laborers. The two coefficients have been recalculated according to the statistical data. Naturally, the former coefficient is higher than the latter one. These two kinds of profit coefficients will be applied to measure the advantages of sufficient labors picking cotton to increase farm income and cut down agricultural water.

The volume of water required for the irrigation of each of the six crops was taken from the statistical data, and the government information includes irrigation data and specific water volumes for each crop. However, the volume of water for irrigating alfalfa is from the supplemental 2007 survey, since there is no such a statistical data. The maximum available water consumption is set as $386m^3$/mu which is a normal irrigation quota set by the government (Management Plan of

Shiyang River Valley, 2006). This quota is the constraint that the farmers face in the scenario analysis, and it is usually the government's responsibility to establish a water distribution plan. The average real water consumption is not applied in this study since (1) most of the farmers do not remember the irrigation volume, and (2) there are significant differences in the irrigation volumes in areas with relatively abundant supplies of groundwater and those with poor supplies of groundwater. In the following study, the share of the normal irrigation quota is changed at 5% intervals to measure the minimum agricultural water consumption.

However, no monthly statistical data about the labor inputs exist. As a result, field survey data about the labor inputs are applied in this study.

Based on the linear programming model and the above data, a simplex table, which includes the farmers' objective function and all of the constraints, is presented (see Table 6.1). Software Lingo 10, which is developed by Lido System, Inc., will be applied to execute the following estimation.

4 Scenarios and Discussions

4.1 Benchmark Scenario (S1)

In reality, the weighted mean irrigation volume was about 308.2m^3/mu in Minqin County in 2006 according to the statistical data (Bureau of Statistics of Minqin County, 2007). The weights applied in this calculation include all of the cultivation shares of 14 crops in Minqin County in 2006. However, data always fluctuate annually according to the planting practices. Therefore, this weighted water consumption is also abandoned as the standard to calculate how much agricultural water can be saved if the farmers implement the most sustainable farming plan.

Based on the maximum available agricultural water in the near future, the water consumption per mu has to decrease. The benchmark scenario (abbreviated as S1) will help determine the minimum need for agricultural water and the effect of a reduction in the consumption of agricultural water. The water levels will be reduced at 5% intervals from 100% to 50% of the normal irrigation quota (386m^3/mu). In 2007, both corn and mutton prices increased significantly. Since corn is the primary feed for sheep, mutton price fluctuates in conjunction with the fluctuation of corn price. To measure the effect of such fluctuation on farm production, the prices of corn and mutton are assumed to increase at 0, 20, 50, and 100%. Correspondingly, there are four sub-scenarios, S1-0, S1-1, S1-2, and S1-3, which are shown in Table 6.2.

Before the reasonable estimates were shown, several sensitivity tests were conducted until the reasonable farming practices appeared. The main results regarding the income, water consumption, and farm sizes are shown in Table 6.3.

One of the objectives of this study was to measure the minimum agricultural water consumption. The estimates concerning the relationship between water consumption and income are shown in Fig. 6.1. Under S1, the farmers are required to fulfill their own needs for food and feed. Figure 6.1 shows that farm income will decrease when agricultural water consumption is reduced to 70-75% of the normal irrigation quota. This result shows that the minimum agricultural water consumption should be set between 70 and 75% of the normal irrigation quote. When the irrigation water is limited to less than 70-75%, the farmers have to abandon parts of their arable lands. As a result, their income will decrease although they had adopted the most reasonable farming practices. In this way, the poor farmers whose income was decreased by the limited water for agriculture will be more difficult to run out of poverty and some low-income farmers will step into poverty again. In conclusion, it would be unreasonable to decrease the water consumption for agriculture in Minqin County to less than 60% of the normal irrigation quota. In other words, the present subsistence farming cannot meet the terms of sustainable agricultural development.

In reality, the weighted mean irrigation volume was about 308.2m^3/mu in Minqin County in 2006 according to the statistical data provided by Bureau of Statistics of Minqin County. The weights applied in this calculation include all of the cultivation shares of 14 crops in Minqin County in 2006 (Bureau of Statistics of Minqin County, 2007).

Seventy to 75% of normal irrigation volume is 270.2~289.5m^3/mu. The comparison of the weighted mean water consumption, 308.2m^3/mu with the estimated 270.2~289.5m^3/mu, shows that there is little difference between them, which might be caused by eliminating several water-intensive crops from the applied model. However, this result shows that the local farmers implemented the most reasonable farming practices when they had to ensure the availability of food for themselves and their families. These results show that the assumptions applied in the linear programming model are reasonable.

4.2 Strategy of Enlarging Cotton Cultivation ─ Scenario 2 (S2)

The estimation results of S1 show that it is very difficult to reduce the consumption of water for agricultural irrigation to a rate less than 60% of normal. Minqin County has to search for other methods to support its agricultural development.

In recent years, with water scarcity, the cultivation scale of cotton increased at a rapid rate since it is a high-value-added and water-saving crop. China imports cotton every year, since the domestic production cannot meet its demand. Cotton sales are assured to Minqin County farmers. Increasing cotton cultivation might help reduce the consumption of water for agriculture without decreasing farm income. Minqin County should plan such a strategy of increasing cotton cultivation to support sustainable agricultural development.

However, since cotton is a typical labor-intensive crop, especially in the picking season, the number of local laborers is insufficient to support a larger crop. If there were enough laborers to pick cotton, it would not be difficult to predict an increase in cotton cultivation. Therefore, it is assumed in this study that, in the picking season, the local cotton farmers can employ enough laborers from other areas to pick cotton. This is Scenario 2 (abbreviated as S2). There are also four sub-scenarios (S2-0, S2-1, S2-2, and S2-3), and they are shown in Table 6.2. S2 will help measure whether the increase of the cotton cultivation area can help Minqin County reduce its consumption of water for agriculture by less than 60% of the normal irrigation quota. Under S2, the farmers will be free of the constraint of insufficient cotton pickers. However, the profit coefficient of cotton production will decrease, since the farmers will have to pay wages to the laborers.

Like S1, S2 is also estimated using the software Lingo 10. The estimates of the farm income variation, water consumption, and farm sizes are also shown in Table 6.3. A comparison of the estimation results for S1 and S2 demonstrates the benefits from having a sufficient number of cotton pickers. Under S1, the farm income will decrease when the available irrigation water is less than 75% of the normal irrigation quota. The income levels at the 75% of normal irrigation quota are set as "1." By comparing the different income levels under S2 with those of "1" (see Fig. 6.2), it can be determined that a proper limitation between 65 and 70% of the normal irrigation quota would make it possible for the farmers to obtain their maximum farm income. This result shows that irrigation water can be reduced to about 5% with the help of a sufficient number of laborers to pick cotton. However, there is still a gap between 65-70% and 60% of the normal irrigation quota.

4.3 Giving up Food Crop Cultivation — Scenario 3 (S3)

The results from the estimates above show that a sufficient number of cotton pickers will not result in a reduction of water consumption for agriculture to less than 60% of the normal irrigation quota. Except hiring additional cotton pickers, Minqin County will need to implement new programs to conserve water for agriculture. To reduce water consumption for agriculture, it will be necessary to discontinue cultivation of the most water-intensive and low-value-added food crops. In this study, this is defined as Scenario 3 (abbreviated as S3). According to the range in prices increases, there are also four sub-scenarios (S3-0, S3-1, S3-2, and S3-3), which are shown in Table 6.2.

The following assumptions are set forth in order to do a simple analysis: (1) the food requirements for the local farmers should be guaranteed by the government, which means that the farmers could obtain wheat at a stable price, and (2) the farmers could also buy as much corn, the main feed, as they need regardless of its market availability. As a result, the farmers will be free from the minimum production constraints of wheat and corn.

The estimates for water consumption, farm income, and farm size are shown in Table 6.3. The farmers are primarily concerned with their income. The income differences between S3 and S1 are shown in Fig. 6.3. The results show that, when the irrigation water supply is kept below 60%, the income difference between S3 and S1 is always positive. This suggests that the substitution of water-saving cash crops for water-intensive food crop cultivation can help the farmers obtain a higher income when the water supply is kept at a lower level. However, if the farmers are allowed to use more than 60% of the quota irrigation, the income difference will change according to the markets of feed and mutton. A sharp increase in the price of corn will result in a dip in farm income since the farmers will cost much more to buy corn and they also have to pay for the substitution of the byproducts of food crops, which they got freely when they cultivated food crops.

Under S3, the estimation results show that the farmers will switch to large-scale alfalfa cultivation and the numbers of sheep will then increase significantly as well. For Minqin County, it is not difficult to sell mutton, since there still is a large mutton market in China.

Giving up water-intensive food crop cultivation will help the farmers conserve water for agriculture (see Fig. 6.4). Especially, under sub-scenario 3-3 (abbreviated as S3-3), a significant amount of irrigation water can be saved. In Minqin County, in addition to conserving water for agriculture and maintaining farm income, another condition for sustainable agricultural development is to prevent the abandonment of all arable land. The simulated farm sizes under the three scenarios are shown in Fig. 6.5. In this figure, it is evident that only under S3 can all arable land be cultivated, even though the consumption of irrigation water is under 60% of the normal irrigation quota. Under S1 and S2, some of the arable land will be abandoned, since the limited water cannot meet the minimum needs of agriculture.

By comparing the results of S1, S2, and S3, only S3 can support a reduction in the consumption of water for agriculture to less than the maximum available water volume (60% of the normal irrigation quota). In addition, only S3 can support all of the arable land to be cultivated. Without considering the influence of sharp rise in feed price, S3 is the best one which can support the sustainable agricultural development in Minqin County. Therefore, eliminating water-intensive food crop cultivation is the most reasonable choice for droughty areas, such as Minqin County.

However, the government should ensure the availability of food for local farmers and their families. The Chinese government can easily do this since it can transfer food from other food production centers, such as Henan, Shandong, and Jilin Provinces. Present developments in information and transportation would make it possible for the government to fulfill these obligations.

5 Conclusions and Implications

Minqin County, an oasis bordered on three sides by desert, is in an important strategic position to prevent two large deserts from merging into one. It is used here as a case study to show how to achieve sustainable agricultural development with limited irrigation water through estimates from a linear programming model. This study is based on three scenarios: benchmark S1, which is based on the present subsistence farming; S2, which assumes there are a sufficient number of cotton pickers; and S3, which is based on S2 but in which the cultivation of water-intensive food crops (wheat and corn) is limited.

The results showed that traditional subsistence agriculture cannot support Minqin County in limiting its agricultural water consumption to less than 60% of the normal irrigation quota, which is assumed to be the maximum volume of available irrigation water for the near future. The lowest level of water consumption can be maintained between 70-75%; otherwise, the farmers are quite likely to abandon some arable land, and their income will decrease significantly. This will contribute to the desertification of arable land and increase rural poverty. Because there is little difference between the real weighted water consumption per mu and 70-75% of the normal irrigation quota, it is clear that (1) the assumptions of the linear programming model are reasonable, and (2) most of the farmers implemented the most reasonable farming practices when they had to ensure the availability of food for themselves and their families.

Under S2, the farmers can adjust their farming more flexibly with a sufficient number of laborers for cotton picking. Therefore, agricultural water consumption can be reduced by more than 5%, but it cannot be lower than 65% of the normal irrigation quota. However, under S3, in which the farmers do not have to guarantee their own food resources, they could use less water to irrigate all of their arable land. As a result, no more arable lands will be abandoned even though the water consumption will be kept at a very low level, approximately 50%. However, a sharp increase in feed (corn) prices will reduce the farmers' income, since the farmers have to pay more for feed.

The results above show that it is currently difficult for droughty areas, such as Minqin County, to continue development with subsistence-oriented farming. However, having a sufficient number of laborers to pick cotton and eliminating the cultivation of water-intensive food crops could help these areas achieve sustainable agricultural development.

Furthermore, to ensure the availability of food for the farmers and their families is the government's duty. The government should transfer food from other water-rich regions to droughty areas like Minqin. It is not difficult for China's government to do so, since wheat and corn are widely cultivated in China. In addition to water resource, other agricultural resources are also unevenly distributed in China. To achieve the sustainable agricultural development, the China's government should reconsider nationwide special agricultural production allotment according to the uneven distribution of agricultural resources as early as possible. This is an important strategy for China. In addition, ensuring the availability of food for the farmers and their families is not enough for droughty areas like Minqin County to meet the objective of sustainable agricultural development. The government should create conditions to facilitate the locals to play their comparative advantages in farming production. For example, the droughty northwest can get higher cotton yield. The government should issue some programs to improve the droughty northwest to cultivate cotton on larger scale. However, unlike food crops, the combination of cash crops with livestock cannot bring farmers stable income, since their prices and yields fluctuate more easily. It is necessary to establish Farmers Associations and Agricultural Insurance Policies to allow farmers to sell commercial farm goods easily and thus achieve a stable farm income. Otherwise, the unstable farm income caused by the farming structure adjustment will less the expected contribution of the adjustment to rural poverty reduction.

Note 1: From 2010, the maximum available water resources can only be allocated to 62.53 ten thousand mu arable land, although there is still 106.52 ten thousand mu arable land (Management Plan of Shiyang River Valley, 2006). As a result, it is highly probable that about 40% of the arable land will be abandoned by the farmers in the near future.

Tables and Figures

Table 6. 1 The Simplex Table of Linear Programming Model

Row name	Columns								RHS
	X_1 Wheat	X_2 Corn	X_3 Cotton	X_4 Caraway	X_5 Sun Flower	X_6 Seed Melon	X_7 Alfalfa	Y_1 Sheep	
Objective Function (yuan)	353	428	810 (1045)	790	535	622	160	143.5	Max
Resource Constraints									
1) Areas (mu)	1	1	1	1	1	1	1	---	<=18.6
2)Food security (kg/mu)	-448.5						-100		<=-964*1.15
3)Water (m^3/mu)	423	455	228	293	300	293	150	---	<=386*18.6
4)Corn for feed (kg)	---	-755	---	---	---	---	---	109.5	<=-365*0.75
5)Crops' byproducts and alfalfa as feed (kg)	---	-333	---	-62.5	---	----	-1167	365	<=0
6)Working hours-Mar. (hours)	2	2	2	2	2	2	1	1.5	<=540
7)Working hours-Apr.(the first) (hours)	8	5	8	7	5	19	1	0.75	<=260
8)Working hours-Apr.(the last) (hours)	0	10	10	0	10	20	0	0.75	<=260
9)Working hours-May (hours)	7	5	40	0	22	32	10	1.5	<=540
10)Working hours-Jun. (hours)	10	25	35	13.5	5	34	10	1.5	<=520
11)Working hours-Jul. (hours)	32.5	14	22	25	15	8	10	1.5	<=400
12)Working hours-Aug. (hours)	0	35	0	2	20	20	10	1.5	<=400
13)Working hours-Sep.(the first) (hours)	0	0	2	20	0	0	5	0.75	<=260
14)Working hours-Sep.(the last) (hours)	0	0	60	0	0	0	5	0.75	<=260
15)Working hours-Oct. (hours)	0	0	40	0	0	0	0	1.5	<=540

Table 6.2 The Supposed Scenarios with Different Conditions

Supposed Conditions	S1				S2				S3			
	S1-0	S1-1	S1-2	S1-3	S2-0	S2-1	S2-2	S2-3	S3-0	S3-1	S3-2	S3-3
Wheat and corn cultivation	○	○	○	○	○	○	○	○	×	×	×	×
Enough labors to pick cotton	×	×	×	×	○	○	○	○	○	○	○	○
Prices' increase (%)	0	20	50	100	0	20	50	100	0	20	50	100
of normal water consumption level (%) 50, 55, 60, 65, 70, 75, 80, 85, 100	○	○	○	○	○	○	○	○	○	○	○	○

Note: Note: (1) “○” means "yes"; “×” means "No"; (2) Prices' increases only include the prices of corn and mutton to increase.

Table 6.3 Simulation Results about Income, Water Consumption and Farm Sizes

			50%	55%	60%	65%	70%	75%	80%	85%	100%
Income (1,000 yuan)	S1	S1-0	9.34	10.31	11.28	12.26	13.19	14.00	14.11	14.11	14.11
		S1-1	10.29	11.49	12.70	13.90	14.56	14.80	14.80	14.80	14.80
		S1-2	11.93	13.53	15.13	16.73	17.43	17.50	17.57	17.77	17.77
		S1-3	15.95	18.15	20.35	22.40	23.56	23.58	23.58	23.58	23.58
	S2	S2-0	10.87	12.15	13.21	14.12	14.47	14.47	14.47	14.47	14.47
		S2-1	10.94	12.22	13.43	14.62	14.98	14.98	14.98	14.98	14.98
		S2-2	12.42	14.02	15.62	17.22	17.66	17.73	17.80	17.87	17.95
		S2-3	16.67	18.88	20.66	22.40	23.56	23.79	23.79	23.79	23.79
	S3	S3-0	14.25	14.97	15.60	15.71	15.73	15.73	15.73	15.73	15.73
		S3-1	15.01	15.45	15.83	15.84	15.84	15.84	15.84	15.84	15.84
		S3-2	16.26	16.27	16.28	16.30	16.30	16.30	16.30	16.30	16.30
		S3-3	20.04	20.04	20.04	20.04	20.04	20.04	20.04	20.04	20.04
Water Consumption (1,000 m3)	S1	S1-0	3.59	3.95	4.31	4.66	5.03	5.38	5.59	5.59	5.59
		S1-1	3.59	3.95	4.31	4.67	5.03	5.34	5.34	5.34	5.34
		S1-2	3.59	3.95	4.31	4.67	5.03	5.38	5.74	6.80	6.81
		S1-3	3.59	3.95	4.31	4.67	5.03	5.05	5.05	5.05	5.05
	S2	S2-0	3.59	3.95	4.31	4.67	5.03	5.16	5.16	5.16	5.16
		S2-1	3.59	3.95	4.31	4.67	4.85	4.85	4.85	4.85	4.85
		S2-2	3.59	3.95	4.31	4.67	5.03	5.39	5.74	6.01	6.35
		S2-3	3.59	3.94	4.31	4.67	5.03	5.27	5.27	5.27	5.27
	S3	S3-0	3.59	3.95	4.31	4.67	4.77	4.77	4.77	4.77	4.77
		S3-1	3.59	3.95	4.31	4.32	4.32	4.32	4.32	4.32	4.32
		S3-2	3.59	3.95	4.31	4.58	4.58	4.58	4.58	4.58	4.58
		S3-3	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79
Cultivated Land Size (mu)	S1	S1-0	11.8	13.0	14.2	15.4	17.0	18.6	18.6	18.6	18.6
		S1-1	13.2	14.8	16.4	18.0	18.6	18.6	18.6	18.6	18.6
		S1-2	13.2	14.8	16.4	18.0	18.6	18.6	18.6	18.6	18.6
		S1-3	13.2	14.8	16.4	17.9	18.6	18.6	18.6	18.6	18.6
	S2	S2-0	13.5	15.1	16.4	17.8	18.6	18.6	18.6	18.6	18.6
		S2-1	13.5	15.1	16.7	18.2	18.6	18.6	18.6	18.6	18.6
		S2-2	13.5	15.1	16.7	18.2	18.6	18.6	18.6	18.6	18.6
		S2-3	13.5	15.1	16.5	17.9	18.6	18.6	18.6	18.6	18.6
	S3	S3-0	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
		S3-1	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
		S3-2	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
		S3-3	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6

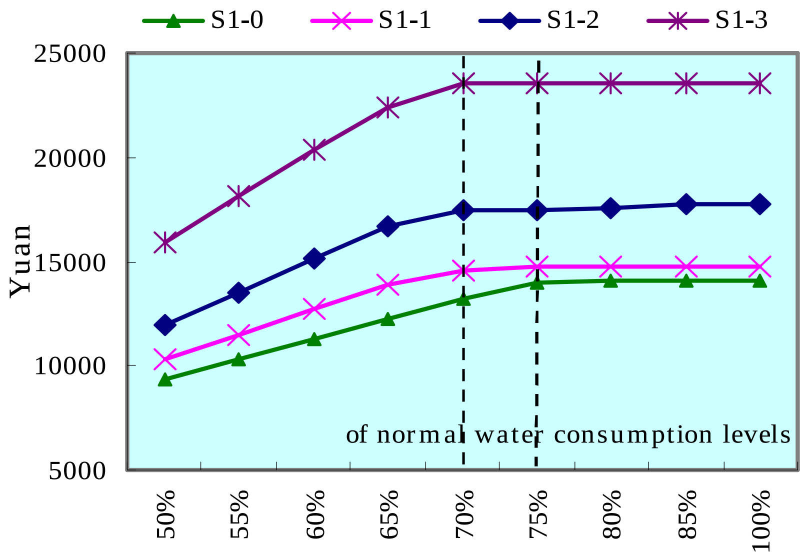


Fig. 6.1 Farm Income and Agricultural Water Consumption Levels

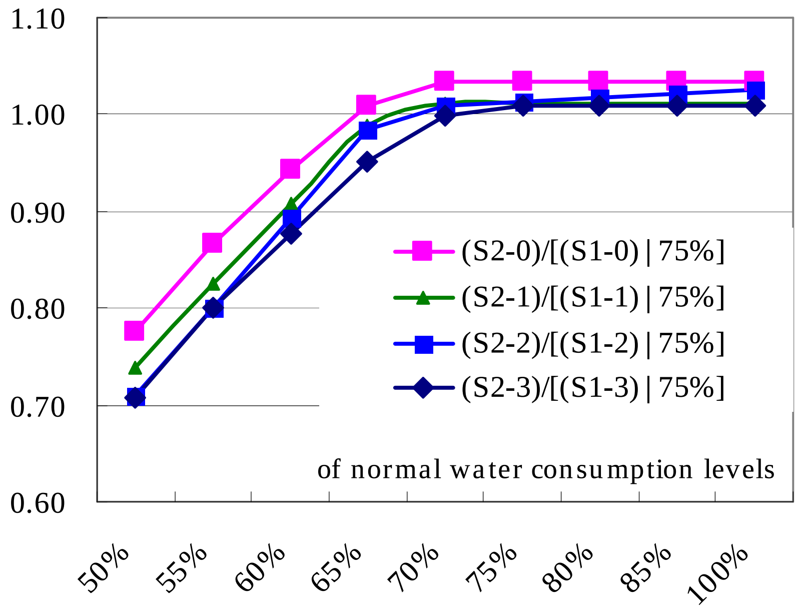


Fig. 6.2 Income Ratio

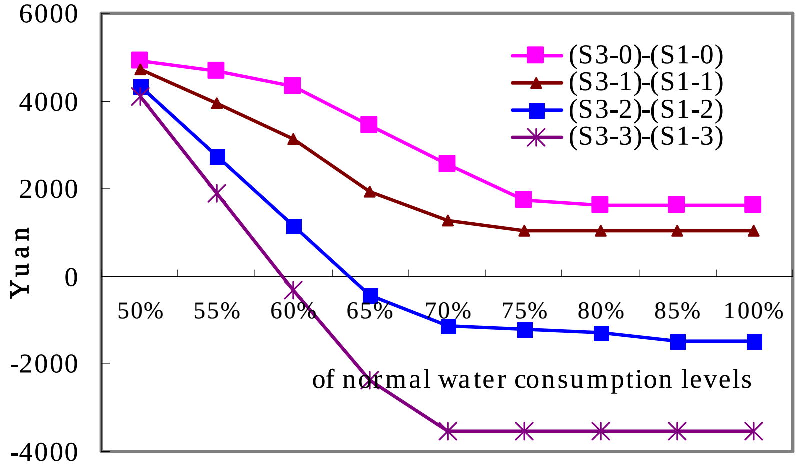


Fig. 6.3 Income Differences between S3 and S1

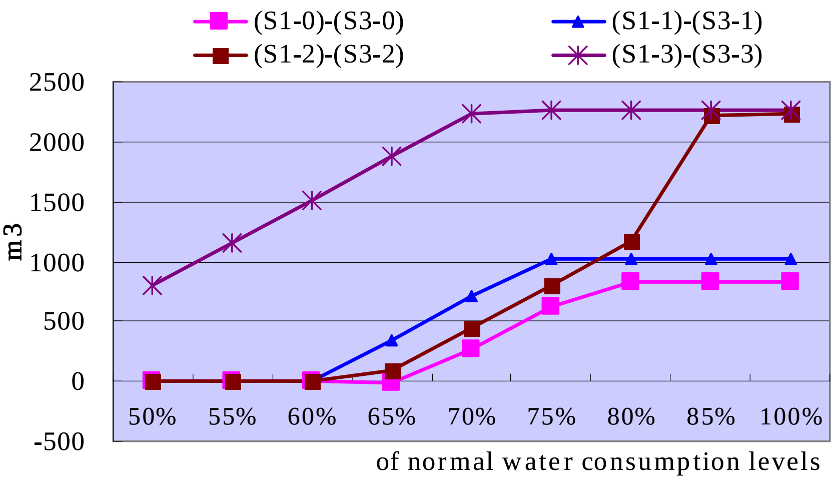


Fig. 6.4 Water Consumption Differences between S3 and S1

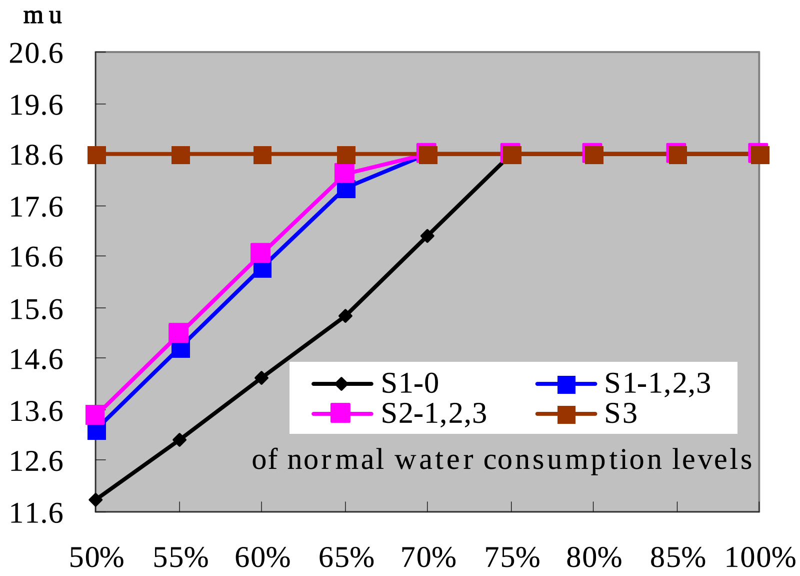


Fig. 6.5 Cultivated Farm Sizes under Different Scenarios

Chapter 7
Summary and Future Study

1 General Findings

The problems of rural poverty, water scarcity, and desertification challenge the sustainable development of the less developed droughty northwest of China. In this area, reducing agricultural water consumption can be expected to solve the above problems because agriculture is not only the main income source for most farmers but is also, to some extent, the means to prevent the area from desertification.

This study achieved three objectives: (1) measuring the role of irrigation in rural poverty reduction and crop production; (2) analyzing the reasons for the technical efficiency variation of the main crops; (3) studying how to get a type of sustainable agricultural development with the limitation of agricultural water consumption in the droughty area. Since the northwest is very vast, it is difficult to adapt a sustainable agricultural development model to the entire area. Therefore, the first objective connecting rural poverty reduction is based on provincial pooled data of China. In addition, other objectives are achieved by a case study of Minqin County, which borders with desert in three sides

The experiences from many developing countries have shown that agriculture is the most important sector in the reduction of rural poverty. One of the main findings of this study, obtained by dividing a long period of the provincial pooled data into two sub-periods, is that improving the irrigation ratio played an increasing positive role in the reduction of rural poverty in China. Improving the irrigation ratio can be expected to have a more significant impact in areas such as the droughty northwest of China. However, for the droughty northwest, it is very difficult to improve the irrigation ratio and cut down agricultural water consumption at the same time without making other changes. To reduce rural poverty by improving the irrigation ratio in the droughty northwest, switching from the present water-intensive farming to water-saving farming should be the key.

In addition, based on a case study of Minqin County, the estimation results show that irrigation plays a key role in the determination of a planting structure and there are still rooms to improve the farmers' technical efficiencies of some main crops, such as wheat and cotton, which are expected to contribute to the above switch. The reasons of the technical inefficiency vary among crops according to their characteristics, such as input-intensive or not and tolerance in natural disaster or not. For the farmers, they should accord the characteristics of crops to improve the technical efficiencies. In addition, groundwater should be treated as a common good in a larger area to guarantee that all farmers can share it in a sustainable way. Otherwise, the intensive water consumption of the water-richer areas will accelerate the decrease of groundwater in the water-poorer areas. Since there are differences in types of wheat cultivation and little differences in technical efficiencies of cotton farmers in the south and the north of Miqnin County, it can be implied that, currently, the problem of water scarcity does not affect the enlargement of cotton cultivation but affects water-intensive wheat a lot.

Using the linear programming model for the estimation, the results show that substituting water-saving farming for water-intensive subsistence farming is the only way to achieve sustainable agricultural development under water constraints. In Minqin, it would be necessary for farmers to combine planting with rearing sheep in pens to prevent a decrease in their income. As a result, commercial farm products will become the main products. However, it would be essential that the government transfers food from other grain production bases to ensure the availability of food for the farmers and their families. In this way, some areas should increase food crop cultivation and some areas increase water-saving crop cultivation. Therefore, the China's government should reconsider nationwide special agricultural production allotment according to the distribution of its water resource. In addition, the government should also develop Farmers Associations and Agricultural Insurance Policies to allow farmers to sell commercial farm goods easily and thus achieve stable farm income.

The detailed estimation results will be introduced separately in the following.

2 Agricultural Development, Irrigation, and Rural Poverty Reduction

Rural poverty is still a serious social problem for China, although great progress in rural poverty reduction has been made since 1978. The experiences from many developing countries have shown that the development of the agricultural sector contributed the most to rural poverty reduction. On the basis of such experiences, in this study, the roles of specific aspects of agricultural development in the reduction of rural poverty in China were analyzed using provincial data from the period of 1988 to 1998.

The problem of rural poverty is much more serious in the droughty northwest. Estimation results show that improving the irrigation ratio played a very positive role in rural poverty reduction. However, other changes, such as the use of fertilizer, did not. The results also demonstrated that non-farm sectors also played a role in rural poverty reduction by providing rural migrant workers with non-farm jobs. Population increase, natural disasters, and the increase of the consumption price index delayed the process of rural poverty reduction. Compared to other areas, such as the east and the center of China, the northwest fared less well in reducing rural poverty.

The above estimation results are very valuable for determining how to reduce rural poverty in the less developed droughty areas. To increase the irrigation ratio seems to be the most effective way. However, for the droughty northwest, the increase in the irrigation ratio should depend on switching from the present subsistence farming to water-saving farming.

3 Technical Efficiencies and the Reasons for Technical Efficiency Variation

In this study, the Stochastic Frontier Production Function is taken to measure the roles of irrigation in cotton and wheat production and the reasons for the technical efficiency variation on the basis of a case study of Minqin County. In this arid area, cotton is cultivated as the main commercial crop, and wheat is cultivated as the main food crop in large scale. The distribution of the technical efficiencies of cotton farmers in different areas is very important to determine if it is possible to increase the cotton cultivation scale in all of Minqin County. The roles of irrigation in wheat production in areas with different groundwater levels are very important to help local farmers determine how to share the groundwater in a sustainable way. At the same time, understanding the reasons for technical efficiency variation is also helpful to switch from subsistence farming to water-saving commercial farming.

3.1 Cotton Production

The plot-level data regarding cotton production are from a field survey conducted by the author in Minqin County in 2006. On the basis of the estimation of a stochastic frontier production function, the results showed that both irrigation and labor inputs, the two key factors of cotton production, had significantly positive effects on increasing the cotton yield. The output elasticity of labor input was the highest if the attention was limited to the estimation coefficients. However, after the cost was considered, the order of the elasticity coefficients changed. The results showed that increasing the same expenditure on electric powers for pumping the groundwater would bring the highest output elasticity. This result showed that water, as the scarcest resource, played the very important role in cotton production. Therefore, it is difficult to reduce the irrigation volume.

Since Minqin is a marginal region connecting with deserts, excluding the damage from natural disaster, the variances of the technical efficiencies of cotton farmers were mainly from the differences in plots' characteristics, such as whether or not they were sandy land and their sizes. Differences in farm management did not contribute to technical efficiency variation. Although one of the surveyed towns near the deserts had more plots affected by desertification and natural disasters than the town near Minqin City, there was no large difference in their average technical efficiencies.

The estimation results show that the present degree of water scarcity does not influence cotton production in all of Minqin County. And there is still a possibility for farmers to improve their technical efficiencies. These estimation results will be benefit of the scale enlargement of water-saving cotton production.

3.2 Wheat Production

The stochastic frontier production function is applied to measure the role of groundwater irrigation on wheat production and identify the factors influencing technical efficiency variation using case studies both in the north and the south of Minqin County. This information is very important for the farmers to improve their technical efficiencies and also to guarantee the farmers, who live in the neighbor areas where groundwater is shared, to utilize the groundwater in a sustainable way.

Because of the difficulty in collecting data on actual groundwater consumption, electricity consumption for irrigation was substituted. The fact that groundwater is shared in the north and south required that wheat production in the two survey plots should be analyzed separately.

The results indicate that, of all factors, the expenditure of one Yuan for electric power for pumping groundwater was a much more important aspect of wheat production when all production costs were considered. Therefore, the farmers would prefer to increase their expenditures on irrigation if that would mean an increase in their wheat yields. Meanwhile, the same expenditures on irrigation played a more important role in wheat intercropping with maize in the south than in wheat mono-cultivation in the north. These outcomes show that it would be difficult to decrease irrigation for the farmers in the water-rich areas. The government would be required to implement some new programs to ensure that all farmers throughout the land utilize the groundwater in a sustainable way.

In addition, the effects of the contributions of farm managers and family size on the variation in technical efficiencies are also assessed. The combination provided a satisfactory explanation of the variation; however, neither of the two aspects alone was statistically significant. Younger farm managers can achieve a higher TE in both the north and the south. For the more input-intensive wheat intercropping in the south, higher education levels and larger families can also help achieve higher TEs. In addition, farmers with part-time jobs cannot intercrop wheat as efficiently as those without part-time jobs.

Although it would be unreasonable to compare the differences in mono-cultivation and intercropping technical efficiencies, an examination of the various planting practices suggests that the water-saving farming pattern would be the trend of agricultural practices.

4 Limitations on Water Consumption and Sustainable Agricultural Development

The achievement of sustainable agricultural development under limitations on water consumption is vital for the droughty northwest. In the droughty areas, sustainable agricultural development must meet three conditions: no reduction in farm income; reduction in agricultural water consumption; and prevention of further desertification of arable lands. The use of estimates obtained with a linear programming model made it possible to meet the objectives stated above in a case study of Minqin County in Gansu Province. The estimation is based on three kinds of scenarios: S1, which is based on subsistence farming; S2, which is based on having a sufficient number of laborers for picking cotton; and S3, which is based on S2 but limits wheat and corn cultivation.

The results of the estimate showed that S1 could not limit agricultural water consumption to less than 60% of the normal irrigation quota, which is estimated to be the maximum available agricultural water for Minqin County in the near future. The Chinese government bases its water consumption plans for agriculture on quotas established for normal irrigation. This normal irrigation quota is not the weighted real water consumption by the farmer but this quota can meet the irrigation requirements of most crops. According to the result, 70-75% of the normal irrigation quota is the minimum agricultural water consumption. Otherwise, some arable land will face a higher probability of being abandoned by farmers, and, as a result, the farm income will also decrease significantly. However, with a sufficient number of laborers to pick cotton (S2), agricultural water consumption can be reduced by more than 5% without decreasing the farm income. Under S3, no arable land will be abandoned even though agricultural water consumption will be kept at a level as low as 50% of the normal irrigation quota. However, a sharp increase in feed (corn) prices will result in a reduction in farm income when the farmers give up food crop cultivation. However, the simulation results of S3 are better than those of S1 and S2. Facing low agricultural water consumption, the farmers will adjust their farming practices to planting crops and rearing sheep in pens to maintain their farm income. Ensuring sufficient supplies of food and labor for picking cotton is a necessary condition for implementing sustainable agricultural development in droughty areas, such as Minqin County.

The government can transfer grain (wheat and corn) from other water-rich grain production bases to droughty areas such as Minqin County to ensure sufficient supplies of food for local farmers. The Chinese government can easily accomplish these transfers, since wheat and corn are cultivated widely throughout the country. Since the distribution of water resources is very uneven, the government should, as soon as possible, change its farming plans to cover a larger region or even the entire country. This is an important strategy that China must implement if it is to meet its food requirements. The assurance of sufficient food supplies for local farmers will not, in and of itself, allow droughty areas such as Minqin County to meet the objectives for sustainable agricultural development. The government should assist the locals in implementing their comparative advantages in agricultural production. Unlike food crops, the combination of commercial crops with livestock does not produce a stable farm income. It is necessary to develop Farmers Associations and Agricultural Insurance Policies so that farmers can sell commercial farm goods easily and thus have a stable farm income. Without such organizations, the role of water-saving and high-value-added farming in supporting sustainable agricultural development will be compromised.

5 Future Studies

In this study, the roles of irrigation on rural poverty reduction and crop production are examined, as are methods for implementing a sustainable agricultural development model with limits on water consumption in the arid northwest areas on the basis of a case study in Minqin County of Gansu Province.

However, China is an enormous country, and its natural resources, such as water, are unevenly distributed. The simulated type of sustainable agricultural development of Minqin County cannot be adapted to all droughty areas. China must, as soon as possible, change its farming practices according to the distribution of natural resources. An overview and exploration of the possibilities for such changes would be a good topic for future studies.

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