INTEGRATED ASSESSMENT OF SUSTAINABLE AGRI-FOOD PRODUCTION SYSTEM IN SHAANXI PROVINCE, CHINA

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Abstract

With a growing population and a rising standard of living, how to maintain food production that meets the increasing demand for food without compromising the ability of future generations to meet their own needs is becoming a pressing issue for the global community, especially in developing countries. In China, sustainable agricultural developed is loudly advocated because of the critical environmental challenges facing its agricultural sector. This study adopts an integrated framework that considers the economic, social, and environmental perspectives simultaneously to understand how agricultural practices in land use and irrigation affect the sustainability of food production systems and how economic, social and ecological goals are perceived and prioritized by peasants.

By using Analytic Hierarchy Process method, this study investigates peasants' perception of sustainability and their preferences of crop land use and irrigation technique in agricultural food production. The surveyed data were collected in 2014 in four prefectural city-regions, including Xi'an, Xianyang, Baoji, and Weinan in Guanzhong Plain, Shaanxi Province, China. The empirical results show that economic benefits are weighed higher than social benefits and environmental impacts by peasants in the study area. With respect to crop land use, peasants prioritize fruit, wheat and corn more than vegetable, cotton, soybean, and canola. In irrigation technique, peasants prioritize sprinkling, drip-irrigation and well-irrigation more than other non-water-saving methods in agricultural production. The sensitivity analysis indicates that if agricultural sustainability is required to be optimized, the trade-offs among crop land uses and among irrigation methods might exist between cash crops and rotation crops, and between water-saving irrigation techniques and well-irrigation.

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1 Introduction

1.1 Research Background

Agriculture has provided the basic food for humans to survive for a long historical time. Today, while agricultural production is under tremendous pressures for meeting the growing food demand, it is, however, faced with great challenges including rapidly growing population, continuing environmental pollution caused by chemical pesticide, aggravated resource consumption and depletion caused by agricultural mechanization and urban development, and excessive soil erosion caused by conventional crop production practices (Lockeretz, 1988). As one of the biggest developing countries, China has more than 25% (1.3 billion) of world's population but only 7% of arable land, and its ability to ensure food security is particularly challenging given its rapid path of urbanization and severity of environmental degradation (Li, 2005). Like many other developed countries and emerging economies, sustainable development of agriculture has been put on the agenda of China's national development since the last century (ERPC, 1994).

The worldwide advocacy of sustainable agriculture has emerged and continually grown with the concept of sustainable development initiated in a report called "Our Common Future" (Brundtland, 1987) released by the UN-solicited Brundtland Commission in 1987. The first concept of sustainable agriculture was put forward by the Food and Agriculture Organization (FAO) conference on agriculture and the environment in the Netherlands in 1991. Its basic principles include to maintain the land-sufficiency for agriculture, guarantee food security, and safeguard the development for this and future generations. More importantly, the proposal of sustainable agriculture prompts for establishing an agricultural mechanism that ensures economy, society, and ecological

environment to develop harmoniously in the long term (Crowley, 2007; Zhao, 2008). The proposal of sustainable agriculture provides a guide for people who are not only concerned with socioeconomic development but also interested in the environmental benefits. It eliminates the ambiguity and controversy with other farming practices that emphasize particularly different but individual dimensions of sustainability, such as organic, ecological, or low-input (Schaller, 1993).

How to make public policies of sustainable agriculture that can be implemented feasibly and effectively is a big concern to any policy makers. A comprehensive understanding of current agricultural systems can provide policy-makers with invaluable information for the future public policies aiming to promote agricultural sustainability. Therefore, many academic studies have assessed agricultural sustainability from different disciplinary backgrounds and perspectives (Hou, 2008; Jorgen, 2002; Kirchner, 2015; Li, 2005; Wang, 2015; XinhuaNet, 2004). However, due to the vagueness of sustainability definitions, scholars from different disciplines have adopted assorted indicators to understand and evaluate the sustainability of agriculture in different parts of the world. After many years of debates and research efforts, some consensus has emerged about conceiving sustainability either on two intersecting pillars, the human and the environmental, or three axes, economic, social, and environmental, or five dimensions, economic, social, environmental, political, and cultural (CIDA, 1997; Dantsis, 2010; Dillon, 2010; Gibson, 2006; Mebratu, 1998). However, the majority of studies analyzing sustainable agriculture focus on socio-economic aspects and environmental sustainability.

This study conceptualizes agricultural sustainability from economic, social and environmental dimensions and argues these three dimensions need to be considered simultaneously in any meaningful assessment of sustainable agriculture. Upon a review of

related academic literature, nine sustainability indicators or decision attributes are identified for use in this study to evaluate agricultural production system. Those decision attributes are crop yield, agricultural income, and water-use efficiency improvement under economic dimension; community cohesion, rural household lifestyle, and rural recreation improvement under social dimension; agricultural chemical runoff and leaching prevention, soil erosion prevention, and reducing water withdrawal from rivers under environmental dimension.

Given the multi-dimensionality of sustainability concept, evaluating sustainable agriculture must involve multiple criteria and decision attributes. This is particularly true when agricultural production systems are concerned, because agriculture is operated by farmers who are also the basis of a vital rural community and utilize environmental resources that are subject to contamination and degradation by agricultural production inputs. Hence, agricultural sustainability evaluation often requires an integrated assessment method that is capable of considering multiple criteria and decision attributes simultaneously. The Analytic Hierarchy Process (AHP) approach stands out in this regard. Not only does it allow economic, social, and environmental evaluation criteria, qualitative and quantitative indicators to be considered simultaneously, but also it offers prioritized solution options to help reach rational and optimized decisions. This research will employ AHP method to assess peasants' perspectives toward sustainable agriculture in China. This integrated assessment research may help governments and policy-makers better implement the sustainable idea and agenda in agricultural production.

1.2 Research Objectives

The goal of this study is to understand peasants' perceptions of sustainability in food production in Guanzhong Plain, Shaanxi Province, China, using an integrated assessment framework. To achieve this goal, the following research objectives are specified:

1) to evaluate how peasants prioritize sustainability goals in their agricultural practices by considering economic, social, and environmental goals of sustainable agriculture simultaneously using the AHP method,

2) to identify peasants' preferences of cropland uses and irrigation techniques, based on peasants' prioritization of sustainability criteria and associated decision attributes, and

3) to assess the trade-offs among different cropland-use and irrigation-method under the scenarios of alternative rankings of sustainability goals using a sensitivity analysis.

The results of this research can provide policy-makers and governments with information to formulate and implement the feasible public policies that promote sustainable agricultural production in the study area and beyond.

1.3 Thesis Outline

This thesis is presented in seven chapters. The second chapter describes the concepts and the assessment framework upon which this study is developed including agricultural system, perspectives on sustainable development and sustainable agriculture. The third chapter describes the study area, data source, and the data analysis steps of the Analytic Hierarchy Process method. Chapter four presents the result of peasants' preferences of economic, social, and environmental concerns in their agricultural

production. Chapters five and six present empirical results on peasants' preferences of seven crop types and six irrigation methods in terms of sustainable evaluation criteria and decision attributes. The sensitivity of peasants' selection of cropland-use and irrigation techniques are then discussed with respect to hypothetical sustainable development scenarios. Chapter seven concludes this thesis by summarizing the academic contributions of the study and presenting recommendations and considerations for public policies as well as future research.

Chapter Two

2 Sustainable Agriculture and Indicators of Sustainability

This chapter provides the context for the assessment of sustainable agriculture. It discusses various perspectives on agricultural sustainability from different disciplines and presents assorted dimensions and indicators for sustainability evaluation. It also examines the characteristics of available integrated assessment methods and identifies their pros and cons in the context of sustainable agriculture. The chapter concludes with a discussion of the research opportunity and feasible sustainability evaluation criteria and indicators.

2.1 Agriculture system

Ever since agriculture exists, it is not only essential to human survival, but also important to human economic and societal development (Zhao, 2008). According to Dr. Wayne Caldwell, agriculture happens because of a diversity of relationships (Caldwell, 2015). The most basic level exists as a relationship between farmers and the land. Farmers farm their land to harvest, then the crops are used for humans to sustain life. At the most complex level, agriculture exists as an intricate web that connects all the relationships between human and natural systems. The natural systems include soil, water, landform, and climate; and the human systems involves farmers, community, processing, and market. There is no way we can understand the complete picture of agriculture just from the perspective of single element.

The development of agriculture always relies on the effort from the coordinated work of each system. A variety of studies have proved that agriculture is one big open system, that every component is closely related to and influenced by each other (Desai, 2007). For example, the "Green Revolution" that brought chemical fertilizers and pesticide

into agriculture and promoted the development of conventional agriculture helped dramatically boost agricultural production, which then, after only two decades, it was proved to weaken human immune system, causing enormous environmental degradation and accumulation of chemicals in agro-ecosystem (Clive, 1990; Desai, 2007; Seufert, 2012). Another topic about how climate change influences agriculture has arisen since 1990s. It is widely accepted that changes in temperature, precipitation, and carbon dioxide concentrations can profoundly restrict agricultural development (Adams, 1998; Kaiser, 1989). Other studies have also shown that not only agricultural systems would be affected by changes in natural systems, but also by social and political systems. Because of the breakdown of socialism in post-Soviet European Russia, massive socio-economic and institutional changes led to substantial agricultural land abandonment (Prishchepov, 2013). Chinese studies on modern agricultural systems have indicated that industrialization and urbanization have attracted more young able-bodied people to leave rural areas for cities to make a living, which has led to the decrease of agriculture-employed population, further causing the decline of agricultural productivity (Qian, 2011).

Besides the changeable conditions and system elements of agriculture, there is one more key element in agriculture that should be emphasized. Denham (1847) said "A field requires three things, fair weather, sound seed, and a good husbandman". According to Croxall (1984), there are four factors can influence agriculture, meteorological factors, land factors, biological factors, and human factors. A good husbandman, epitomizing the labor force in all agricultural practices, is referred to as a farmer or peasant today. Croxall (1984) used a metaphor to explain why humans can greatly affect agriculture. External environmental conditions set the scene for agriculture. Biological organisms like plants and animals are the players. Humans are not only the backers of the system but also the hungry

audience, which makes human the most difficult decision-making role of all, the producer in the person of the grower.

Peasants have intimate connections to the land, besides in the person of the growers. They are also the direct perceivers of land, which make them the risk takers. Peasants always face numerous types of risk during agricultural production, such as production risks from the unpredictable nature of the weather; price or market risks; institutional risks including political, sovereign, or contractual risks; human or personal risks; and financial risks (Hardaker, 2015). Even so, peasants since ancient times strived to overcome the environment, adapt or adjust cropping strategies, and make decisions in the face of uncertain conditions in order to reduce risks, as well as increase the chances of improving income and yield (Gould, 1963; Jain, 2015). Different from other stakeholders, peasants' agricultural decisions greatly depend on their whole life experiences. Those experiences are normally formed by a complex mix of economic, social, cultural, political, and environmental factors, most of which are variable and beyond the control of individual peasant (Smit, 1997). In most cases, peasants are risk averse when faced with significant risky incomes and wealth outcomes. They generally aim to be economically successful over the long-term.

Generally speaking, it is important to realize that, from a system perspective, any changes in possible elements in agricultural system might lead to the change in other factors. More importantly, those changes might further affect the entire agricultural system.

2.1.1 Perspectives on sustainable agriculture

Since last century, there has been a growing awareness of the necessity of sustainable development (SD). It presents a public concern with respect both to natural

resources and to the environment, suggesting people have grown awareness of the environmental consequences of human activities, and raised social and political concerns about human development issues (Robinson, 2004; Sandra, 1989). However, it is unlikely for humans to stop the socio-economic development in consideration of the environment. In this context, sustainability is the term bridging development and the environment (Rogers, 2010). The concept of sustainable development appeared on the late 1980s and early 1990s (Beckerman, 1994; Brundtland, 1987; IUCN/UNEP/WWF/FAO/UNESCO, 1980; Mitcham, 1995). The most popular definition of sustainable development currently, is the one proposed by World Commission on Environment and Development (WCED) in the book "Our common future". In briefly, sustainable development is "…the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (p.43)" (Brundtland, 1987). This definition has raised a widespread concern about human impacts on the environment. People started to talk about sustainable development from a variety of perspectives. Sustainable development has become the watchword for non-governmental organizations, the keyword of governments' policies, the slogan of developmental and environmental activists, and the theme of conferences and learned papers. Sustainable agriculture is one of the hot topics.

Before sustainable agriculture became a popular term, people spoke of regenerative, alternative, low input, environmental, and organic agriculture. Current developing situations of most countries in this world equate "to meet the needs of the present generations" with feeding the growing population. Agriculture has being under tremendous pressure to meet the food demand. Notable problems in agriculture have been ameliorated, such as water availability fluctuation, soil erosion, degradation of soil quality, the contamination of the environment by chemical fertilizers and pesticides, and the depressed

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commodity prices and high production costs caused low farm income (Lockeretz, 1988).

Yet, the definition of sustainable development is a broad concept with vagueness, which makes it open to many interpretations from different perspectives, including agronomic, environmental, economic, social, political, and cultural. For example, from a political perspective, sustainable agriculture has been seen as an important public policy issue, and usually spoken as an effective solution to food security, concerned by every country in the world (Anderson, 2014; Beddington, 2010; Belesky, 2014). Based on a series of studies, food security was referred to self-sufficiency, defined as "…access by all people to enough food to live a healthy and productive life" (Pinstrup, 2009). Food sovereignty is used to measure the extent.

However, sustainable agriculture has also been interpreted more in actual operational process from economic, social, cultural, and environmental perspectives. For agriculturalists, they have focused on sustaining yield, nutrient cycling of nutrient management, crop rotations, biotechnology and crop breeding, and pest management in sustainable agricultural systems (Conway, 2013; Edwards, 1990; Smit, 1989). Here, the focus is on environmental stewardship so that long term crop yield can be sustained.

From an economic perspective, sustainability is seen as a side of efficiency. It emphasizes the use of resources to benefit both present and future generations in the long run efficiency (Conway, 2013). There is a dominant view in American agriculture that views agricultural sustainability as food sufficiency. Farrell (Douglass, 1984) in an economic analysis of agriculture concluded that food export demand would keep growing, making resources costs and environmental damage to continue to mount. They will trigger both market and policy response to find new and more efficient ways to conserve scarce resources. Recently, research has focused more on market mechanisms, reduction of

agricultural inputs, improving farm-income, and removal of poverty (Kilian, 2006; Pretty, 2001; Sanders, 2006). All studies point out that economic changes may not be the prime mover of sustainable agriculture, but the fallout.

From a social perspective, sustainable agriculture suggests the reflection of social values. Sociologists regard it as a development path which is in accordance with the traditional cultures and institutions (Conway, 2013). Related examinations expressed three keywords of agricultural sustainability based on the social perspective, community, justice, and participation (Barbier, 1987; Lapping, 1982; Smit, 1989). As expressed by Cobb (1984) he argued that people should not be simply viewed as instruments of agricultural production, but also given values for their contributions to personal interrelations in community, as well as their interconnections with broader communities. Sustainability in question is, therefore, also relevant to the rural communities that make it possible.

From an environmental perspective, sustainable agriculture represents a way of providing sufficient food without compromising natural resource endowment. Sustainability emphasizes a responsibility for the environment and a stewardship of natural resources (Conway, 2013). Scholars have studied the carrying capacity in pastoral systems, conservation tillage, water quality, soil carbon sequestration, and so on (Antle, 2001; Conway, 2013). For example, Logan (Clive, 1990) discovered that water quality impacts associated with accelerated erosion and nutrient and pesticide losses, will jeopardise the environment and sustainable agriculture. Laflen (Clive, 1990) suggested that soil erosion is a big threat to the limited and available agricultural land. More importantly, it is a major threat to a sustainable agriculture.

2.1.2 Definition and indicators of sustainable food production system

On the basis of sustainable agriculture under discussion in full swing, scholars have raised their attention to the sustainable development of agricultural food production. According to Brklacich (1991), that the heart of much interest in the sustainability of agriculture is environmental degradation and the potential impacts on environmental and food production. But, it does not mean that concerns over the sustainability of food production is only confined to environmental degradation. The foregoing discussions have also proved that scholars from various disciplines discovered different perspectives that could affect sustainable agriculture. Therefore, it is important to consider the sustainable development of agricultural food production systems from a systematic point of view. As various perspectives and elements are included, sustainable food production can be better understood.

Nevertheless, because of the vagueness of sustainability definitions, further evaluation of the sustainability of food production systems requires more clear definitions and indicators. Douglass acknowledges varied applications of sustainability to provide three basic definitions in agricultural food system: stewardship, food sufficiency, and community (Douglass, 1984; Smit, 1989). These three definitions have then further developed by Brklacich (Brklacich, 1991). By examining a large body of literature, he identified six major perspectives that can used to comprehend a sustainable food production system. These six perspectives are: (1) environmental accounting, (2) sustained yield, (3) carrying capacity, (4) production unit viability, (5) product supply and security, (6) equity, respectively (Brklacich, 1991). He also stated that, to a large extent, (1) and (3) are rooted in the environment and resource stewardship, (2) and (4) draw from economic view, (5) and (6) relate to social justice. From Brklacich's conclusion, what can be perceived is that,

with respect to sustainable food production systems, it is important to consider economic, social, and environmental dimensions simultaneously.

For many years, the difficulty of evaluating sustainability also contributed to a lively debate about the resting pillars of sustainability. What comes to consensus is whether it is best to conceive of sustainability resting on two intersecting pillars (the human and the environmental), three (economic, social, and environmental), or five (economic, social, environmental, political, and cultural) (CIDA, 1997; Gibson, 2006; Mebratu, 1998). However, the three dimension paradigm (economic, social, and environmental) have been the most well-known and well-used pillars of sustainability. They are also the three dimensions adopted in this research.

Identifying the dimensions has helped select the indicators to further dissect the sustainable food production system. So far, research hasn't reached a consensus about what parameters can be used to accurately calculate or measure the level of sustainability in agricultural production (Below, 2012; Caviglia, 2001; Jain, 2015; Pannell, 1999). According to Zander et al. (1999), there might be three reasons. The first refers to the concept of sustainability, which comprise multiple and conflicting goals that are not clearly defined in terms of measurable parameters. The second suggests that a consensus has not been reached on the parameters, which could possibly be used to evaluate the sustainable degree of land-use, or how the necessary trade-offs between the parameters is to be assessed. The last one indicates the complexity of interactions between economic, social and environmental systems, which leads to difficulties of predicting how agricultural land use should be changed so that a desired level of sustainability can be achieved (Zander, 1999). However, since the 1990s, a variety of research has provided their understandings of indicators and attributes that can be used to evaluate the sustainability in food production.

Based on Douglass's (1984) and Brklacich's (1991) perspective, a body of literature was selected to further identify the dimensions and indicators that were used in sustainable food production related research. According to Table 2.1, a great amount of literature relating to sustainable food production assessment uses indicators and attributes sorted in economic, social, and environmental dimensions.

How to properly select the indicators usually depends upon the different levels of assessment. At the national scale, food security, financial health, water, nutrient, animal welfare, community wealth, energy, bio-diversity, are possibly the most important categories of indicators chosen by international organizations (Shobri, 2016). For example, as stated by Wen (1992), Xu (1992), and Zhao (2008), sustainable agricultural development in China has encountered various obstacles, such as, growing population and high population density, cultivated land loss, water scarcity, pollution caused by chemical fertilizers and pesticides, and environmental degradation. So the indicators they chose to assess those challenges include GDP, urbanization level, population, food self-sufficiency percentage, and sources of supplement and loss. Additionally, Dillon et al. (2010), adopted sustainability indicators to assess Irish agriculture that included market return, the direct payments as a percentage of gross output, demographic viability, isolation, methane emissions, and organic nitrogen and phosphorus. On the other hand, at the farm level or household level, when peasants are making their own decisions, the indicators or decision attributes are most likely their critical concerns in agricultural practices. For example, Bernués et at. (2016) and Bélanger et al. (2012) revealed farmers' perceptions of sustainable agriculture at the farm level, based on economic indicators including farm income, inputs and outputs, crop yields, and self-sufficiency, social indicators including quality of life and labor conditions, and environmental indicators including soil fertility and erosion

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prevention, water purification and waste management. In another case study, Mazur et al. (1992) suggested community cohesion as another indicator for appraising social dimensions of African sustainable agriculture. He suggested that agricultural households and individuals are indispensable components in agricultural production, and agricultural individuals and households form their communities. It would be illogical to expect their agricultural production process to be sustainable if they cannot socially sustain themselves. As indicated in Li's (2001) study, water-use efficiency has also been adopted as one of economic indicators to assess sustainable agricultural development.

Table 2.1 Overview of dimensions assessing the sustainability of food production systems and the accompanying indicators

Reference	Theme	Dimensions & Indicators		
		Economic	Social	Environmental
(Aurbacher, 2013)	Field crops management	Yield	Working days	Soil moisture, Air temperature, Precipitation
(Bélanger, 2012)	Assess dairy farm	Yield (perennial crops and annual crops)		Soil quality, Land drainage
(Bernués, 2016)	Perceptions of farmers and non-farmers	Farm structure & size, Profitability	Labour conditions, Quality of life, Farm continuity	Water purification and waste, Soil fertility & erosion prevention, Air quality regulation, Regulation of water flows
(Binder, 2012)	Milk value added chain	Hourly wage, Subsidies	Social acceptance, Level of education	Greenhouse gas emissions, Biodiversity
(Castellini, 2012)	Poultry production system	Net income, Revenue, etc.	Labor safety	Ecotoxicity, Ecological footprint
(Dantsis, 2010)	Plant production system	Water-use efficiency, Gross margin, Yield	Proactivity	Fertilizer and pesticide use, Chemical runoff and leaching
(Dillon, 2010)	Irish agriculture	Viability, Market return	Demographic viability, Isolation	Methane emissions, Organic nitrogen and phosphorus
(Macias, 2008)	Social impact of community-based agriculture		Food security, Social integration, Natural human capital	
(Malanson, 2014)	Simulation crop change in response to climate	Yield, Income	Labor, Willingness	Monsoon precipitation
(Mazur, 1992)	Local knowledge systems in African Sustainable agriculture	Inputs	Communities, Households, Individuals	
(Meares, 1997)	Differences between conventional and sustainable agriculture		Gender, Quality of life, Solidarity in networks	
(Peng, 2007) & (Xu, 2012)	"Grain for Green" Project	Income, Poverty reduction, Grain production	Minority economic development, Social status of women	Carbon sequestration, Soil erosion prevention, Ecological environment conservation
(Yadav, 2000)	Cropping system	Green manuring inputs		Soil organic carbon
(Sadati, 2010)	Farmer's attitude on sustainable agriculture	Maximize productivity, efficiency, profitability	Household lifestyle	Soil and water conservation, Chemical leaching prevention, Soil erosion and degradation prevention

(Sattler, 2010)	Production practices	Gross margin	Acceptance for implementation	Nitrate leaching to groundwater, Pesticide entries to surface water, Soil erosion
(Thivierge, 2014)	Cash-crop farm			Soil quality, Water quality
(van Asselt, 2014)	Evaluate potato production	Net income, Annual turnover		Chemical runoff and leaching, CO_2 emission
(Van Thanh, 2015)	Banana farmers' adoption	Economic status	Education, Labour assess	Chemicals using
(Zhao, 2008) & (Wen, 1992; Xu, 1992)	Chinese agriculture	GDP, Yield of grain, Input & output of grain per capita	Urbanization level, Total, urban, and rural population,	Sources of supplement & loss, Changes of cultivated land
(Shobri, 2016)	Malaysian agriculture (crop commodities)			Soil health and substrate management, Irrigation and fertigation, Waste and pollution

2.1.3 Summary

Previous experiences have shown that blindly pursuing economic growth and productivity improvement in agriculture, at the cost of jeopardizing the environment is not endurable. It makes us suffering the consequences of what we do to the environment for economic development, and compromises the ability of future generations. The concept of sustainable development has particularly emphasized the importance of conserving natural resources and environment. It provides a goal or a direction for people to look at, that agriculture should also take environmental, social, and economic dimensions into account simultaneously, so that the sustainable development of agricultural food production could be economically viable, socially acceptable, and environmentally non-degrading. In order to implement the sustainable development of agriculture, not only three dimensions should be theoretically considered, technically speaking, it is also important to take all related indicators under these dimensions into consideration.

However, there are a great amount of indicators that can be used to evaluate sustainability, how to properly select among them depends upon the different level of assessment. In this research, study is at the farm level considering peasants' perceptions of sustainability in agriculture production. So besides three sustainable dimensions should be included, nine indicators under economic, social, and environmental dimensions were also selected for the assessment. They are crop yield, agricultural income, and water-use efficiency improvement under economic dimension; community cohesion, rural household lifestyle, and rural recreation improvement under social dimension; agricultural chemical runoff and leaching prevention, soil erosion prevention, and reducing water withdrawal from rivers under environmental dimension. These nine indicators are used as the decision attributes for peasants to identify and choose their preferences of alternative crop land-uses

or irrigation techniques.

2.2 Assessment Framework

In recent years, a variety of holistic assessment approaches have been widely used in sustainable development related research (Dizdaroglu, 2014; Jayaraman, 2015; Yigitcanlar, 2015; Zhang, 2014c). Many of them have also been adopted in the assessment of agricultural systems (Antle, 2001; Gerbens-Leenes, 2003; Goglio, 2017; Liu, 2007; Zhou, 2007). The key concern of conducting the assessment of sustainability is how to integrate economic, social, and environmental dimensions simultaneously. Apparently, scholars from different disciplinary background have different perceptions of those dimensions, as well as their preferred assessment method to deal with the interrelationships among dimensions and indicators. They usually prioritize their disciplines' focus (Yin, 2004). For a comprehensive assessment of sustainable agricultural production systems, which involves multiple economic, social, and environmental evaluation criteria, multiple indicators or decision attributes, as well as multiple groups of decision-makers, peasants and stakeholders, the selection of an appropriate method is vital.

2.2.1 Integrated assessment

Integrated assessment (IA) was initially designed for studying the effects of climate change and has been developed and widely used since then. IA has so far been acknowledged by international researchers, and is seen as a powerful holistic tool for scientific support to the assessment of sustainable agriculture, land-use allocations, policy implications, energy supply systems, and decision-making related problems (Abaza, 2004; Bland, 1999; Ewert, 2014; Reidsma, 2012, 2011; Sattler, 2010).

The definition of IA remains in some dispute, but a consensus has been reached.

Building on two characteristics defined by Parson (Parson, 1994), a), IA provides some significant information for decision-makers to use; b) rather than restricting issues within the bounds of single research discipline, a broader set of methods, styles of study, degrees of confidence are combined together by IA. Rotmans (1998) suggested IA is a structured process which can deal with complex issues through using knowledge from various scientific disciplines or stakeholders. In this context, available integrated insights can be generated for decision makers. Notwithstanding the existent diversity, two elements of IA are now commonly accepted: interdisciplinary and decision support (Gough, 1998; Rotmans, 1998). Yin and Wang (2004) further replenished five characteristics of IA for sustainability assessment. They are 1) policy-oriented, bridging the effects of climate change and sustainable development; 2) systematicness and interdisciplinary; 3) multiple objectives and multiple sectors evaluation; 4) multiple interest groups involved and their trade-offs; 5) advancing analytical methods. They also suggested that not every integrated assessment research needs to meet all these features. Researchers could select an appropriate IA approach based on their own requirements by using these characteristics as a guide. A number of IA approaches and techniques have been developed and applied since last century.

Table 2.2 briefly summarise a series of IA approaches which have commonly been applied to agriculture related decision problems (Amini, 2010; García, 2014; Veisi, 2016; Zhou, 2007). They can be generally sorted into three categories: system analysis, linear programming, and multi-criteria decision analysis. It is argued that such approaches can help to understand the trade-offs among various sustainability goals.

Cost-Benefit Analysis (CBA) has proved to be one of the most popular approaches assessing policies, especially economic benefits under the influence of climate and

environment changes. But CBA focuses more on economic benefits, and transfers economic, social, and environmental consequences of policy or project assessment to a monetary unit (Sain, 2017; Yin, 2004; Zhou, 2007). It is the biggest limitation for sustainable agricultural assessment, as it always comes with some qualitative or unquantifiable variables that make it difficult to implement CBA. Besides, as a systematic analysis approach, CBA can only deal with one objective to achieve one particular goal. Yet, sustainable development requires considering multiple and conflicting objectives at the same time.

CHAC Model was initially designed by the World Bank in order to study the agricultural development in Mexico. As a linear programming model tool for policy-makers, CHAC has been widely used to address questions of pricing policies, trade policies, employment programmes, and some categories of investment allocation (Yin, 2004). However, as stated by Thorbecke (1982), CHAC is not particularly well suited for analysing agricultural research and extension programmes, crop insurance policies or credit policies. The Land Evaluation Model (LEM), also is a linear programming model designed at the University of Guelph to evaluate the sustainability of land utilization(Yin, 2004). Both the CHAC Model and Land Evaluation Model are single-objective linear programming models and they generally deal with only one important aspect of agricultural resources utilizing system. Practically speaking, CHAC emphasises the economic dimension, while LEM focuses on the sustainability of land-use. They are unable to handle multiple dimensions' problems involved various decision attributes.

Goal programming (GP) is a branch of multi-objective optimization programmes. Unlike system analysis or linear programming only allowing one objective, GP is not only designed to get a result based on the objective of optimizing the economy, but also seeks to

get a best answer through considering multiple objectives. However, GP requires decision makers to provide an ordinal ranking of the objectives before analysis, which is a disadvantage for sustainable agriculture assessment (Abraham C., 1975; Jayaraman, 2015; Yin, 2004), because the resting pillars of sustainable development (economic, social, and environmental) should be treated as equally important.

TEAM (Tool for Environmental Assessment and Management) is a decision support software system developed by the U.S. Environmental Protection Agency. It was designed to assist regional and local decision-makers to cope with the complex challenges of the assessment of consequences and selection of appropriate adaptation strategies. TEAM adopts a multi-criteria approach to evaluate actions dealing with climate change impacts to costal zones, water resources, and agriculture (Julius, 2000). So TEAM is an appropriate integrated assessment method to evaluate the adaptation policies of climate changes' influences and consequences, and find the most satisfactory one (Yin, 2004). But it is not a suitable integrated assessment method for this research, as it basically does assessment from an environmental perspective.

To sum up, due to the complexity of sustainable agricultural food production evaluation, approaches capable of balancing multi-objectives, incorporating imprecise and uncertain information in decision making prove to be invaluable.

Table 2.2 Overview of Integrated Assessment approaches

Category	Concept	Methods	
System analysis (SA)	SA is a problem-solving methodology that involves a 'system' or 'holistic' perspective by taking all aspects of the situation into account, then breaking apart the parts and figuring out how it works, in order to achieve "a particular goal".	Cost and Benefit Analysis (CBA)	
Linear programming (LP)	LP is a mathematical method using various linear inequalities to some scientific management situation, aims at finding the best value obtainable under different situation, in order to achieve "the best plan".	Single objective	CHAC model
			Land Evaluation Model (LEM)
		Multi-objectives	Discrete MOP
			Continuous MOP
Goal Programing (GP) *	GP is a generalisation or extension of linear programming, which handles multiple conflicting objective measures.		
Multiple criteria decision analysis (MCDA)	MCDA is one of the sub-discipline under operations research, which has been widely adopted to evaluate multiple and conflicting criteria in decision -making problems.	Tool for Environmental Assessment and Management (TEAM)	
		Analytic Hierarchy Process (AHP)	

2.2.2 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) was developed by Saaty in the 1970s. It has been widely applied to multiple criteria researches, such as in agricultural decision making, planning, resource allocation, and conflict resolution, including agricultural water management (Shabbir, 2016; Sun, 2017), crop selection (Abdollahzadeh, 2016), land management (Bello, 2009; Duke, 2002), alternative farming systems selection (Mawapanga, 1996), and irrigation system selection (Montazar, 2007; Okada, 2008). For example, Mawapanga and Debertin (1996) adopted the AHP to assess conventional, biological, and organic farming system based on farmers' decisions. The result revealed the preference of farmers in Kentucky in 1996, which ranked biological farming first, ahead of conventional and organic farming. Their priority of farming objectives were health, profit, sustainability, and environment. Okada et al. (2008) applied the AHP to evaluate 16 irrigation projects in order to quantify effects of management and hardware improvements on irrigation project performance. Through analyzing the pairwise comparison results from three irrigation experts, the performance of 16 irrigation projects in terms of serviceability of water delivery, managing entities, and suitability of hardware were generated.

According to Satty (1990) AHP is a mathematical method that provides a comprehensive framework to structure a decision problem. By building a hierarchical decision schema, the AHP can represent and quantify its elements, relate them to the overall goals, as well as evaluate alternative solutions. Rather than providing a correct decision, AHP helps decision-makers reach rational and optimized decisions by finding one among many options that suits their goals and their understanding of the best (Satty, 1990; Xu, 2012).

One hypothetical example has commonly been used to help users understand the

AHP mechanism - choosing an automobile, which is regarded as a decision making problem reflecting customer preferences. Customers might take cost, safety, style, and capacity as the evaluation criteria for making their decision. They might also subdivide four major criteria into several sub-criteria or decision attributes. For example, the cost criterion can be subdivided into purchase price, fuel costs, and resale value; and capacity criterion into cargo capacity and passenger capacity. Several brands of cars have many alternatives. Based on all the given information, customers are required to combine their own preferences to do the trade-offs by pairwise comparing each major criterion with respect to the goal, and do the same to every sub-criterion with respect to the upper level criterion, and every alternative with respect to the sub-criteria. Then the weighting of cost, safety, style, and capacity, as well as their sub-criteria, and alternative can all be calculated. In this context, customers would know the importance of each criteria and sub-criteria with respect to their goal. With the help of the AHP software to arrange and total the global priorities for each of the alternatives, customers can get a clear ranking order of each car and use it to find the most suitable alternative car in the end. Additionally, another benefit of the AHP is that it allows for sensitivity analysis. For example, customers who once valued cost more importantly than safety, might change their minds to value safety more. The weighting change that happens to the evaluation criteria might or might not alter the final priority order of alternative car depending on how robust the alternative is. Nevertheless, if the decision is in a broader strategic level, the alternative options or solutions are too sensitive to changes in the identified priorities, then the results would have little utility for decision-makers.

In recent years, the AHP has been widely applied to agricultural sustainability assessment. For example, Rezaei-Moghaddam and Karami (2007) adopted AHP for selecting among two competing sustainable agricultural development models in Iran.

They invited farmers, environmentalists, rural women and experts to participate in the evaluation. The evaluation model consisted of productivity, profitability, employment under economic dimension; life quality, equity, and participation under social dimension; and environmental protection, wise use of resources, product quality under environmental dimension. The result indicated that environmental criteria is the most important decision attributes for sustainable agriculture of Iran. Further sensitivity analysis indicated that Environmental Modernization-based sustainable agricultural model has required a higher priority to be the theoretical base of agricultural development in Iran. An analogy to the sustainable agricultural decision-problem in choosing rural agriculture projects was found in the Land-Care Programme in South Africa. Mulder and Brent (2006) adopted 5 decision attributes under economic criteria (e.g. investment, profitability, management level), 7 decision attributes under social criteria (e.g. community participation, employment opportunities), and 6 decision attributes under environmental criteria (e.g. air, water, soil, animal) to evaluate potential project proposals, in order to compile an effective Land-Care programme portfolio.

2.3 Conclusion

The environmental consequences of people focusing too much on economically successful production during a long period of time, has wakened people to foster the sustainable development. The development of an economically viable, socially acceptable, and environmentally non-degrading way not only to feed this generation, but considering the future generations without compromising their ability to meet their need. In this context, the advocacy of sustainable agriculture has been supported by countries and regions across the world. However, it is easier said than done. On the basis of current agricultural systems, what kind of agricultural development can be called sustainable? What factors would affect the sustainability of agriculture?

Governments and institutions have focused on different fields, including the sustainable development of food production, food distribution, and food consumption. Various perspectives including food security, food sovereignty, economic development, social equity, political stability, natural resource stewardship, and environment protection came from different fields of experts, but have also increased the difficulty. Accordingly, scholars and researchers have developed a variety of top-down and bottom-up holistic approaches to study and evaluate the sustainability of agricultural systems.

By using an integrated assessment approach, the Analytic Hierarchy Process, this research is focused on simultaneously considering economic, social, and environmental goals of sustainable agricultural production to find out how peasants prioritize these goals in their agricultural practices. Also through evaluating peasants' weights of nine sustainability indicators among three dimensions, this study aims at understanding how peasants make their agricultural practice decisions. Furthermore, based on peasants' decisions, this study attempts to identify their preferences of crop land-use and irrigation techniques so that the sustainability of current agricultural food production system can be evaluated.

Chapter Three

3 Methodology

This chapter presents research methodology. After a description of the study area, it presents and discusses the survey questionnaire, data source, and data collection process. Then, it discusses the AHP method used for data analysis. The chapter concludes with a summary.

3.1 Study Area

As one of the most significant birthplaces of Chinese civilization, Shaanxi enjoys the certain status of agricultural and economic contribution to its nation. It is located in the central hinterland of China, with an area of 205,800 km^2 (Liu, 2007). The contour of Shaanxi province elongates a north-south trending shape, and its unique topography has given Shaanxi diverse climatic conditions for agricultural development. Guanzhong Plain, also called Wei River Plain, is the basin sitting in between the northern Loess Plateau and the southern Qinling Mountains. It is consisted of five prefecture level city-regions: Xi'an, Baoji, Xianyang, Weinan, and Tongchuan (Figure 3.1).

More than half of Shaanxi's agricultural population comes from Guanzhong Plain. As is shown in table 3.1, the GDP of Guanzhong Plain was 1096.98 billion Yuan in 2014, accounting for about 62% of the total GDP in Shaanxi. Its agriculture, manufacturing, and services sectors have a provincial share of 59.26%, 56.70%, and 70.44%, respectively. Its agricultural employment accounts for more than half of the provincial agricultural employment, even though the total working population in Guanzhong Plain is only one-sixth of the provincial working population (table 3.2) (Shaanxi, 2015).
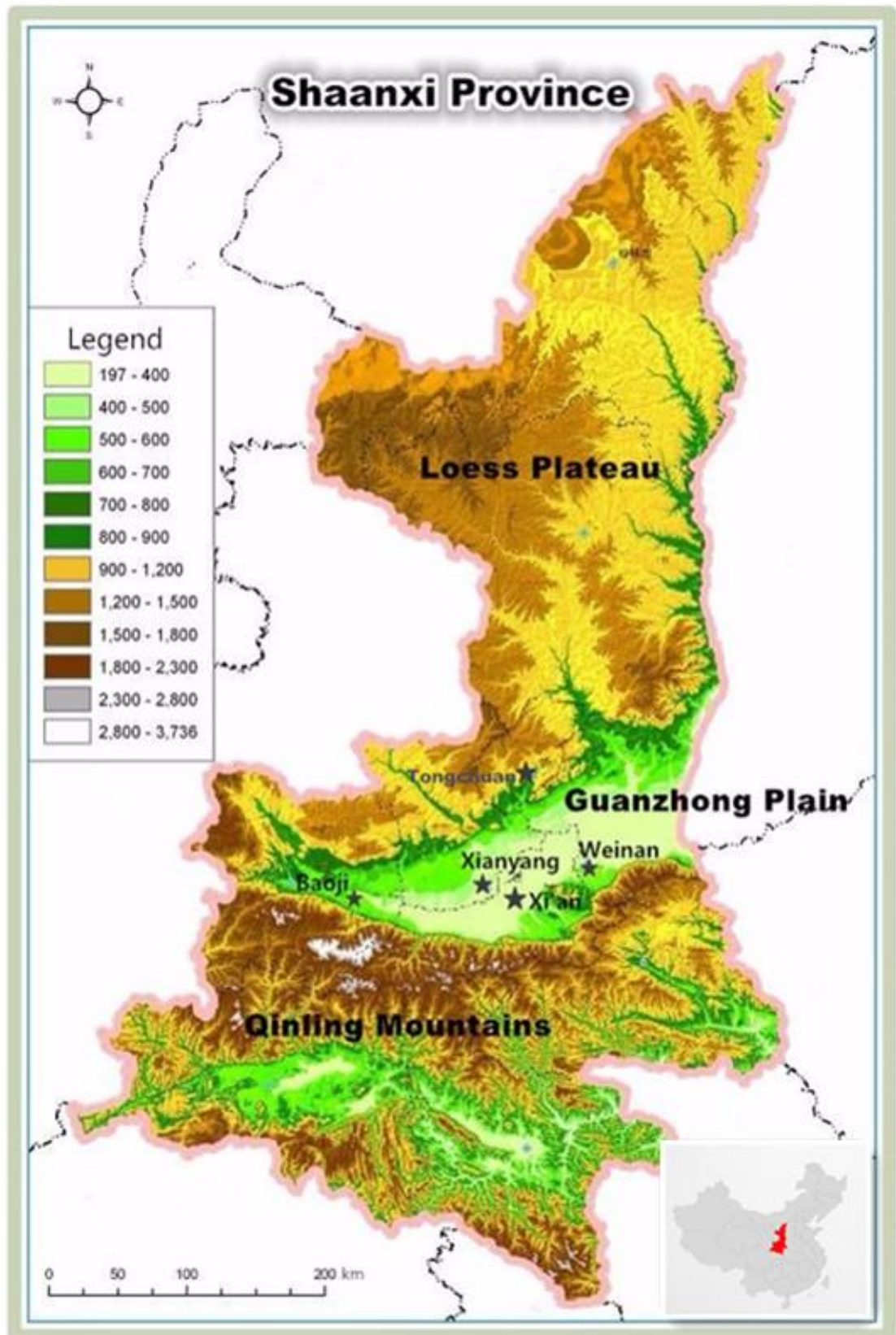
Figure 3.1 The Topography of Shaanxi Province and Guanzhong Plain

Table 3.3 presents the total output of major agricultural products in Guanzhong Plain. As it can be seen from the table, almost 90 percent of wheat and cotton, and two-thirds of corn, vegetable, and fruit yields in Shaanxi were produced in Guanzhong Plain. It is fair to say that agricultural production of Guanzhong Plain has an imperative position in the province. The region is also considered as one of the significant agricultural production bases in China.

However, from the last century, Guanzhong Plain has faced several serious challenges to its agricultural production. Resulting from the "Grain for Green" project, urban encroachment, the adjustment of agricultural structure, and natural disasters, its cultivated land, like in many other regions in China, has decreased dramatically. According to the Shaanxi Statistic Yearbook, by 2014, the cultivated land in Shaanxi declined about 25% compared to that in 1978. Water-scarcity represents another major chaleenge in the province. The water resource allocation in Shaanxi varies a lot. Guanzhong Plain acquires 647.6mm average annual rainfall, approximately equals to national average annual rainfall. Even though there are several rivers running through the territory, such as Wei River and Jing River, the total available water resources for Guanzhong Plain are still very limited, because most of the rivers are sediment-filled and has limited capacity (Shaanxi, 2015). Under these severe circumstances, Shaanxi has a very long history of using water-saving irrigation techniques. As the most important agricultural production region in Shaanxi, Guanzhong Plain has adopted various water-saving irrigation approaches include sprinkling, micro irrigation, use of low pressure pipe, and canal seepage control (Table 3.4). These water-saving irrigation techniques have also been proved to be effective. According to the statistical yearbook data, water-saving irrigation area in Guanzhong Plain accounts for 80% of that in Shaanxi.

Table 3.1 The national account of Guanzhong Plain in 2014 (Unit: 100 million Yuan RMB)

	Gross Domestic Product (GDP)	Agricultural Sector	Manufacturing Sector	Services Sector
Shaanxi	17689.94	1564.94	9577.24	6547.76
Xi'an	5492.64	214.55	2194.78	3083.31
Xianyang	2085.15	321.72	1227.70	535.73
Baoji	1642.90	161.33	1051.65	429.92
Weinan	1423.75	207.16	751.34	465.25
Tongchuan	325.36	22.61	204.88	97.87
Total	10969.8	927.37	5430.35	4612.08

Note. Data for national account from Shaanxi Province Statistical Yearbook (2014)

Table 3.2 The working population of Guanzhong Plain

	Working Population (X_1)	Agri-crop production population (X_2)	Share of total working population (X_2 / X_1)
Shaanxi	1996160	1050945	52.65%
Xi'an	409685	105559 (18.31%)	25.77%
Xianyang	258638	155622 (26.99%)	60.17%
Baoji	200904	96317 (16.70%)	47.94%
Weinan	288947	201067 (34.87%)	69.59%
Tongchuan	38190	18040 (3.13%)	47.24%
Total	1196364	576605	48.20%

Note. Data for agricultural employment population from Shaanxi Province Census Data (2010)

Table 3.3 The output of major crop products by city (2014) (Unit: 10,000 tons)

	Wheat	Corn	Soybean	Cotton	Canola	Peanuts	Fiber crops	Flue-cured Tobacco	Vegetables	Fruits
Shaanxi	417.24	539.57	25.52	4.22	41.56	10.13	0.0631	7.20	1724.68	1553.98
Xi'an	87.35	83.30	1.40	0.03	0.80	0.08			316.28	99.66
Xianyang	95.64	84.44	1.04	0.01	4.45	0.04			411.85	561.73
Baoji	78.92	60.85	1.35	0.01	1.81		0.0189	0.63	136.36	131.97
Weinan	103.72	95.52	1.83	4.02	3.66	3.04		0.32	238.81	292.06
Tongchuan	6.86	15.54	0.35						16.45	69.06
Total	372.49	339.65	5.97	4.069	10.72	3.16	0.0189	0.96	1119.75	1154.48
Total/Shaanxi	89.27%	62.95%	23.39%	96.42%	25.79%	31.20%	29.95%	13.29%	64.93%	74.29%

Note. Data for the output of major farm products by city from Shaanxi Province Statistical Yearbook (2014)

Table 3.4 The agricultural cultivated land and irrigated area in Guanzhong Plain (2014) (Unit: 1,000 hectares)

	Cultivated Land	Irrigated Area by Facilities	Effective irrigated Area	Water-saving Irrigation Area	Spray Irrigation	Micro Irrigation	Low pressure pipe	Canal seepage control
Shaanxi	2865.99	1525.08	1226.49	850.62	27.5	34.16	270.79	518.17
Xi'an	240.49	187.16	165.56	137.96	5.21	2.58	63.30	66.87
Xianyang	353.96	287.32	229.86	159.13	2.65	6.24	56.26	93.97
Baoji	298.36	193.23	149.53	137.98	5.76	5.30	38.75	88.17
Weinan	511.14	421.27	329.65	221.56	2.21	6.57	37.58	175.20
Tongchuan	64.64	28.42	18.25	18.03	0.73	4.78	10.37	2.15
Total	1468.59	1117.40	892.85	674.66	16.56	25.47	206.26	426.36
%	51.24%	73.27%	72.80%	79.31%	60.22%	74.56%	76.17%	82.28%

Note. Data for the agricultural cultivated land and irrigated area from Shaanxi Province Statistical Yearbook (2014)

3.2 Data Source

This research employs a survey data set collected in 2014, under the project "Food Security Assessment System (FSAS)" funded by Tectrra Inc. The survey was designed by the project team comprising researchers from the University of Lethbridge and Chinese National Engineering Research Center for Information Technology in Agriculture (NERCITA).

The valid number of respondents surveyed in Guanzhong Plain is 380, consisting of 142 from Baoji, 99 from Xianyang, 87 from Weinan, and 52 from Xi'an. Tongchuan is not included in the survey as the region plays a trivial role in the region and its agricultural population accounts for only around 3% in Guanzhong Plain. This research will use the survey data from Xi'an, Xianyang, Baoji, and Weinan to represent Guanzhong Plain.

A total of 37 questionnaires were handed out by the president of Agro-technological Extension Association (CATEA) in Yangling Demonstration Zone (located in Xianyang), in the training session of agricultural technology participated by rural peasants and cooperate producers. The rest of the survey was completed by undergraduate and graduate students from Northwest Agriculture and Forestry University. These students came from different counties located in Xi'an, Xianyang, Baoji, and Weinan. The students went into their respective rural homes to conduct the face-to-face interview and survey with peasants after some training and test surveys in Northwest Agriculture and Forestry University. Considering the complexity of the designed questionnaires and low literacy level in rural Shaanxi, the respondent selection strategy was to select peasants with some educational background, rich experience in crop production, and being exposed to various kinds of crop types and irrigation methods in order to guarantee the data validity and reliability.

During the survey, respondents were firstly asked to make the pairwise comparison with respect to the sustainability evaluation criteria according their preferences. Table 3.5 presents an example of questions in the questionnaire (for details, please see Appendix One: AHP Questionnaire for the complete questionnaire). Respondents were asked to compare the importance of economic benefits and social benefits, the importance of economic benefits and environmental impacts, and the importance of social benefits and environmental impacts, considering the goal - sustainable food production. By giving numerical judgement values, the intensity of importance of economic benefits, social benefits, and environmental impacts can be generated. Secondly, respondents were asked to do the pairwise comparison of nine decision attributes with respect to the specific sustainability criteria. Last, respondents were asked to make pairwise comparisons among seven different cropland uses options, and also among six different irrigation methods, respectively, with respect to the decision attributes.

Table 3.5 The intensity of importance of criteria for sustainable food production

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Economic benefits																		Social benefits
Economic benefits																		Environmental impacts
Social benefits																		Environmental impacts

A total of 380 effective interviews were conducted across four regions in Guanzhong Plain, with 52 interviews from Xi'an, 99 from Xianyang, 142 from Baoji, and 87 from Weinan. Table 3.6 presents the personal information of 380 survey respondents from study area, also collected in the questionnaire (for details, please see Appendix Two: Family and farm information). The average age of respondents is

around 50 years old, while the average age of respondents from Xi'an and Weinan is younger than respondents from Xianyang and Baoji. About two-thirds of respondents acquired middle-school and above education. 47% of respondents from Xi'an, 37% of respondents from Xianyang, and 30% of repondents from Weinan suggested that agricultural income accounts for more than 50% of their total income, while only 18% of respondents from Baoji rely for half of their total income on agriculture. As for the planting area, more than 90% of respondents from Xi'an, Xianyang, and Baoji cultivate less than 10 mu of cropland, while respondents from Weinan cultivate more land.

Table 3.6 The profile of survey respondents from study area

	Xi'an	Xianyang	Baoji	Weinan	Total
Sample size	52	99	142	87	380
Gender					
Male	28	72	95	47	242
Female	24	27	40	37	128
Average age	47.82	53.86	52.86	48.31	50.71
Education					
College and above	4	7	13	7	31
High-school	17	19	18	31	85
Middle-school	19	41	65	40	165
Primary and under	12	32	46	9	99
Agri-income as % of total income					
≥50%	24	37	25	26	112
25%-50%	18	24	31	38	111
<25%	9	38	82	23	152
Planting area (1 hectare = 15 mu)					
> 30 mu	1	1	2	4	8
11 mu - 30 mu	4	5	2	16	27
<10 mu	46	91	132	67	336

It is clear that Baoji is surveyed disproportionally high given the distribution of agricultural population in the region. Because each respondent carries the same weight in the AHP analysis, this sample distribution might distort the final AHP result toward responses from the peasants in Baoji. To address this sample imbalance problem, a random sampling using proportional probability to population (PPP) method is employed to select respondents from the 380 effective surveys (table 3.7). As a result

of this resampling, a total of 242 observations were selected, with 45 interviews from

Xi'an, 67 from Xianyang, 41 from Baoji, and 87 from Weinan.

Table 3.7 Sampling results

City region	Agri crop-production population	Percentage	Collected sample size	Theoretical sample size	Ratio	Actual Sample size
Xi'an	105559	18.90%	52	72	52.50%	45
Xianyang	155622	27.86%	99	106	77.40%	67
Baoji	96317	17.24%	142	66	47.90%	41
Weinan	201067	36.00%	87	137	1.00	87
Total	558565	100.00%	380	380		242

3.3 Data Analysis with Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is an intuitive approach to formulate and

analyze decision problems with conflicting objectives and multiple attributes

(Ramanathan, 2001). A detailed application of AHP will be provided in this section.

Broadly speaking, the general objective of adopting AHP to decision-making

problems is to bridge the ultimate goal with actual feasible options. Multiple conflicting

objectives and affiliated decision attributes are attached to the assessment process in

order to optimize the ultimate goal. These objectives and affiliated decision attributes

are the expectations that can be viewed as essential qualities or conditions of the

ultimate goal. To some extent, those are also the restrictions of practical options. After

assembling the goal, evaluation criteria, as well as the decision attributes, it is about to

quantitatively score to what extent every alternative enable to fulfill these decision

attributes. As for decision makers or stakeholders, what they need to do is the pairwise

comparison according to their preferences in order to make the decision that satisfies

evaluation benchmarks the best among all the options.

With the purpose of better solving decision problems with AHP, it is necessary

to manipulate it by the right steps. Like many other Multiple-Criteria-Decision Analysis

approaches, application of the AHP to a decision problem usually involves steps of problem modelling, pairwise comparison, weights valuation, weights aggregation and consistency test (Ishizaka, 2009). The application of the AHP in this research can be explained in following steps:

Step 1: Defining the goal and structuring into hierarchical model

Figure 3.2 presents a simple illustration of three level hierarchy model (Saaty, 1994). The topmost level is usually the goal of decision-problem. The intermediate levels correspond to evaluation criteria, and decision attributes, the lowest level consists of the related options (Ramanathan, 2001).
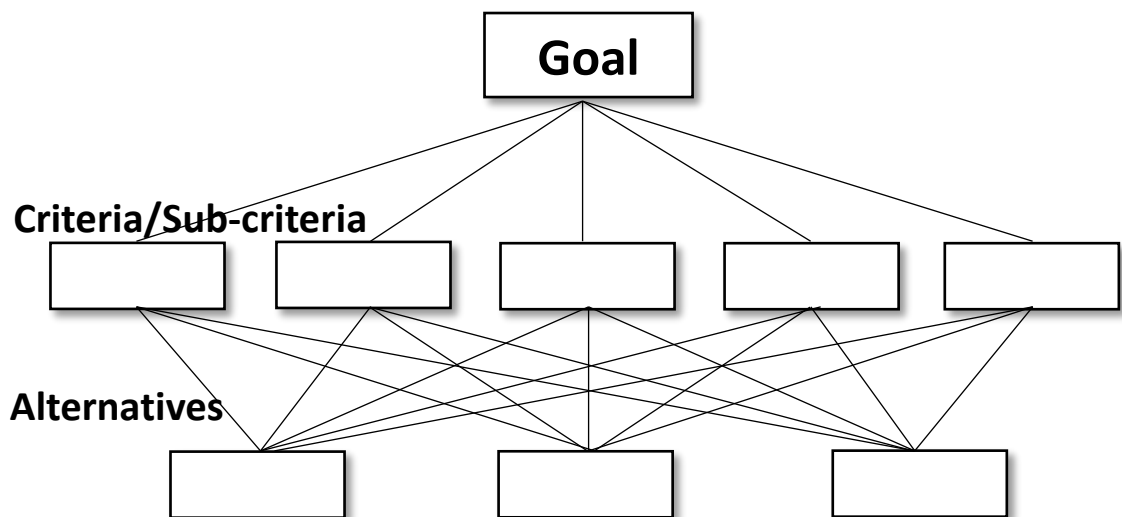
Figure 3.2 A simple illustration of three level hierarchy model

Step 2: Pairwise comparisons and the judgmental matrix

The constituents of every level in the hierarchy are compared pairwise by decision-makers in this step, with respect to a specific component in the immediate upper level. The numerical judgement evaluation scale is adopted to represent the intensity of importance (Saaty, 2003).

Table 3.8 The Fundamental scale for pairwise comparisons

Numerical Value	Verbal Scale	Explanation
1	Equal Importance	Two elements contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong or demonstrated importance	An element is favored very strongly over another; its dominance demonstrated in practice
9	Extreme Importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values.		

The pairwise comparison results could be synthesized into a judgmental matrix for the purpose of easier analysis, denoted as A:

$$
\mathbf{A} = \begin{vmatrix}
1 & a_{12} & \dots & a_{1i} & \dots & a_{1j} & \dots & a_{1n} \\
a_{21} & 1 & \dots & a_{2i} & \dots & a_{2j} & \dots & a_{2n} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
a_{i1} & a_{i2} & \dots & 1 & \dots & a_{ij} & \dots & a_{in} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
a_{j1} & a_{j2} & \dots & a_{j1} & \dots & 1 & \dots & a_{jn} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
a_{n1} & a_{n2} & \dots & a_{ni} & \dots & a_{nj} & \dots & 1
\end{vmatrix} = (a_{ij})_{\text{nxn}}
$$

Where A is usually made by decision makers, used to compute the priorities of the corresponding elements. As a_{ij} represents the pairwise comparison rating or relative importance for element i and element j, a_i represents the row elements, a_j is for column element.

Step 3: Eigenvalues, Eigenvectors, and Consistency Test

Once the judgmental matrix is built, the eigenvalue and the eigenvector of each element can be computed. According to Saaty (Saaty, 1980), for an ideal case of perfect consistency

$$Aw = nw$$

Where A is the comparison matrix $(n \times n)$, $w = w_1, w_2, ..., w_n$; w is the weight.

However, a certain degree of inconsistency occurs in subjective pairwise comparisons of elements. In this case, Saaty (Duke, 2002; Saaty, 1980, 1990) proposed a redefinition

$$Aw = \lambda_{max} w$$

Where λ_{max} is the maximum eigenvalue (Perron root) of matrix A.

Usually, there are four kinds of approximation algorithms that can be used to calculate the eigenvector, including Asymptotic Normalization Coefficient, Geometric Mean Method, Power Method, and Least Squares Method (Zhang, 2014a). The Geometric Mean Method is more populated than others (Wang, 2005).

(1) Calculate the product m_i of each column:

$$m_i = \prod_{j=1}^{n} a_{ij}, i = 1, 2, ..., n$$

(2) Calculate the nth root of the product m_i (vector $\overline{w_i}$):

$$\overline{w_i} = \sqrt[n]{m_i}, , i = 1, 2, ..., n$$

(3) Normalize vector $\overline{w_i} = (\overline{w_1}, \overline{w_2}, ..., \overline{w_n})$:

$$w_i = \frac{\overline{w_i}}{\sum_{k=1}^{n} \overline{w_k}}, i = 1, 2, ..., n$$

(4) Generate new vector $w_i{}' = A \times w_i$ and compute the maximum eigenvalue λ_{max}:

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{Aw_i{}'}{w_i}$$

Because subjectivity is usually involved in decision making problem, testing the consistency is necessary. Saaty (Saaty, 1987; Saaty, 1980) has proved that if $\lambda_{max} \geq n$, it allows the AHP to test the degree of inconsistency in respondents' rating. The consistency index for an $(n \times n)$ matrix,

$$CI = \frac{(\lambda \max - n)}{(n-1)}$$

Then the consistency of the judgemental matrix could be determined by

$$CR = \frac{CI}{RI}$$

Where CR is the consistency ratio,

CI is the consistency index,

RI is called the random index.

If CR is higher, it means the input judgements are not consistent and reliable. In general, values of consistency ratio of 0.1 or less ($CR \leq 0.1$) are considered to be desired. Higher CR values usually imply that the pairwise comparison ratings need to be revised.

Step 4: Synthesizing the local priorities and global priorities

When the result of consistency proves to be reliable, the next step would be to synthesize the local priorities and conclude the global priority (Ishizaka, 2009; Ramanathan, 2001).

$$p = \sum_i w_j \cdot l_i$$

Where p is global priority,

l_i is weight (vector w_i) of the criterion i,

w_j is weight (vector w_j) of the objective j.

Therefore, the priority can be used as reference for decision-makers to make their decisions.

3.4 Sensitivity analysis

There is one more step to complete the analysis of AHP decision making assessment process: sensitivity analysis. The importance and usefulness of Sensitivity Analysis (SA) is widely recognized. Fiacco (1983) addressed this in his book: "… a sensitivity and stability analysis should be an integral part of any solution methodology.

This has been well recognized since the inception of scientific inquiry and has been explicitly addressed from the begging of mathematics. (p.3)"

In most models, uncertainties exists in parameters. According to Pannell (1996), the modeler is likely to be unsure of their current values, and to be even more uncertain about future values, such as productivity and technology. This kind of uncertainty can be seen as one of the primary causes leading to the usefulness and recommendations of sensitivity analysis in decision-making. When parameters are not certain, sensitivity analysis could provide information listed as follows (Pannell, 1996):

1. How robust the optimal solution is in terms of different parameter values;

2. Under what circumstances the optimal solution would change;

3. How the optimal solution changes in different situations;

4. How much worse off the decision-makers would be if they ignored the changed situation and stayed with the original or some other strategies.

In this step, the input data are modified slightly in order to examine the priority ranking stability and observe the impact on the results. Usually, if the ranking does not change, the results are said to be robust. If the ranking changes dramatically, it means the results may have little use for decision-makers.

3.5 Summary

With an interest in understanding the current agricultural food production system in Guanzhong Plain, Shaanxi, this study aimed to identify peasants' priorities of the economic, social, and environmental goals, also their preferences of land-use and irrigation techniques in Xi'an, Xianyang, Baoji, and Weinan. The AHP method helps decompose the decision-problem and make it more straightforward, by developing a hierarchical model to sort related evaluation criteria, quantitative and qualitative attributes, and various options so that participants can better do the pairwise

comparisons. More importantly, the AHP allows the change of weights to create different scenarios. By doing so, the trade-offs of land-use and irrigation options in terms of different evaluation criteria and decision attributes can be generated.   The following chapters share the results and analysis for this study of agricultural food production system.

Chapter Four

4 Peasants' Priorities in Food Production System

The objective of this chapter is to explore peasants' preferences of economic, social, and environmental concerns during their agricultural cultivation. It will first present the analytic hierarchy model that is suited for assessing land-use and irrigation options based on the selected sustainability criteria and decision attributes. It will then presents the empirical results on peasants' weightings of sustainability criteria and decision attributes in Guanzhong Plain. Geographic variations in peasants' prioritization in suitability criteria and decision attributes will also be discussed. The chapter ends with a summary.

4.1 AHP Decision Hierarchy

As an evaluation system, AHP needs to establish a nested hierarchy of criteria that can be employed to evaluate available options. In this research, three levels of criteria are specified in the hierarchical process (Fig. 4.1 and Fig. 4.2). The top level is referred to the goal. The second level is called evaluation criteria, which compares the economic, social, and environmental dimensions of sustainable development. The sub-criteria or as called decision attributes, hereafter, are at the third level of the hierarchy. For each of the sustainability dimension, there are three decision attributes are identified, based on peasants' concerns. Under the economic criterion, yield, income, and water-use efficiency are the decision attributes. Household life-style, community cohesion, and recreation are chosen as decision attributes to represent the social dimension of sustainable food production. Environmental decision attributes include chemical runoff and leaching prevention, reducing water withdrawal from the river, and soil erosion prevention. The lowest level of the decision hierarchy includes seven special crop options and six feasible irrigation options for cultivation when different decision attributes are considered.

In the survey, every respondent was asked to complete 201 pairwise comparisons. First, they were asked to decide the importance among three major economic, social, and environmental criteria. Then, respondents were asked to pairwise compare the decision attributes under each major criteria. For example, under economic benefits, peasants need to select the intensity of importance for comparing all yield improvement and farm-income improvement, yield improvement and water-use efficiency improvement, farm-income improvement and water-use efficiency improvement. After they finish these, they were required to make pairwise comparisons between 7 land-use options, as well as the pairwise comparisons between 6 irrigation options, with respect to each decision attributes. Because the overall mean consistency ratio of the pairwise comparison judgement are all smaller than the required threshold, which is 0.1 or less, the results are sound and reliable.
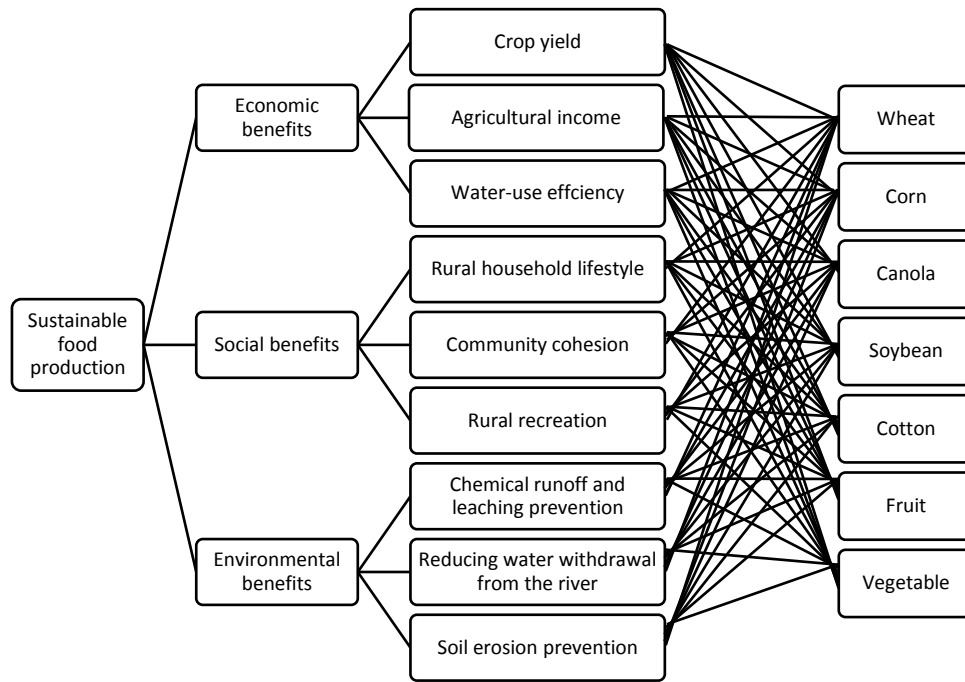
Figure 4.1 AHP decision hierarchical model to rank the land-use for agricultural production in Guanzhong Plain
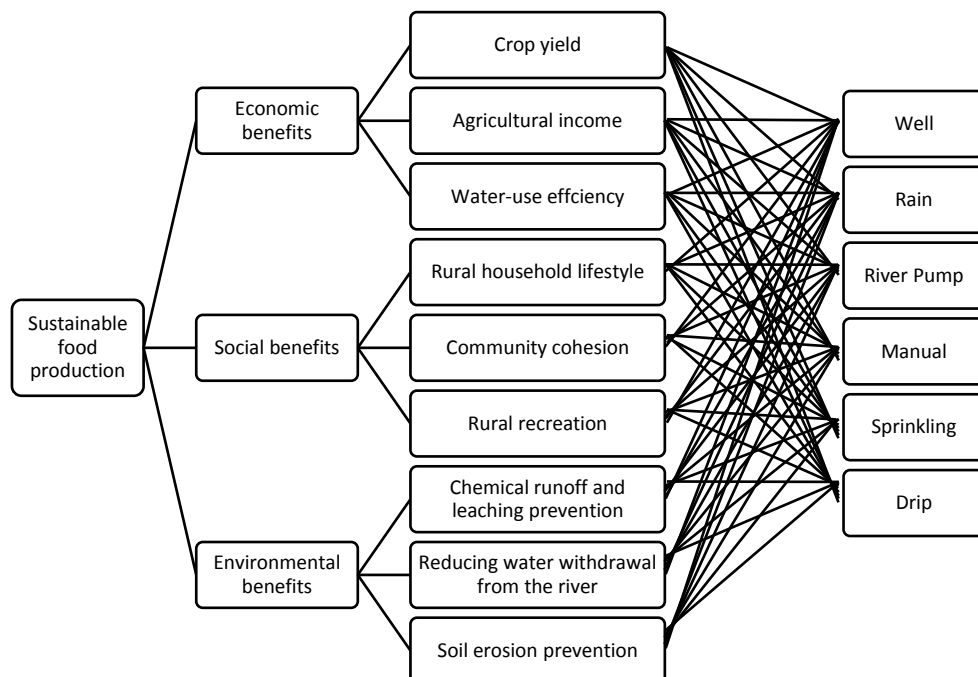
Figure 4.2 AHP decision hierarchical model to rank the irrigation-techniques for agricultural production in Guanzhong Plain

4.2 The Priority of Sustainability Criteria and Decision Attributes in Guanzhong Plain

Table 4.2.1 presents the priority weights calculated for three sustainability evaluation criteria as well as nine decision attributes. The AHP analysis results indicate that maintaining economic benefits plays the most significant role in peasants' agricultural production activities. Specifically, the weighting of economic benefits (57.5%) is more than twice as important as the environmental impacts and social benefits, while the environmental impacts and social benefits share similar weightings, 21.6% and 20.9%, respectively. Apparently, peasants' top three concerns are related to economic benefits. Improving yield is peasants' top concern (23.5%). The second concern of farm-income improvement receives a share of 22.4 percent, and it is followed by water-use efficiency improvement (11.6%). Next, household life-style with 10.6% turns out to be the biggest concern for respondents with respect to the social benefits, while the community cohesion (5.7%) and rural recreation (4.5%) only get its half weightings. As for environmental impacts, concerns of chemical runoff and leaching, with a share of 8.6%, out-weight two other attributes, water withdrawal from the river (7.1%), and soil erosion (5.9%).

Table 4.2.1 Weightings for criteria and decision attributes in Guanzhong Plain

Evaluation Criteria	Decision Attribute	Attribute Weight
Economic benefits (57.5%)	Crop yield	23.5%
	Agricultural income	22.4%
	Water use efficiency	11.6%
Social benefits (20.9%)	Rural household lifestyle	10.6%
	Community cohesion	5.7%
	Rural recreation	4.5%
Environmental impacts (21.6%)	Chemical runoff and leaching	8.6%
	Water withdrawal from the river	7.1%
	Soil erosion	5.9%
Total		100.0%

4.3 Regional Variation of the Priority of Sustainable Objectives

In order to understand the geographical differences in peasants' preferred goals, another regional variation analysis is done based on four agricultural city regions in Guanzhong Plain, Xi'an, Xianyang, Baoji, and Weinan. The findings are presented in tables 4.3.1 to 4.3.4.

Across all four prefectural city regions, it is not surprising to find that the economic benefits remain the top priority for peasants in the survey. Under economic benefits, both yield and farm-income are the most important concerns for surveyed peasants from four city regions. Yield and income are indispensable material to support their lives, their families, communities, and their next year cultivation. Also, the priority of the concerns under social benefits across all city regions is the same. Peasants rank household lifestyle above community cohesion. Rural recreation remains at the bottom. Apparently, most peasants value family harmony more. It is reasonable to think that harmonious families are the cornerstones of a cohesive community.

Other than the similarities, there are also several noteworthy regional variation among four city-regions' peasants, in both development objectives and concerns.

Although improving economic benefits is the most important attribute has reached by all respondents, the peasants from Xi'an, Xianyang, and Weinan value environmental impacts a little more than social benefits, the proportions exceed about half weights of economic benefits. Whereas peasants from Baoji are lack of the awareness of the importance of environmental impacts on agriculture, the weighting is only one-sixth of the economic benefits'. And under the economic benefits, peasants from Xi'an and Xianyang prioritize farm income higher than yield, while peasants from Baoji and Weinan rank yield as the most important concern. From the perspective of regional socioeconomic development status, the overall economic development level, agricultural industrial structure and competitiveness of Xi'an and Xianyang is stronger than Baoji and Weinan. That makes peasants from Xi'an and Xianyang have more income channels. On the contrary, peasants from Baoji and Weinan focus more on the yield so that their income can be improved.

Except the regional variation in economic and social interests, peasants from four city regions also have some divergence on the importance of different environment-related factors. The respondents from Xianyang rank water withdrawal from the river the highest, but in other three prefectural city regions, concerns of chemical runoff and leaching receive the highest priority under economic impacts. This might due to the rapid development of secondary industry in Xianyang in recent years. The industrial development has put extra pressures to its water scarcity. For this reason, agricultural water has been cut down in order to supply the water to the secondary industry. For peasants, with the continuous decrease of agricultural water, they might need to find their way out by withdrawing water from the rivers, and increasing water-use efficiency.

Table 4.3.1 Weightings for criteria and decision attributes in Xi'an

Evaluation Criteria	Decision Attributes	Attribute Weight
Economic benefits (50.3%)	Crop yield	19.7%
	Agricultural income	22.7%
	Water use efficiency	7.9%
Social benefits (22.0%)	Rural household life style	11.4%
	Community cohesion	6.4%
	Rural recreation	4.3%
Environmental impacts (27.7%)	Chemical runoff and leaching prevention	12.0%
	Reducing water withdrawal from the river	8.2%
	Soil erosion prevention	7.5%
Total		100.0%

Table 4.3.2 Weightings for criteria and decision attributes in Xianyang

Evaluation Criteria	Decision Attributes	Attribute Weight
Economic benefits (51.7%)	Crop yield	19.5%
	Agricultural income	21.9%
	Water use efficiency	10.2%
Social benefits (23.8%)	Rural household life style	12.3%
	Community cohesion	6.1%
	Rural recreation	5.3%
Environmental impacts (24.5%)	Chemical runoff and leaching prevention	8.3%
	Reducing water withdrawal from the river	10.5%
	Soil erosion prevention	5.8%
Total		100.0%

Table 4.3.3 Weightings for criteria and decision attributes in Baoji

Evaluation Criteria	Decision Attributes	Attribute Weight
Economic benefits (70.8%)	Crop yield	37.3%
	Agricultural income	23.3%
	Water use efficiency	10.2%
Social benefits (17.9%)	Rural household life style	10.4%
	Community cohesion	4.3%
	Rural recreation	3.3%
Environmental impacts (11.3%)	Chemical runoff and leaching prevention	4.8%
	Reducing water withdrawal from the river	4.0%
	Soil erosion prevention	2.4%
Total		100.0%

Table 4.3.4 Weightings for criteria and decision attributes in Weinan

Evaluation Criteria	Decision Attributes	Attribute Weight
Economic benefits (58.3%)	Crop yield	22.0%
	Agricultural income	21.5%
	Water use efficiency	14.8%
Social benefits (18.2%)	Rural household life style	8.1%
	Community cohesion	5.2%
	Rural recreation	4.8%
Environmental impacts (23.5%)	Chemical runoff and leaching prevention	9.6%
	Reducing water withdrawal from the river	6.7%
	Soil erosion prevention	7.3%
Total		100.0%

4.4 Summary

In summary, the objective of peasants' agricultural food production sustainable development is still economy-oriented. Peasants from Guanzhong Plain all share certain similar priorities of development objectives and concerns during food production. Regional variation reveals further differences of the economic and agricultural development level, the awareness of society and collective, as well as environmental awareness, between four different city-regions. For improving yield and income, they apparently are the top concerns for peasants across all four city regions. While peasants from Xi'an, Xianyang, and Weinan have arisen certain awareness of the importance of environmental impacts during agricultural production. Yet peasants from Baoji are concerning economic benefits almost six times more than environmental impacts', and four times more than social benefits. According to the statistic data, the laggard rural economic and agricultural development level may have led to the result that peasants in Baoji show partiality to economic benefits. Even though the economic development level of Weinan is similar to Baoji, Weinan has formed competitive characteristic and environmental patterns of agricultural development. Therefore the agricultural development level of Weinan is higher than Baoji. While peasants in Baoji are short of agricultural inputs such as modern facilities and financial investment, which led to its lower agricultural modernization and development level. Peasants in Baoji are still focused more on traditional farming practices with lower production efficiency. Plus the geographical and topographic conditions, may have resulted in peasants concentrate more on developing forestry and animal husbandry producing than crop farming.

As for social benefits, there is no big difference between four city regions. From peasants' perspectives, the community cohesion and recreation improvement under social benefits are not as much important as a better household lifestyle.

Chapter Five

5 Peasants' Preferences of Agricultural Land-Use in Sustainable Food Production System

This chapter aims at exploring a consensus among peasants' decisions about land-use. Specifically, it is to understand how peasants attempt to choose crop type mixes to maximize their identified sustainable objectives and interests. Then based on the results, the sensitivity analysis will be conducted to assess the effects of changes in the prioritization of sustainability criteria. Specifically, it will compare peasants' priorities and the priorities that generated from hypothetical weightings of sustainability goals so that the trade-offs peasants might face with can be discovered.

5.1 Prioritization of Land-use Options

Seven different crop types are included in the survey for surveyed peasants to consider. They are two grain crops, wheat and corn, and five cash crops, canola, soybean, cotton, fruit, and vegetable.

5.1.1 Peasants' decision in Guanzhong Plain

Table 5.1.1.1 presents peasants' preference of crop-type with respect to the objectives of sustainable food production, in Guanzhong Plain. For the general goal, fruit gets the highest score (0.191) becoming peasants' the most prioritized crop. It is followed by grain crops wheat (0.177) and corn (0.164) and then by cash crops vegetable (0.152). Cotton (0.110), soybean (0.104), canola (0.101) share a similar and lower score value. The priority of peasants' preferences varies a little in terms of environmental impacts, and economic, social benefits. When considering economic benefits, fruit (0.212), vegetable (0.171), and wheat (0.167) tend to be peasants' most preferred types of crop. Similarly, following fruit (0.196), wheat (0.181) outweighs vegetable (0.161) a little, when peasants consider their social benefits. When peasants

consider the environmental impacts, fruit falls out of top three while wheat (0.198) reaches the top, followed by corn (0.174) and soybean (0.138). As for canola, soybean, and cotton, they are less favored by peasants. Apparently, wheat and corn are the main grain crops for peasants from Guanzhong Plain. Fruit is the major cash crop, which has also proved that it is well-founded in the region. The yield and scale of Shaanxi's fruit has ranked the first in the country for the past few years (Shaanxi, 2015).

Table 5.1.1.2 shows the relative priority weights of crop land use types with respect to the individual decision attributes under economic, social, and environmental criteria. The result indicates that, there is no big difference between peasants' preferences with respect to major objectives and exact attributes. Top four places are taken turns by grain crops of wheat and corn, cash crops of fruit and veggies. Fruit outperforms all other crops becoming the first, with respect to all social decision attributes (0.191 for household lifestyle, 0.204 for community cohesion, and 0.198 for recreation), economic decision attributes of crop yield (0.216) and farm-income (0.260), and environmental decision attribute of soil erosion (0.191). Wheat gets the highest score among remaining decision attributes: water-use efficiency (0.196) under economic benefits, chemical runoff and leaching (0.204), and water withdrawal from the river (0.217) under environmental impacts. Except fruit and wheat frequently appear to be peasants' preferences, vegetable and corn are in the second echelon of peasants' priority. For example, corn is ranked the second highest for yield (0.193), water-use efficiency (0.164), and all environmental impacts' attributes (0.174 for chemical runoff and leaching, 0.176 for water withdrawal from the river, and 0.171 for soil erosion); and vegetable is ranked the second in the priority for farm-income (0.212) and community cohesion (0.169). As for the rest, canola, soybean, and cotton, they are less preferred by the surveyed peasants.

In general, fruit and vegetable are peasants' favorite cash crops considering the economic benefits and social benefits; wheat and corn are peasants' favorite grain crops considering environmental impacts. The result is reasonable because regardless of the cropping index, the net return of fruit and vegetable is always much higher than other crops. Grain crops beat other cash crops, because they are peasants' basic food crops, and they require less water than fruit and vegetable. More importantly, from peasants' perspectives, to a large degree, growing wheat and corn can receive a certain amount of subsidies from the government. According to current government policy, peasants can receive 150 YUAN per mu for growing wheat and corn. This can help peasants increase their household income. In this context, soybean, canola, and cotton are less competitive. For cotton, the required working days is almost equal to growing vegetable and fruits, but the return is much less. So is canola. As for soybean, the advantage is it requires less material inputs and working days, however, there is no governmental subsidy for growing soybean, the market value of soybean is less what than peasants' expect, and the low yield, all lead to peasants' low initiative (Qin, 2014; Shaanxi, 2015).

Table 5.1.1.1 Weights of crop options with respect to evaluation criteria in Guanzhong Plain

Weights	Goal	Economic Benefits	Social Benefits	Environmental Impacts
Wheat	17.7%	16.7%	18.1%	19.8%
Corn	16.4%	16.4%	15.5%	17.4%
Canola	10.1%	8.9%	10.5%	12.5%
Soybean	10.4%	9.4%	9.7%	13.8%
Cotton	11.0%	10.3%	10.6%	12.9%
Fruit	19.1%	21.2%	19.6%	13.6%
Vegetable	15.2%	17.1%	16.1%	10.0%
Total	100.0%	100.0%	100.0%	100.0%

Table 5.1.1.2 Weights of crop options with respect to decision attributes in Guanzhong Plain

Weights	Economic			Social			Environmental		
	Crop Yield	Agricultural income	Water-use efficiency	Household lifestyle	Community cohesion	Rural recreation	Chemical runoff and leaching	Water withdrawal from the river	Soil erosion
Wheat	18.3%	12.7%	19.6%	19.0%	16.9%	17.5%	20.4%	21.7%	17.1%
Corn	19.3%	12.6%	16.4%	15.3%	15.3%	16.1%	17.4%	17.6%	17.1%
Canola	7.4%	8.4%	12.6%	10.8%	9.8%	10.6%	13.1%	12.9%	11.3%
Soybean	8.4%	8.2%	12.8%	9.7%	9.6%	9.7%	13.9%	15.0%	12.3%
Cotton	8.3%	11.0%	13.1%	10.2%	11.0%	10.8%	12.9%	13.3%	12.4%
Fruit	21.6%	26.0%	13.7%	19.1%	20.4%	19.8%	11.4%	11.1%	19.1%
Vegetable	16.7%	21.2%	11.8%	15.9%	16.9%	15.5%	10.7%	8.4%	10.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

5.1.2 Regional variation in peasants' land use prioritization

In order to explore the geographical differences in peasants' preferences of land-use in terms of sustainable food production, the results of the AHP analysis for Xi'an, Xianyang, Baoji, and Weinan are detailed in tables 5.1.2.1 to 5.1.2.8.

Tables 5.1.2.1 to 5.1.2.4 present peasants' preferences of crop types with respect to the objectives of sustainable food production in Xi'an, Xianyang, Baoji, and Weinan. It can be clearly found that with respect to the agricultural production goal, peasants from four city regions give their priorities to grain crops wheat and corn, and cash crops, fruit and vegetable. Correspondingly, soybean, canola, and cotton are less preferred. And across all four regions, growing wheat and corn turns out to be the most favorable land-use types, and vegetable is the least favorite one for peasants when they are considering the environmental impacts. In addition, there are quite a few regional differences in land-use preferences by the surveyed respondents. In Xi'an, Xianyang, and Weinan, growing fruit with overwhelming weights outperforms all other options, with respect to the overall goal, and considering economic and social benefits. Also in Xi'an and Weinan, vegetable acquires the second biggest score in the same assessment criteria, while in Xianyang wheat obtains the second highest score. One apparent difference in peasants' preferences between Xi'an and Weinan appears on considering environmental impacts. In Weinan, corn gets the highest score, while in Xi'an, wheat obtains the biggest score. Comparing with other three prefectural city regions, Baoji is unique. Because it is very much dominated by food staple production in agriculture. In Baoji, wheat and corn are the most preferred crop land uses to achieve the goal of sustainable food production and they are ranked the highest in all three evaluation criteria. Unlike other three regions, the score values of fruit and vegetable in Baoji with respect to the goal is significantly smaller.

Table 5.1.2.1 Weights of crop options with respect to evaluation criteria in Xi'an

Weights	Goal	Economic Benefits	Social Benefits	Environmental Impacts
Wheat	16.4%	13.4%	15.3%	21.7%
Corn	14.7%	14.0%	13.1%	16.9%
Canola	10.6%	8.6%	10.4%	13.7%
Soybean	10.7%	8.8%	9.3%	14.8%
Cotton	10.6%	8.7%	10.5%	13.5%
Fruit	20.5%	26.5%	21.8%	10.5%
Vegetable	16.6%	20.0%	19.7%	9.0%
Total	100.0%	100.0%	100.0%	100.0%

Table 5.1.2.2 Weights of crop options with respect to evaluation criteria in Xianyang

Weights	Goal	Economic Benefits	Social Benefits	Environmental Impacts
Wheat	19.0%	17.9%	18.3%	21.9%
Corn	17.9%	17.9%	17.0%	18.8%
Canola	9.1%	8.3%	8.6%	11.4%
Soybean	9.5%	8.4%	8.5%	12.8%
Cotton	10.2%	9.7%	9.6%	11.7%
Fruit	20.6%	22.3%	23.2%	14.4%
Vegetable	13.7%	15.5%	14.8%	8.9%
Total	100.0%	100.0%	100.0%	100.0%

Table 5.1.2 3 Weights of crop options with respect to evaluation criteria in Baoji

Weights	Goal	Economic Benefits	Social Benefits	Environmental Impacts
Wheat	28.6%	28.7%	28.6%	27.5%
Corn	16.6%	16.4%	16.6%	17.8%
Canola	11.6%	10.8%	13.6%	13.0%
Soybean	10.1%	9.7%	10.7%	11.6%
Cotton	9.5%	9.3%	9.4%	10.5%
Fruit	12.9%	13.9%	10.9%	10.2%
Vegetable	10.7%	11.1%	10.2%	9.3%
Total	100.0%	100.0%	100.0%	100.0%

Table 5.1.2.4 Weights of crop options with respect to evaluation criteria in Weinan

Weights	Goal	Economic Benefits	Social Benefits	Environmental Impacts
Wheat	14.4%	13.5%	15.2%	15.6%
Corn	15.8%	15.9%	14.5%	16.3%
Canola	10.4%	9.0%	10.7%	13.1%
Soybean	11.2%	10.1%	9.5%	14.6%
Cotton	12.7%	12.2%	11.7%	14.1%
Fruit	19.8%	21.7%	21.2%	15.1%
Vegetable	15.7%	17.6%	17.3%	11.2%
Total	100.0%	100.0%	100.0%	100.0%

Tables 5.1.2.5 to 5.1.2.8 present the weights of seven crop types with respect to individual decision attributes under each of the economic, social, and environmental criteria in four city regions.

Compared to other three agricultural regions, Baoji is again unique. Wheat and corn are ranked the highest in almost every decision attribute. The only exception happens in considering the income and yield of economic benefit, where fruit is promoted to be one of the top three peasants' prioritized crop types. However, in Xi'an, Xianyang, and Weinan, fruit receives the highest score for many decision attributes. In Xi'an, its score is the highest all economic and social decision attributes. In Xianyang and Weinan, fruit is also the most preferred crop in achieving economic and social goals other than improving water use efficiency. Given Xi'an is a larger urban centre, it is expected that vegetable is a preferred crop after fruit in achieving economic and social goals by the surveyed peasants in Xi'an and Weinan. In Xianyang, it is wheat and corn gaining the top score in economic and social attributes. With regard to environmental decision attributes, across all four prefectural city-regions, the results are quite consistent. The highest scores are basically all given to wheat and corn. The lowest scores are given to vegetable.

In general, such regional variation is caused by a variety of reasons. Even though the main cropping types in Guanzhong Plain is grain crops, wheat and corn, and cash crops, fruit and vegetable, different city-regions have their own superiority in terms of geographical conditions and growth advantage. For Xi'an, Xianyang, and Weinan, they are located in the centre of Guanzhong Plain, the downstream area of Wei River, the flat basin between the northern Loess Plateau and southern Qinling Mountains. Such topography favours large scale agricultural production and facilitate sophisticated production practices, such as crop rotation, inter-cropping, multi-cropping and use of

agricultural facilities. Therefore, peasants in this three city regions have better geographical conditions for growing vegetables, cotton, and a small amount of peanuts. On the contrary, the topography in Baoji is more complicated. Located in the westernmost part of Guanzhong Plain, Baoji is surround by mountains on three sides. Diversified elevation goes against the mechanized production at the large scale, and different climatic condition has led to the frequent disasters, such as spring frost damage and drought. Besides producing main products of food grain and fruit, such unique topography gives Baoji the particular growth advantage growing fiber crops and flue-cured tobacco. Other than the reasons of geographical conditions and growth advantage, there are also some socioeconomic and political factors causing the regional variation. According to the statistical yearbooks, government reports, and related researches, that the proportion of agricultural labor force, the agricultural labor productivity, and agriculture value added in Baoji are all lower than in the other three cities' (Gao, 2012; Jia, 2013; Liu, 2015; NDRC, 2015; Statistics, 2015; Yang, 2010).

Table 5.1.2.5 Weights of crop options with respect to decision attributes in Xi'an

Weights	Economic			Social			Environmental		
	Crop Yield	Agricultural income	Water-use efficiency	Household lifestyle	Community cohesion	Rural recreation	Chemical runoff and leaching	Water withdrawal from the river	Soil erosion
Wheat	15.7%	8.0%	18.7%	16.7%	13.4%	13.5%	21.0%	25.7%	19.5%
Corn	17.8%	9.8%	14.4%	14.0%	11.5%	12.5%	18.9%	15.3%	15.1%
Canola	7.3%	7.8%	12.4%	10.6%	10.3%	9.9%	13.8%	12.7%	14.3%
Soybean	8.4%	8.2%	10.6%	9.1%	9.7%	9.6%	14.1%	16.3%	14.6%
Cotton	7.3%	9.6%	9.7%	9.9%	11.7%	10.4%	13.7%	13.4%	13.3%
Fruit	25.2%	31.7%	19.7%	20.4%	23.6%	23.6%	9.6%	9.5%	12.6%
Vegetable	18.4%	24.9%	14.5%	19.3%	19.8%	20.6%	9.0%	7.0%	10.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 5.1.2.6 Weights of crop options with respect to decision attributes in Xianyang

Weights	Economic			Social			Environmental		
	Crop Yield	Agricultural income	Water-use efficiency	Household lifestyle	Community cohesion	Rural recreation	Chemical runoff and leaching	Water withdrawal from the river	Soil erosion
Wheat	18.6%	14.7%	21.9%	18.2%	18.0%	18.8%	22.6%	24.8%	14.7%
Corn	20.4%	14.9%	18.7%	17.0%	16.5%	17.6%	19.7%	19.1%	16.6%
Canola	6.8%	7.6%	12.1%	8.8%	8.5%	8.3%	12.2%	12.0%	8.8%
Soybean	7.1%	7.5%	12.4%	8.6%	8.5%	8.4%	13.6%	13.0%	10.9%
Cotton	7.8%	10.3%	12.1%	9.7%	9.5%	9.3%	11.8%	11.6%	12.0%
Fruit	23.2%	27.5%	11.5%	23.0%	23.6%	23.1%	10.4%	10.9%	29.2%
Vegetable	16.0%	17.4%	11.2%	14.7%	15.3%	14.6%	9.7%	8.6%	7.8%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 5.1.2.7 Weights of crop options with respect to decision attributes in Baoji

Weights	Economic			Social			Environmental		
	Crop Yield	Agricultural income	Water-use efficiency	Household lifestyle	Community cohesion	Rural recreation	Chemical runoff and leaching	Water withdrawal from the river	Soil erosion
Wheat	32.2%	24.0%	30.5%	28.0%	29.9%	29.1%	26.4%	28.1%	28.9%
Corn	18.2%	14.8%	14.8%	15.5%	18.3%	17.9%	17.6%	19.1%	16.0%
Canola	9.8%	11.5%	12.4%	14.1%	11.7%	14.4%	13.0%	13.2%	12.5%
Soybean	9.0%	10.0%	11.4%	11.2%	9.7%	10.4%	12.4%	11.0%	11.1%
Cotton	8.0%	10.2%	11.6%	9.4%	9.2%	9.7%	10.1%	11.5%	9.9%
Fruit	13.1%	16.0%	10.3%	11.5%	10.6%	9.1%	10.6%	9.2%	11.2%
Vegetable	9.6%	13.6%	8.9%	10.2%	10.6%	9.4%	9.9%	7.9%	10.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 5.1.2.8 Weights of crop options with respect to decision attributes in Weinan

Weights	Economic			Social			Environmental		
	Crop Yield	Agricultural income	Water-use efficiency	Household lifestyle	Community cohesion	Rural recreation	Chemical runoff and leaching	Water withdrawal from the river	Soil erosion
Wheat	14.6%	10.2%	15.4%	16.6%	13.6%	14.2%	16.6%	16.3%	13.5%
Corn	19.0%	11.7%	16.5%	14.0%	15.0%	14.9%	14.9%	17.3%	17.5%
Canola	6.8%	7.6%	12.6%	11.4%	9.2%	10.9%	13.4%	14.3%	11.2%
Soybean	8.6%	7.3%	14.1%	9.5%	9.6%	9.5%	14.0%	16.6%	13.4%
Cotton	9.0%	11.6%	16.1%	11.1%	12.3%	12.2%	14.3%	14.7%	13.3%
Fruit	24.0%	26.9%	14.6%	20.0%	22.0%	22.4%	14.3%	12.4%	19.2%
Vegetable	18.0%	24.7%	10.8%	17.4%	18.3%	15.9%	12.5%	8.5%	12.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

5.2 Sensitivity of Preferred Crop Land-use Options

Sensitivity analysis is conducted to assess the effects of changes in criterion weighting on prioritization in land use options, in order to see if changes in the weightings of major evaluation criteria will significantly alter the results analyzed in the previous section. Because the AHP results would have little utility for the policy-makers or authorities to understand what peasants are thinking, if the land-use results are sensitive to changes in the identified priorities. Sensitivity analysis is done by changing the weights of three sustainable criteria to assess their effects on the priority ranking of crop types. More importantly, further discussion will be drawn to compare peasants' crop production priorities and the priorities that generated from hypothetic weightings of sustainable development, so that the trade-offs peasants might face with if the sustainability in their agricultural food production is required to be optimized can be discovered.

5.2.1 Sensitivity of preferred crop land-use option in Guanzhong Plain

Figure 5.2.1.1 presents a visual version of surveyed results about the priority ranking of crop types under the weights given to three major evaluation criteria by respondents in Guanzhong Plain. Figures 5.2.1.2 to 5.2.1.4 present the overall changes in the priorities of crop-type options with the altered weights of three evaluation criteria. The sensitivity of land use option is assessed with a scenario that each of the evaluation criteria is assigned 100% weight. If the ranking of land use option is significantly changed accordingly, our AHP analysis results reported in the previous sections may be sensitive.
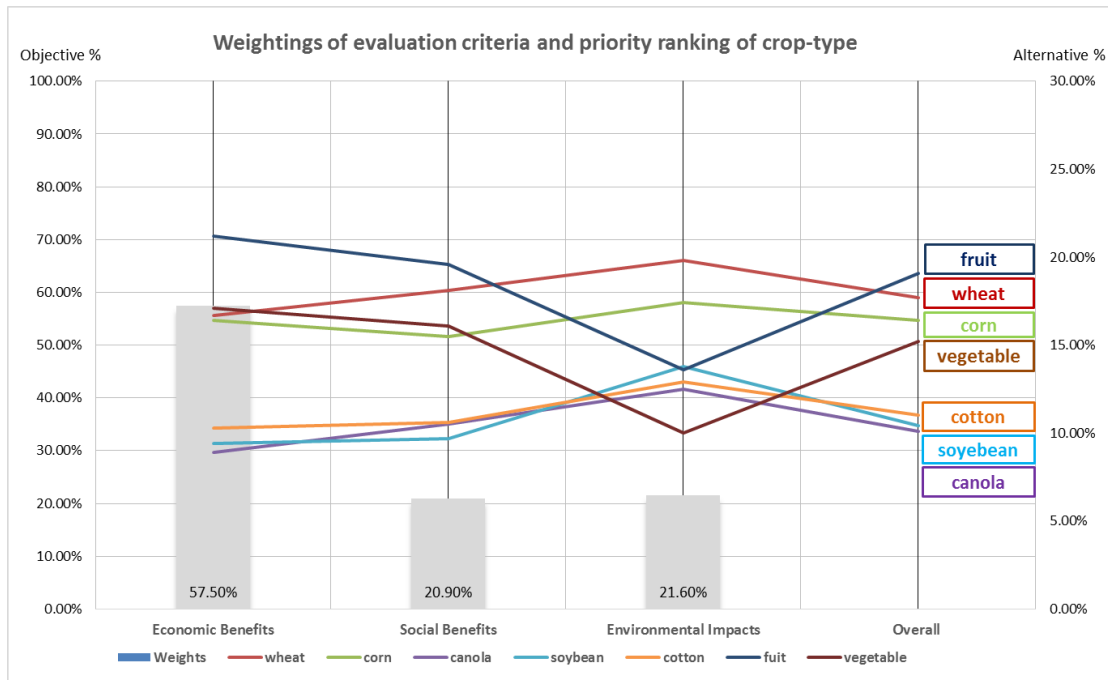
Figure 5.2.1.1 Weightings of evaluation criteria and priority ranking of crop options

According to Figures 5.2.1.2 to 5.2.1.4, fruit, wheat, and corn are not sensitive to all scenarios of weight changes to evaluation criteria. They always stay within the top four places. However, vegetable and soybean are significantly sensitive to the changes in the weights of evaluation criteria. Specifically, if economic benefits are given a weight of 100%, vegetable gets a higher priority than wheat and corn. If social benefits are given a weight of 100%, the order of priority is altered to fruit, wheat, vegetable, and corn. Furthermore, if environmental impacts are given a weight of 100%, wheat and corn receive the highest priority, but surprisingly soybean takes the third place which used to stay at the bottom, while vegetable becomes the last. These findings also prove that the agricultural food production structure in Guanzhong Plain is focused on wheat and corn as grain crops and fruit as the main cash crop.
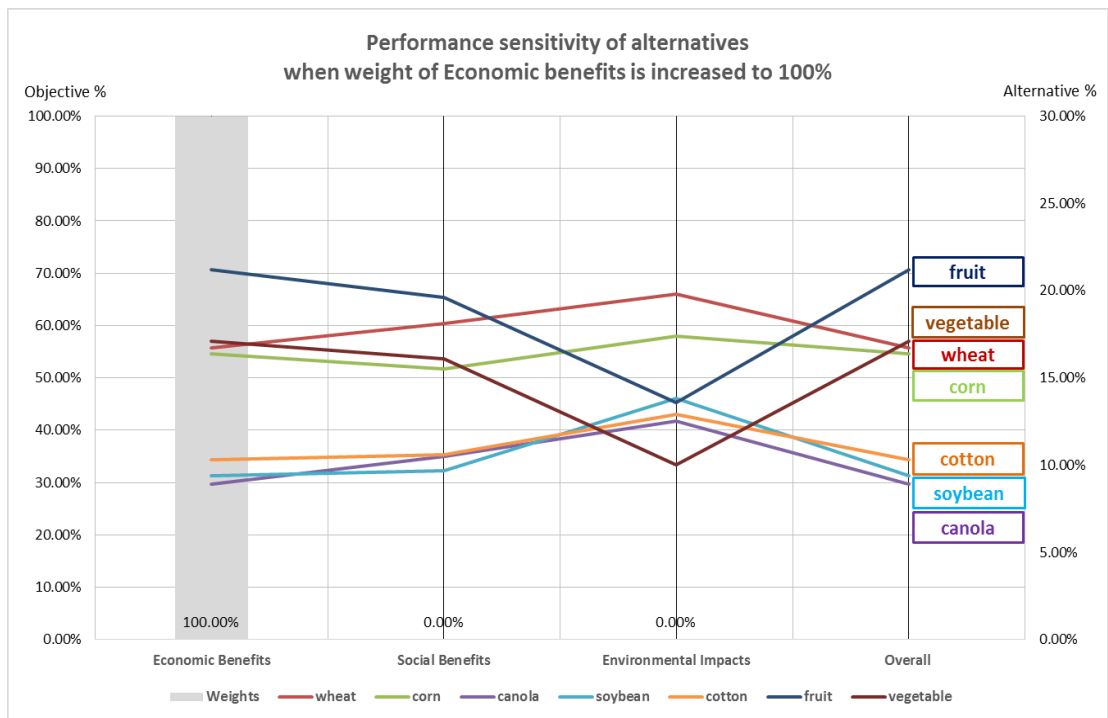
Figure 5.2.1.2 Sensitivity of crop option rankings with a weight of 100% for economic evaluation criterion
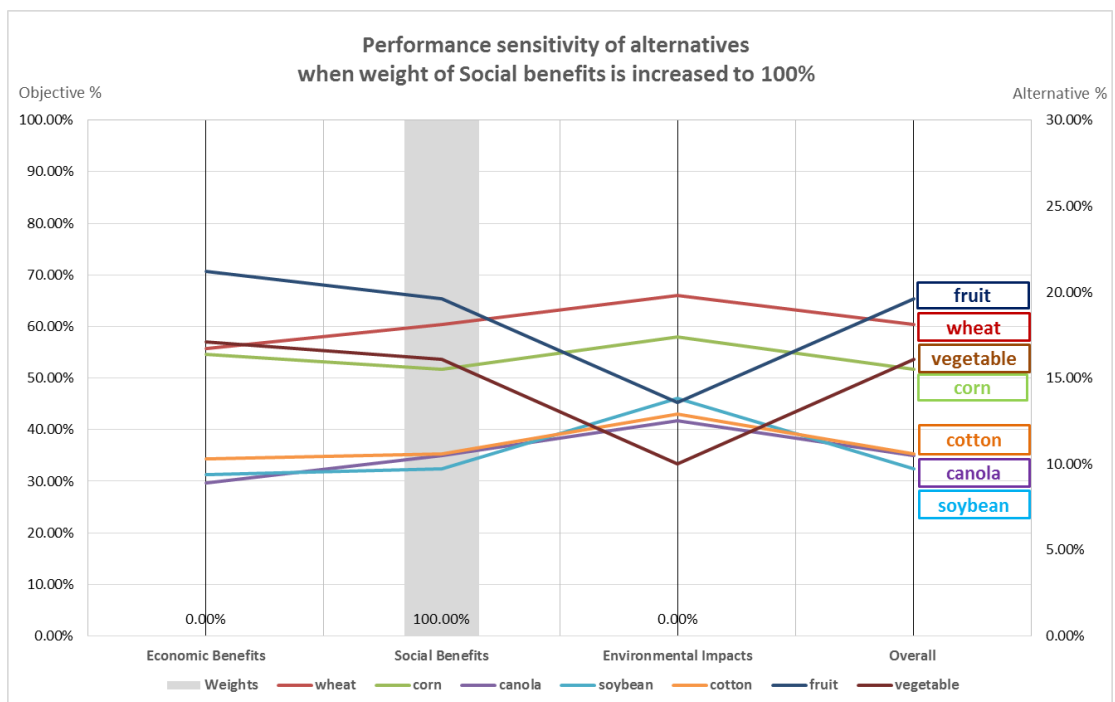
Figure 5.2.1.3 Sensitivity of crop option rankings with a weight of 100% for social evaluation criterion
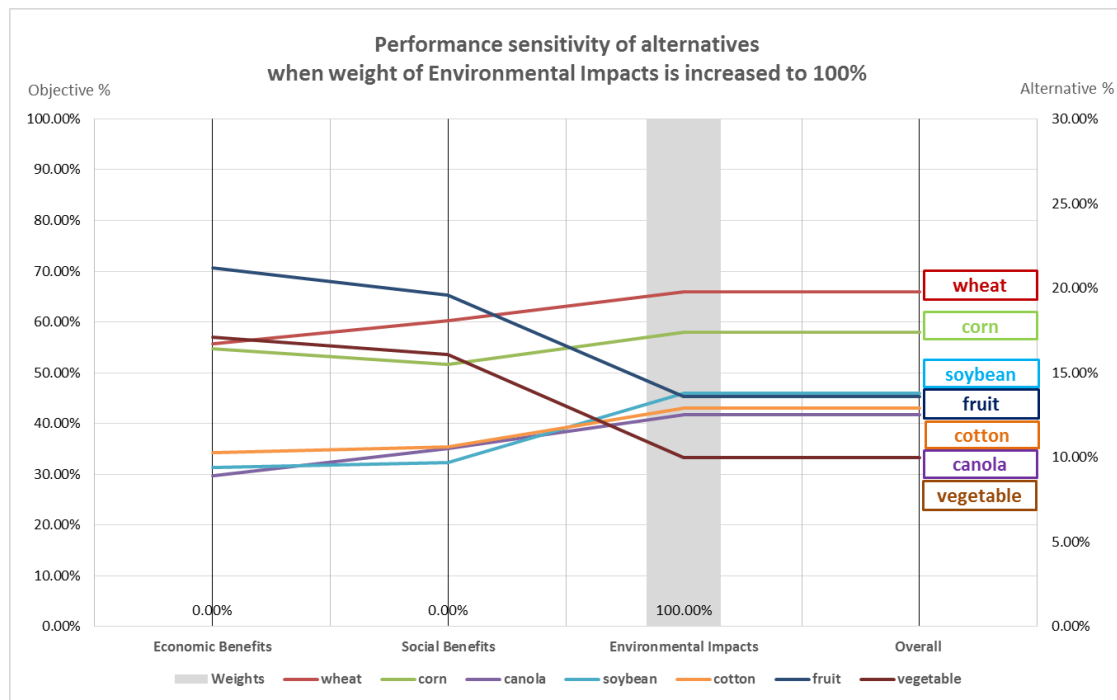
Figure 5.2.1 4 Sensitivity of crop option rankings with a weight of 100% for environmental evaluation criterion

Table 5.2.1.1 summarises the changes in priority ranking of crop options under three scenarios. First, under the scenario of giving 100% weight to economic criterion. The weights for fruit and vegetable may increase significantly. Soybean, wheat, and canola will further lose their plantation priority greatly. Cotton will also become less important, albeit at less extent. Corn will be insensitive to this scenario. This result reveals that, as cash crops vegetable and fruit can always bring about higher economic returns to peasants. It means if economic growth is prioritized further more in agricultural policies in the future, peasants in Shaanxi will devaluate food crops and decrease their initiative even more. Second, under the scenario of giving 100% weight to social criterion, weights for corns, canola and cotton may decrease moderately. In contrast, other crops will increase their priority moderately. The finding indicates that peasants' decision about the development of crop production in Shaanxi, is not significantly sensitive to the social dimension of factors. An increasing weighting in social consideration may increase plantation focus on cash crops a little more. Peasants

may also choose to grow more wheat and soybean, as market demands and prices for these crops tend to be stable. And avoid corn, canola, and cotton, whose market price fluctuate significantly in recent years. Given that corn production demands more labor, other crops such as canola and soybean, an increasing social dimension will also mean a swing from corn to other less labor demanding crops due to increasing opportunity labor cost. Last, under the scenario of giving 100% weight to environmental criterion, weights for fruit and vegetable will decrease significantly by a magnitude of more than 5 percentage points in weighting scheme. Wheat, corn, soybean, canola, and cotton will all increase their plantation weights significantly. Because compared to fruit and vegetable, other crops requires much less water input and chemical fertilizer. It is evident that if environmental protection is emphasized and promoted more, the entire crop plantation structure may be altered significantly. And more or less, peasants will be affected, thereby change their preferences.

In order to understand the absolute magnitude of change in priority ranking in crop options, Table 5.2.1.1 also reports the total change in priority ranking for each crop (see X_8). It is found that the total magnitude of change for fruit and vegetable, is the largest, and then followed by canola, soybean, wheat and cotton. Corn is the least sensitive crop in the study region.

Last but not least, a hypothetical scenario of a sustainable agricultural food production system is also included in the table. In this research, the three resting pillars of the sustainable development is economic, social, and environmental dimension, so by giving the equal weight (33.33%) to each criterion, the trade-offs of the weights of crop-types can be calculated. It is found that if the sustainability of current agricultural land-use system is required to be optimized, that the trade-offs will be mainly between cash crops of vegetable and fruits, and rotational crops of wheat, soybean, and canola.

There is barely no trade-offs with respect to growing corn and cotton. This finding also indicates that, in Guanzhong Plain, peasants highly prefer growing fruit and vegetable instead of other cash crops and grain crops. For the long-term development of agriculture, more importantly in a sustainable way for economy, society, and environment, peasants might need to focus more on growing wheat, soybean, and canola, and moderately reducing the plantation of vegetable and fruit.

Table 5.2.1.1 Trade-offs of the weights of crop-types in Guanzhong Plain (Unit: Percentage)

Weight scenario for evaluation criteria	Priority ranking of crop options and changes							
	wheat	corn	soybean	canola	cotton	fruit	vegetable	Total
Original (X_1)	17.70	16.40	10.10	10.40	11.00	19.10	15.20	100.0
100% weight for economic criterion (X_2)	16.70	16.40	8.90	9.40	10.30	21.20	17.10	100.0
X_3: $X_2 - X_1$	-1.00	0.00	-1.20	-1.00	-0.70	+2.10	+1.90	
100% weight for social criterion (X_4)	18.10	15.50	10.50	9.70	10.60	19.60	16.10	100.0
X_5: $X_4 - X_1$	+0.40	-0.90	+0.40	+0.70	-0.40	+0.50	+0.90	
100% weight for environmental criterion (X_6)	19.80	17.40	12.50	13.80	12.90	13.60	10.00	100.0
X_7: $X_6 - X_1$	+2.10	+1.00	+2.40	+3.40	+1.90	-5.50	-5.20	
X_8: $|X_3| + |X_5| + |X_7|$	3.50	1.90	4.00	5.10	3.00	8.10*	8.00*	
Equal weight for all criteria (X_9)	18.20	16.40	10.70	11.00	11.30	18.10	14.30	100.0
X_{10}: $X_9 - X_1$	+0.50	0.00	+0.60	+0.60	+0.10	-1.00	-0.90	

5.2.2 Regional variation in sensitivity of preferred land-use options

Tables 5.2.2.1 to 5.2.2.4 summarise the changes in priority ranking of crop options under three scenarios in four city regions, Xi'an, Xianyang, Baoji, and Weinan.

Across all four city regions, under the scenario of giving 100% weight to economic criterion, it is foreseeable that the weights for fruit and vegetable may all significantly increase. Particularly in Xi'an, weights for fruit may rise by a magnitude of 6 percentage points in weighting scheme, it's about three to six times bigger than other three regions. But wheat, soybean, canola, and cotton will further lose their plantation priority to varying degrees. Corn will be the most insensitive one to this scenario. This result indicates that peasants are fully aware of food crops bring a low rate of economic returns while cash crops such as fruit and vegetable can bring them great returns. It also means if economic benefits is prioritized more, peasants from all four city regions will further lose their initiative for food-crops plantation, as well as other cash crops even more. Especially based on the circumstance of current peasants are already lack of initiative of growing grain crops because of the low return and high input, such situation will only aggravate the situation. Especially in Xi'an, which is the most sensitive city-region to this scenario, while Baoji is the least sensitive one. This may cause by different level of economic development and market requirement.

Under the scenario of giving 100% weight to social criterion, weights for fruit and vegetable may increase visibly in Xi'an, Xianyang, and Weinan, except Baoji's is reduced slightly. As for the rest crops, across four city-regions, the plantation priority of wheat, corn, soybean, and canola will slightly fluctuate. Their weights all drop to varying degree in Xi'an and Xianyang, except the plantation percentage of soybean slightly grows in Baoji and Weinan. Cotton is the only kind of crop across four city-regions that keep losing its plantation priority in this scenario. This finding indicates

that cash crops such as fruit and vegetable can bring more social benefits to peasants, compared to food crops. The profitable returns of such cash crops are reasonable enough for peasants keep growing interests on their plantation, and the rising market requirement makes peasants more united to work together. It also means that if social growth is prioritized more, peasants from Xi'an, Xianyang, and Weinan will reduce their interests in food crops and turn to cash crops, while Baoji seems to be the least sensitive city-region because there is no change happen to its food crops.

Under the scenario of giving 100% weight to environmental criterion, weights for fruit and vegetable will drop dramatically in all four city-regions. Especially in Xi'an, the weight for fruit may decrease by a magnitude of 10 percentage points, and vegetables' may decrease 7.6 points in the weighting scheme. And it is followed by Xianyang and Weinan. Baoji is the least sensitive one may due to its original share is smaller than the others, therefore the intensity of the impact may be lower. As the water consumed cash crops may decrease their weights dramatically, the rest crops wheat, corn, soybean, canola, and cotton may all increase their plantation weights significantly. This finding intuitively indicates that if environmental protection is encouraged more, the entire crop production focus of Xi'an, Xianyang, Baoji, and Weinan may be significantly transferred from vegetable and fruit to food crops and other cash crops. Within which, corn is again the least sensitive crop in four city regions, which may get the smallest amount of weight increase.

As for the regional variation in terms of the absolute magnitude of changes in priority ranking in crop options, it is found that the largest magnitudes of change is fruit across all four regions. Xi'an and Xianyang also include vegetable, while Baoji and Weinan is soybean. Corn is always the least sensitive crop type.

Similar to the entire Guanzhong Plain, the hypothetical scenario is also included

in the tables 5.2.2.1 to 5.2.2.4, for the purpose of exploring the regional variation of the sustainability in four city-regions' agricultural food production system. The results of four regions are quite consistent, and in accordance with Guanzhong Plain. It is found that if the sustainability of current agricultural land-use system is required to be optimized, that the trade-offs will be mainly between cash crops of fruits and vegetable, and rotational crops of wheat, soybean, and canola. There is barely no trade-offs with respect to growing corn and cotton. This finding indicates that, in Xi'an, Xianyang, Baoji, and Weinan, if the sustainability of agricultural food production system is required to be optimized, peasants might all need to moderately reduce the plantation of fruit and vegetable, instead growing more wheat, corn, soybean, cotton, and canola.

Table 5.2.2.1 Trade-offs of the weights of crop-types (Xi'an) (Unit: Percentage)

Weight scenario for evaluation criteria	Priority ranking of crop options and changes							
	wheat	corn	soybean	canola	cotton	fruit	vegetable	Total
Original (X_1)	16.40	14.70	10.60	10.70	10.60	20.50	16.60	100.0
100% weight for economic criterion (X_2)	13.40	14.00	8.60	8.80	8.70	26.50	20.00	100.0
X_3: X_2 - X_1	-3.00	-0.70	-2.00	-1.90	-1.90	+6.00	+3.40	
100% weight for social criterion (X_4)	15.30	13.10	10.40	9.30	10.50	21.80	19.70	100.0
X_5: X_4 - X_1	-1.10	-1.60	-0.20	-1.40	-0.10	+1.30	+3.10	
100% weight for environmental criterion (X_6)	21.70	16.90	13.70	14.80	13.50	10.50	9.00	100.0
X_7: X_6 - X_1	+5.30	+2.20	+3.10	+4.10	+2.90	-10.00	-7.60	
X_8: $|X_3|$ +$|X_5|$ + $|X_7|$	1.20*	0.10	0.90	0.80	0.90	2.70*	1.10*	
Equal weight for all criteria (X_9)	16.80	14.70	10.90	11.00	10.90	19.60	16.20	100.0
X_{10}: X_9 - X_1	+0.40	0.00	+0.30	+0.30	+0.30	-0.90	-0.40	

Table 5.2.2.2 Trade-offs of weights of crop-types (Xianyang) (Unit: Percentage)

Weight scenario for evaluation criteria	Priority ranking of crop options and changes							
	wheat	corn	soybean	canola	cotton	fruit	vegetable	Total
Original (X_1)	19.00	17.90	9.10	9.50	10.20	20.60	13.70	100.0
100% weight for economic criterion (X_2)	17.90	17.90	8.30	8.40	9.70	22.30	15.50	100.0
X_3: X_2 - X_1	-1.10	0.00	-0.80	-1.10	-0.50	+1.70	+1.80	
100% weight for social criterion (X_4)	18.30	17.00	8.60	8.50	9.60	23.20	14.80	100.0
X_5: X_4 - X_1	-0.70	-0.90	-0.50	-1.00	-0.60	+2.60	+1.10	
100% weight for environmental criterion (X_6)	21.90	18.80	11.40	12.80	11.70	14.40	8.90	100.0
X_7: X_6 - X_1	+2.90	+0.90	+2.30	+3.30	+1.50	-6.20	-4.80	
X_8: $|X_3|$ +$|X_5|$ + $|X_7|$	1.10	0.00	1.00	1.20	0.40	1.90*	1.90*	
Equal weight for all criteria (X_9)	19.40	17.90	9.40	9.90	10.30	20.00	13.00	100.0
X_{10}: X_9 - X_1	+0.40	0.00	+0.30	+0.40	+0.10	-0.60	-0.70	

Table 5.2.2.3 Trade-offs of the weights of crop-types (Baoji) (Unit: Percentage)

Weight scenario for evaluation criteria	Priority ranking of crop options and changes							
	wheat	corn	soybean	canola	cotton	fruit	vegetable	Total
Original (X_1)	28.60	16.60	11.60	10.10	9.50	12.90	10.70	100.0
100% weight for economic criterion (X_2)	28.70	16.40	10.80	9.70	9.30	13.90	11.10	100.0
X_3: X_2 - X_1	+0.10	-0.20	-0.80	-0.40	-0.20	+1.00	+0.40	
100% weight for social criterion (X_4)	28.60	16.60	13.60	10.70	9.40	10.90	10.20	100.0
X_5: X_4 - X_1	0.00	0.00	+2.00	+0.60	-0.10	-2.00	-0.50	
100% weight for environmental criterion (X_6)	27.50	17.80	13.00	11.60	10.50	10.20	9.30	100.0
X_7: X_6 - X_1	-1.10	+1.20	+1.40	+1.50	+1.00	-2.70	-1.40	
X_8: $|X_3|$ +$|X_5|$ + $|X_7|$	1.00	1.00	2.60*	1.70	0.70	3.70*	1.50	
Equal weight for all criteria (X_9)	28.30	17.00	12.50	10.70	9.80	11.70	10.20	100.0
X_{10}: X_9 - X_1	-0.30	+0.40	+0.90	+0.60	+0.30	-1.20	-0.50	

Table 5.2.2.4 Trade-offs of the weights of crop-types (Weinan) (Unit: Percentage)

Weight scenario for evaluation criteria	Priority ranking of crop options and changes							
	wheat	corn	soybean	canola	cotton	fruit	vegetable	Total
Original (X_1)	14.40	15.80	10.40	11.20	12.70	19.80	15.70	100.0
100% weight for economic criterion (X_2)	13.50	15.90	9.00	10.10	12.20	21.70	17.60	100.0
X_3: X_2 - X_1	-0.90	+0.10	-1.40	-1.10	-0.50	+1.90	+1.90	
100% weight for social criterion (X_4)	15.20	14.50	10.70	9.50	11.70	21.20	17.30	100.0
X_5: X_4 - X_1	+0.80	-1.30	+0.30	-1.70	-1.00	+1.40	+1.60	
100% weight for environmental criterion (X_6)	15.60	16.30	13.10	14.60	14.10	15.10	11.20	100.0
X_7: X_6 - X_1	+1.20	+0.50	+2.70	+3.40	+1.40	-4.70	-4.50	
X_8: $|X_3|$ +$|X_5|$ + $|X_7|$	1.10	0.70	1.60*	0.60	0.10	1.40*	1.00	
Equal weight for all criteria (X_9)	14.80	15.60	10.90	11.40	12.70	19.30	15.40	100.0
X_{10}: X_9 - X_1	+0.40	-0.20	+0.50	+0.20	0.00	-0.50	-0.30	

5.3 Summary

This chapter presents peasants' preferences of agricultural land-use with respect to various economic, social, and environmental factors from four major city-regions in Guanzhong Plain. Also the potential trade-offs they might face with if the optimization of the sustainability of the agricultural food production system is required.

The results indicate that the crop production for current Central Shaanxi, peasants is mainly focused on wheat, corn, fruit, and vegetable. Fruit and vegetable are peasants' favorite cash crops considering the economic benefits and social benefits, while wheat and corn are peasants' most preferred grain crops considering environmental impacts. Compared to those crops, soybean, cotton, and canola are less preferred. As for the regional variation, peasants from Xi'an, Xianyang, and Weinan share lots of similarities, while Baoji is unique. This is caused by a variety of reasons, including the agricultural modernization level, economic development level, the support from provincial and national governments, the proportion of agricultural labor force, the agricultural labor productivity, and the added value of agriculture. Moreover, the results also show that surveyed peasants may adjust their preferences according to their different economic, social, and environmental demands.

Sensitivity analysis indicates that the priorities of crop-type selection may change, to a small extent, if the weights of decision attributes are altered. The results show that wheat, corn, and fruit are not sensitive. This indicates that the structure of Guanzhong Plain's crop-production would not change, wheat, corn, and fruit always are peasants' first choices. And corn as food crop, is less sensitive than wheat, and insensitive to any weight change with respect to decision attributes. This might be caused by the market demand for corn is saturated, while vegetable is extremely sensitive to environmental decision

attributes. As for regional variation, Xi'an peasants' preferences turns out to be the most sensitive, while Baoji is the least sensitive. The hypothetical scenario results show that if the sustainability of current Central Shaanxi's agricultural food production system is required to be optimized, the trade-offs peasants may face with will be mainly between cash crops of vegetable and fruit, and rotational crops of wheat, soybean, and canola.

Chapter Six

6 Peasants' Preferences of Irrigation techniques in Sustainable Food Production System

This chapter aims at exploring a consensus among peasants' decisions about the use of irrigation technology. Specifically, it reports what kind of irrigation technique peasants choose to maximize their identified sustainability objectives and interests. Then based on the results, the sensitivity analysis results are presented to understand the effects of priority changes under the hypothetical weightings of sustainability goals.

6.1 Prioritization of Irrigation Options

There are six irrigation methods participated in the survey for respondents to decide. Other than natural precipitation rain, the rest irrigation methods reflect three main types of agricultural irrigation methods, including: a) Surface water irrigation techniques: pumping water from the rivers and manually irrigation; b) Water saving irrigation techniques: sprinkling, drip irrigation; c) Groundwater irrigation: well-irrigation.

6.1.1 Peasants' preference of irrigation techniques in Guanzhong Plain

Table 6.1.1.1 presents peasants' preference of irrigation techniques with respect to the objectives of sustainable food production in Guanzhong Plain. Generally speaking, water-saving irrigation get the highest score, as drip-irrigation with a score of 0.220 and sprinkling with a score of 0.217 become peasants' most prioritized irrigation methods for the general goal. They are closely followed by using well-irrigation (0.186). The priorities of other irrigation methods follow by pumping water from the river (0.130), manually irrigation (0.125), and natural precipitation (0.123). When peasants are considering different economic, social benefits, and environmental impacts, the priority does not alter

greatly. Basically, using water-saving irrigation techniques and well-irrigation keep on the top, and other three remain less favored places. It is worth noticing that using water-saving and well irrigation techniques tie for the first place when social benefits come to consideration, while manually irrigation is the least favored irrigation method for peasant. Apparently, the old picture of farmers are at the mercy of the forces of nature has complete changed. The main irrigation in the agricultural food production of Guanzhong Plain is dominated by water-saving techniques. This result also indicates that the water-saving techniques in Guanzhong Plain have been extensively implemented and widely accepted by peasants.

Table 6.1.1.2 shows the relative priority weights of irrigation methods with respect to the specific factors under environmental, social, and economic criterion. The result indicates that, there is no big difference between peasants' preferences with respect to major objectives or the specific decision attributes. All three kinds of water saving and well-irrigation techniques are ranked the highest score. Drip-irrigation outperforms all other watering methods becoming the most preferred technique, with respect to all environmental decision attributes (0.226 for chemical runoff and leaching, 0.223 for water withdrawal from the river, and 0.255 for soil erosion),household lifestyle (0.201) under social benefits, and crop yield (0.225), water-use efficiency (0.265) under economic benefits. Well-irrigation becomes the top favorite among the remaining decision attributes: community cohesion (0.203) and recreation (0.204). Except sprinkling (0.212) gets the highest score for considering the income. Except water-saving irrigation and well-irrigation techniques, other surface water irrigation methods and using rainfall turn out to be less preferred for all decision attributes.

To sum up, water-saving irrigation and well-irrigation techniques are peasants' most

preferred watering methods in Guanzhong Plain, no matter what evaluation factors. On the contrary, using manual irrigation, pumping water from the river, and depending on rainfall are much less preferred. This result indicates that most peasants from Guanzhong Plain have widely accepted and adopted the water-saving techniques. Over a long period of agricultural production history, peasants have used free flooding irrigation or manual watering to water their cropland. The hazards are pretty obvious. Free flooding irrigation or heedless manual-watering has caused a very low water-use efficiency. According to government research report, that the water consumption of agricultural production amounts to two-thirds of the total water consumption in China, and among them the effective utilization is less than half. More important, free flooding irrigation will raise the groundwater level. After the evaporation of water on the soil surface, salt and alkali will be left on the cropland. Soil salinization and alkalization restrict yield of crops because of soil hardening, soil nutrition waste, and expressing disease. Guanzhong Plain is located in western water-scarcity area of China. Free flooding irrigation goes against not only to the sustainable development of agricultural production, but to peasants' vital interests. Besides restricting the yields, there is also the high expense of water-input. According to the scientific calculation, if there is one hectare of orchard, free flooding irrigation would consume 1800 tons of water, but water-saving techniques would only use 25% of that. In recent years, peasants are growing awareness of using water-saving techniques to help reduce the water-input in their agricultural production. With financial support from governments, they are more willing to choose water-saving techniques.

Table 6.1.1.1 Weights of irrigation options with respect to evaluation criteria in Guanzhong Plain

Weights	Goal	Economic Benefits	Social Benefits	Environmental Impacts
Well	18.6%	19.0%	19.8%	16.4%
Rain	12.3%	11.3%	14.2%	13.0%
River Pump	13.0%	13.0%	13.8%	12.3%
Manual	12.5%	12.3%	12.7%	12.7%
Sprinkling	21.7%	22.1%	19.8%	22.3%
Drip	22.0%	22.3%	19.8%	23.3%
Total	100.0%	100.0%	100.0%	100.0%

Table 6.1.1.2 Weights of irrigation options with respect to decision attributes in Guanzhong Plain

Weights	Economic			Social			Environmental		
	Crop Yield	Agricultural income	Water-use efficiency	Household lifestyle	Community cohesion	Rural recreation	Chemical runoff and leaching	Water withdrawal from the river	Soil erosion
Well	21.0%	19.2%	14.4%	19.3%	20.3%	20.4%	17.4%	16.7%	14.4%
Rain	9.5%	12.8%	11.9%	16.1%	11.8%	12.7%	12.4%	14.1%	12.6%
River Pump	12.9%	14.0%	11.2%	13.0%	14.8%	14.4%	13.1%	12.2%	11.2%
Manual	12.0%	12.7%	12.1%	12.0%	13.5%	13.3%	12.9%	12.9%	12.3%
Sprinkling	22.2%	21.2%	23.8%	19.6%	19.9%	20.1%	21.6%	21.8%	24.0%
Drip	22.5%	20.0%	26.5%	20.1%	19.7%	19.1%	22.6%	22.3%	25.5%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

6.1.2 Regional variation in peasants' preference of irrigation techniques

In order to explore the geographical differences in peasants' preferences of irrigation methods in terms of sustainable food production, the results of the AHP analysis for Xi'an, Xianyang, Baoji, and Weinan are presented in tables 6.1.2.1 to 6.1.2.8.

Tables 6.1.2.1 to 6.1.2.8 show peasants' preferences of irrigation techniques with respect to the objectives of sustainable food production in Xi'an, Xianyang, Baoji, and Weinan. It can be clearly found that with respect to the agricultural production goal, peasants across four areas, give their priorities to the water-saving irrigation techniques. Especially in terms of environmental impacts, it appears that drip-irrigation and sprinkling are the most ideal and preferred irrigation methods for peasants from different city-regions. They have ranked well-irrigation a higher score then manual, rain, and river-water irrigation. There are still a divergence of preference within regions. Apparently, in Xi'an, Xianyang, and Weinan, the priorities of water-saving irrigation techniques is transcendent. Drip-irrigation can be found outperform all other watering methods with respect to all evaluation criteria. It is closely followed by sprinkling, which acquires the second highest score in the same assessment criteria. The third place is taken by well-irrigation. Comparing with other three prefectural city regions, Baoji is once again unique. It appears that using well-irrigation dominated the entire agricultural production process. It acquired around 30 percent of peasants' preferences. Then it is followed by using water pumping from the rivers, sprinkling, and rain-water. Surprisingly, drip-irrigation only shows its priority tying for the second with sprinkling when peasants consider environmental impacts. Also peasants from Baoji show the least preference for drip-irrigation considering the economic and social benefits.

Table 6.1.2.1 Weights of irrigation options with respect to evaluation criteria in Xi'an

Weights	Goal	Economic Benefits	Social Benefits	Environmental Impacts
Well	14.0%	15.3%	14.9%	11.0%
Rain	12.8%	11.3%	13.3%	15.2%
River Pump	13.4%	13.6%	14.7%	12.1%
Manual	12.9%	12.8%	13.1%	12.9%
Sprinkling	22.8%	22.7%	21.9%	23.7%
Drip	24.0%	24.3%	22.1%	25.1%
Total	100.0%	100.0%	100.0%	100.0%

Table 6.1.2.2 Weights of irrigation options with respect to evaluation criteria in Xianyang

Weights	Goal	Economic Benefits	Social Benefits	Environmental Impacts
Well	22.1%	22.6%	24.7%	18.6%
Rain	10.6%	9.7%	12.6%	10.6%
River Pump	12.0%	12.3%	12.7%	10.9%
Manual	10.7%	10.5%	10.5%	11.2%
Sprinkling	21.7%	22.0%	19.4%	23.3%
Drip	22.8%	22.9%	20.0%	25.4%
Total	100.0%	100.0%	100.0%	100.0%

Table 6.1.2.3 Weights of irrigation options with respect to evaluation criteria in Baoji

Weights	Goal	Economic Benefits	Social Benefits	Environmental Impacts
Well	33.8%	35.1%	31.7%	29.0%
Rain	13.3%	12.5%	16.5%	13.6%
River Pump	14.1%	14.2%	14.4%	13.6%
Manual	13.0%	12.8%	13.0%	14.1%
Sprinkling	13.3%	13.2%	12.7%	14.8%
Drip	12.5%	12.3%	11.7%	14.8%
Total	100.0%	100.0%	100.0%	100.0%

Table 6.1.2.4 Weights of irrigation options with respect to evaluation criteria in Weinan

Weights	Goal	Economic Benefits	Social Benefits	Environmental Impacts
Well	14.1%	13.8%	15.8%	13.7%
Rain	13.1%	12.5%	15.2%	13.1%
River Pump	12.2%	11.9%	13.7%	11.8%
Manual	12.8%	12.6%	13.8%	12.8%
Sprinkling	23.7%	24.4%	20.7%	24.1%
Drip	24.1%	24.9%	20.8%	24.6%
Total	100.0%	100.0%	100.0%	100.0%

Tables 6.1.2.5 to 6.1.2.8 present the weights of six irrigation options with respect to individual decision attributes under economic, social, and environmental criteria in four city regions.

There are several interesting findings when zooming into peasants' preferences of irrigation under the precise attributes. In Xi'an, Xianyang, and Weinan, sprinkling and drip-irrigation out-weight all other irrigation techniques with respect to all economic, social, and environmental attributes. The peasants from these three city-regions prefer well-irrigation a little less than sprinkling and drip-irrigation. By contrast, using water pumping from the river, manual irrigation, and natural precipitation are less preferred. However, there is no denying that using natural precipitation is an economic practically, social harmoniously, and environmental friendly way to water the cropland. Peasants' from four areas, more or less, give their preferences to the rain-water. Especially in Baoji, peasants consider using rain-water as the second preference for their social benefits. Their top priority was given to well-irrigation with an unshakeable position. As for sprinkling and drip-irrigation, peasants from Baoji only rank them as the second favorites considering the environmental impacts.

In general, the regional variation of peasants' preferences for irrigation techniques reflects the economic development level of agriculture. It also indicates the different stages of agricultural modernization. Apparently, from the broader perspective, adopting water-saving irrigation and well-irrigation techniques has become the mainstream of agricultural production. But specifically speaking, peasants from different city-regions have diverse preference. Peasants from Xi'an, Xianyang, and Weinan share similar preferences of using sprinkling and drip-irrigation, while peasants in Baoji favor well-irrigation more. As mentioned in the previous chapter, the economic development level of Baoji is laggard than other three cities. In other words, a certain amount of peasants in Baoji cannot afford the

installation of sprinkler or drip irrigation technology to further reduce the water-input. Although the economic development level of Weinan is similar to Baoji, because of its tremendous contribution to the agricultural crop production, it has earlier developed more advanced water-saving irrigation techniques with the support of national water-saving projects. Besides, Baoji is located in the upstream of Wei River, because of convenient access to reservoir and channels, peasants from Baoji acquire relatively abundant water-resource than peasants in other three downstream city-regions. Such difference of natural conditions has led to the difference of water-price. For peasants from Baoji, using well-irrigation and pumping water from the rivers combining reservoir and channels require less economic input compared to sprinkling and drip-irrigation. As a matter of fact, well-irrigation and pumping water from the rivers combining reservoir and channels are the typical type of irrigation technique widely adopting in water-scarcity regions in western China. Except the small investments, quick returns, easy to access and manage, the advantages also include help balance the level of ground water and surface water in order to prevent surface subsidence and relieve soil salinization. Nonetheless, compared to sprinkling and drip-irrigation, they have been proved highly efficient water saving. Using sprinkler make sure the water spreading over the plants evenly, and trickle irrigation make sure plants get enough water, both techniques without wasting more water. While well-irrigation and pumping water from the rivers combining reservoir and channels, it is inevitable to cause infiltration and the occurrence of surface evaporation. In the past few years, Shaanxi governments have provided certain funds for improving canals and channels. Yet in terms of the water-use efficiency and minimize the environmental impacts, peasants from Guanzhong Plain all agree on sprinkling and drip-irrigation.

Table 6.1.2.5 Weights of the options (irrigation) with respect to decision attributes in Xi'an

Weights	Economic			Social			Environmental		
	Crop Yield	Agricultural income	Water-use efficiency	Household lifestyle	Community cohesion	Rural recreation	Chemical runoff and leaching	Water withdrawal from the river	Soil erosion
Well	16.7%	15.4%	11.6%	14.8%	15.3%	14.8%	11.6%	10.3%	10.7%
Rain	7.4%	14.4%	12.1%	16.0%	10.4%	10.3%	15.9%	16.2%	13.0%
River Pump	13.5%	14.2%	12.0%	14.2%	14.7%	16.0%	12.3%	11.6%	12.3%
Manual	13.1%	12.3%	13.2%	12.3%	14.1%	13.7%	13.2%	11.2%	14.1%
Sprinkling	24.3%	20.9%	24.0%	21.5%	22.6%	21.8%	23.0%	24.9%	23.6%
Drip	25.0%	22.8%	27.0%	21.3%	22.9%	23.3%	23.9%	25.7%	26.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6.1.2.6 Weights of the options (irrigation) with respect to decision attributes in Xianyang

Weights	Economic			Social			Environmental		
	Crop Yield	Agricultural income	Water-use efficiency	Household lifestyle	Community cohesion	Rural recreation	Chemical runoff and leaching	Water withdrawal from the river	Soil erosion
Well	23.9%	25.0%	15.1%	24.7%	25.1%	24.2%	20.4%	19.0%	15.1%
Rain	7.8%	11.5%	9.6%	14.7%	10.8%	9.9%	9.9%	11.4%	10.2%
River Pump	12.5%	13.2%	9.8%	12.6%	13.2%	12.4%	11.7%	11.1%	9.4%
Manual	10.4%	10.8%	10.3%	10.2%	10.8%	11.0%	11.1%	11.6%	10.4%
Sprinkling	22.7%	20.1%	24.6%	18.6%	19.8%	21.0%	22.1%	22.8%	25.8%
Drip	22.7%	19.5%	30.6%	19.2%	20.4%	21.5%	24.8%	24.1%	29.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6.1.2.7 Weights of the options (irrigation) with respect to decision attributes in Baoji

Weights	Economic			Social			Environmental		
	Crop Yield	Agricultural income	Water-use efficiency	Household lifestyle	Community cohesion	Rural recreation	Chemical runoff and leaching	Water withdrawal from the river	Soil erosion
Well	37.9%	33.8%	27.2%	32.0%	31.2%	31.5%	30.9%	27.7%	27.3%
Rain	12.9%	11.2%	13.9%	16.1%	14.6%	20.5%	12.8%	14.6%	13.6%
River Pump	13.2%	16.1%	13.4%	14.6%	14.5%	13.4%	14.6%	12.7%	12.8%
Manual	11.4%	14.9%	13.4%	13.0%	13.6%	12.2%	13.3%	15.3%	13.8%
Sprinkling	12.5%	13.1%	15.8%	12.7%	13.1%	12.1%	13.6%	15.8%	15.8%
Drip	12.1%	10.9%	16.2%	11.6%	13.0%	10.3%	14.8%	13.8%	16.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6.1.2.8 Weights of the options (irrigation) with respect to decision attributes in Weinan

Weights	Economic			Social			Environmental		
	Crop Yield	Agricultural income	Water-use efficiency	Household lifestyle	Community cohesion	Rural recreation	Chemical runoff and leaching	Water withdrawal from the river	Soil erosion
Well	15.7%	13.5%	11.1%	14.8%	16.4%	17.0%	14.0%	14.7%	12.4%
Rain	11.0%	13.9%	12.7%	17.5%	12.8%	13.8%	11.9%	15.1%	12.7%
River Pump	12.1%	13.3%	9.5%	11.9%	15.5%	15.0%	12.6%	11.9%	10.6%
Manual	12.5%	12.7%	12.5%	12.3%	15.3%	15.0%	13.3%	13.4%	11.6%
Sprinkling	23.7%	24.1%	26.0%	20.9%	20.4%	20.6%	24.1%	21.7%	26.3%
Drip	25.1%	22.5%	28.3%	22.7%	19.8%	18.5%	24.2%	23.3%	26.4%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

6.2 Sensitivity of Preferred Irrigation Techniques

Sensitivity analysis is also conducted to see if the irrigation-technique selection results are sensitive to changes in the identified priorities. It is done by changing the weights of three sustainable criteria to assess their effects on the priority ranking of irrigation methods. More important, further discussion will be drawn to compare peasants' priorities of irrigation methods and the priorities that generated from hypothetic weightings of sustainable development, so that the trade-offs peasants might face with if the sustainability in their agricultural food production is required to be optimized can be discovered.

6.2.1 Sensitivity of preferred irrigation methods in Guanzhong Plain

Figure 6.2.1.1 presents a visual version of surveyed results about the priority ranking of irrigation options under the weights given to three major evaluation criteria by respondents in Guanzhong Plain. Figures 6.2.1.2 to 6.2.1.4 show the overall changes in the priorities of irrigation methods with the altered weights of three evaluation criteria. The sensitivity of crop options is assessed with a scenario that each of the evaluation criteria is to assign 100% weight. If the ranking of irrigation option is significantly changed accordingly, the AHP analysis results reported in the previous sections may be sensitive.
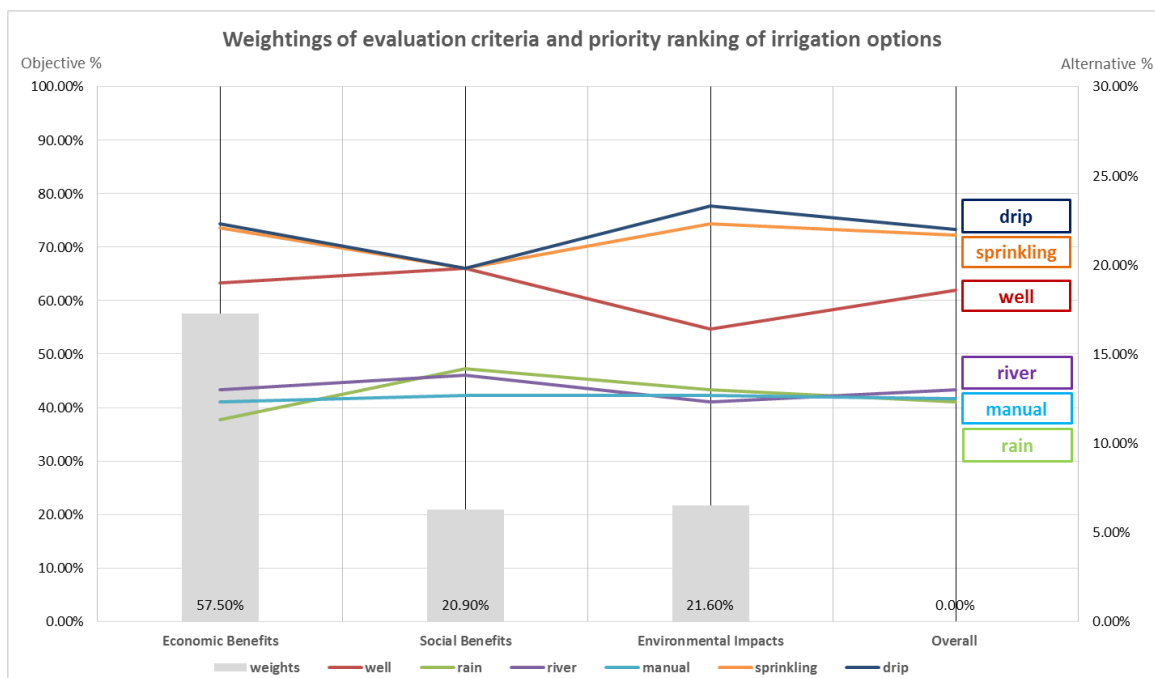
Figure 6.2.1.1 Weightings of evaluation criteria and priority ranking of irrigation options

According to Figures 6.1.1.2 to 6.2.1.4, water-saving irrigation techniques (including sprinkling and drip-irrigation) and well irrigation are insensitive to all weight changes. They always stay in top three places. It means that surveyed peasants may stick to these three watering methods no matter what weight changes happen to their economic, social returns or environmental concerns. More specific, if economic benefits are given a weight of 100%, the priority of irrigation options would not change. If social benefits are given a weight of 100%, the priority of drip-irrigation might drop a little. Using manual-watering becomes the least favored. If environmental impacts are given a weight of 100%, the value score of well-irrigation would drop signicantly.
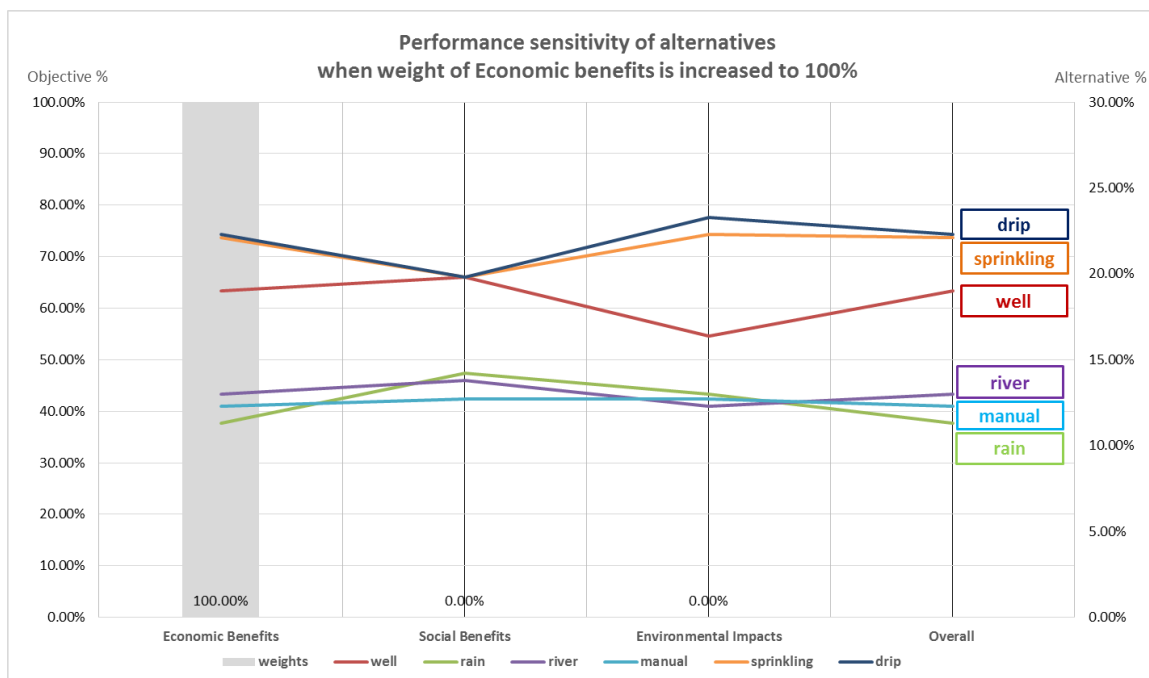
Figure 6.2.1.2 Sensitivity of irrigation option rankings with a weight of 100% for economic evaluation criterion
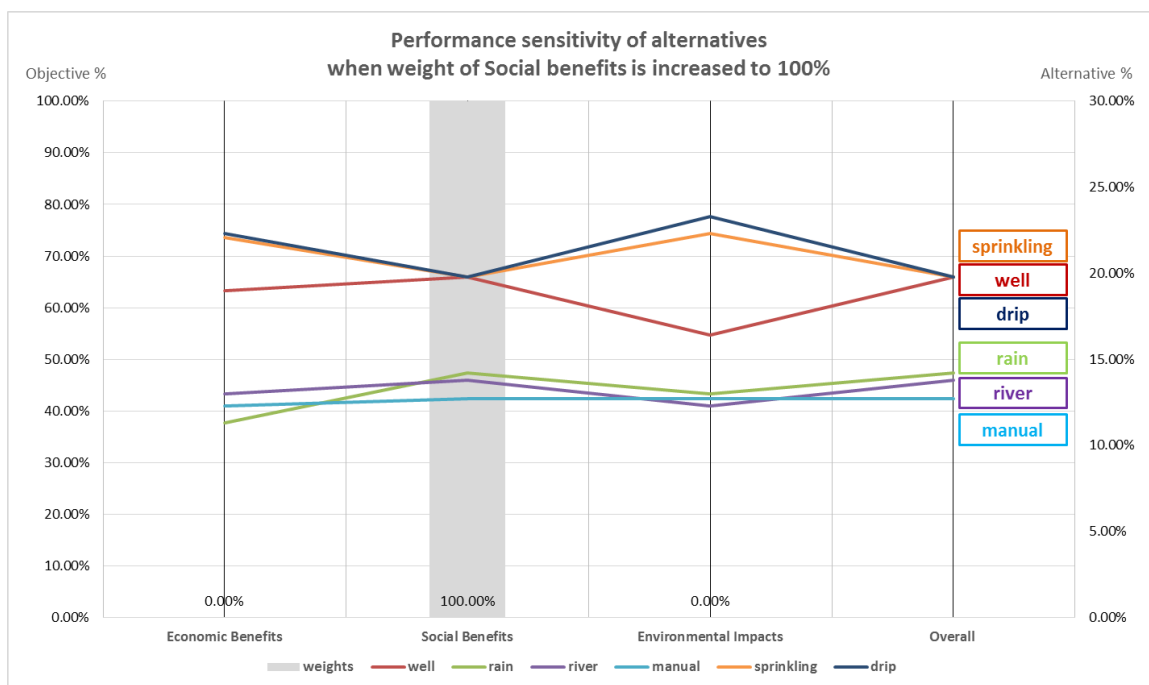
Figure 6.2.1.3 Sensitivity of irrigation option rankings with a weight of 100% for social evaluation criterion
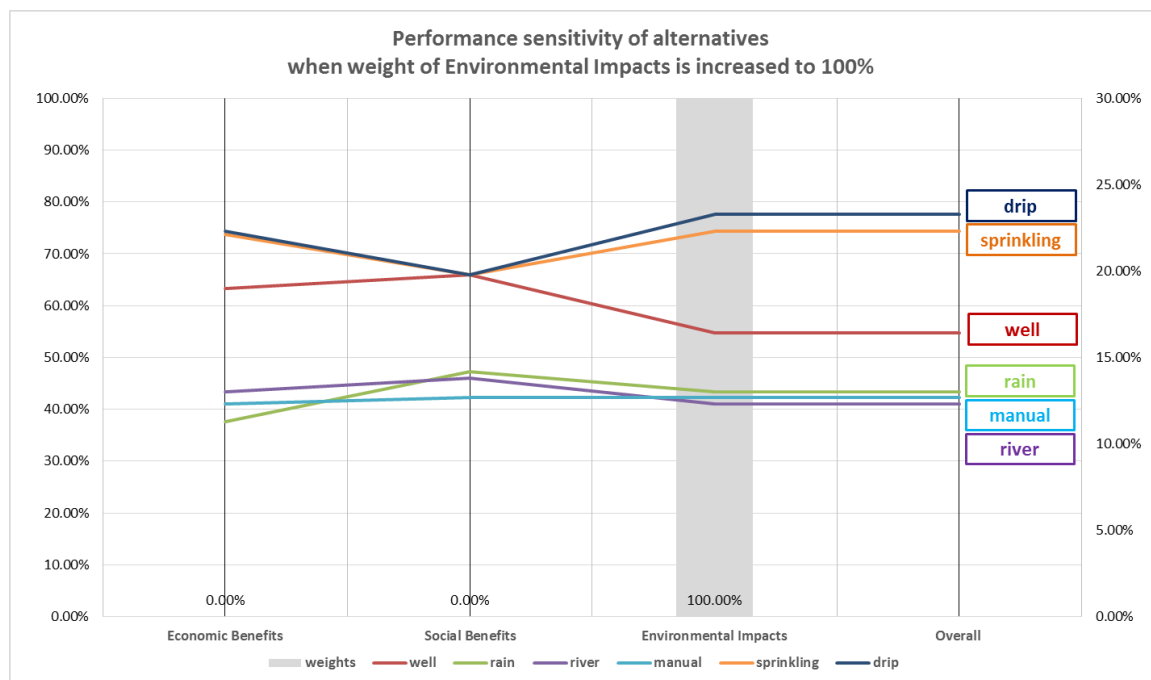
Figure 6.2.1.4 Sensitivity of irrigation option rankings with a weight of 100% for environmental evaluation criterion

Table 6.2.1.1 summarises the changes in priority ranking of irrigation options under three scenarios.

Under the scenario of giving 100% weight to economic criterion, weights for water-saving irrigation methods and well-irrigation may slightly increase. Rain and manual irrigation will lose their priority accordingly, while the scenario does not affect the portion of using river-water. This result suggests that using water-saving irrigation techniques and groundwater irrigation might save peasants more economic inputs. Since the change is very slim, the finding can be interpreted as if economic growth is prioritized furthermore, generally speaking peasants in Shaanxi basically would not change their irrigation system. Under the scenario of giving 100% weight to social criterion, weights for sprinkling and drip-irrigation techniques may be witnessed to significantly decrease. On the contrary, other watering methods might increase their priority, especially using well-irrigation. This

finding indicates that agricultural irrigation system in Guanzhong Plain is sensitive to the social benefits. An increasing weighting in social consideration may cause a little reduction of peasants' preference of water-saving sprinkling and drip-irrigation, peasants may prefer more well-irrigation and natural precipitation. Last, under the scenario of giving 100% weight to environmental criterion, it appears except using well-irrigation and river-water, the preferences of other irrigation methods would all increase in various degrees. It is evident that sprinkling and drip-irrigation could help reduce water resources waste as well as prevent soil erosion, natural precipitation is totally environmental-friendly.

In order to understand the absolute magnitude of change in priority ranking in irrigation options, Table 6.2.1.1 also reports the total change in priority ranking for each method (see X_8). It is found that the total magnitude of change for drip-irrigation, well-irrigation, and rain is the largest, then followed by sprinkling and pumping water from rivers. Using manual irrigation is the least sensitive irrigation method in the study region.

Last but not least, the hypothetical scenario of a sustainable agricultural food production system is also included in the table. In this research, the three resting pillars of the sustainable development is economic, social, and environmental dimension, so by giving the equal weight (33.33%) to each criterion, the trade-offs of the weights of irrigation methods can be calculated. It is found that if the sustainability of current agricultural irrigation system is required to be optimized, the trade-offs peasants might face with are very slim.

Table 6.2.1.1 Trade-offs of weights of irrigation methods in Guanzhong Plain (Unit: Percentage)

Weight scenario for evaluation criteria	Priority ranking of irrigation options and changes						
	well	rain	river	manual	sprinkling	drip	Total
Original (X_1)	18.60	12.30	13.00	12.50	21.70	22.00	100.0
100% weight for economic criterion (X_2)	19.00	11.30	13.00	12.30	22.10	22.30	100.0
X_3: $X_2 - X_1$	+0.40	-1.00	0.00	-0.20	+0.40	+0.30	
100% weight for social criterion (X_4)	19.80	14.20	13.80	12.70	19.80	19.80	100.0
X_5: $X_4 - X_1$	+1.20	+1.90	+0.80	+0.20	-1.90	-2.20	
100% weight for environmental criterion (X_6)	16.40	13.00	12.30	12.70	22.30	23.30	100.0
X_7: $X_6 - X_1$	-2.20	+0.70	-0.70	+0.20	+0.60	+1.30	
X_8: $|X_3| + |X_5| + |X_7|$	3.80*	3.60*	1.50	0.60	2.90	3.80*	
Equal weight for all criteria (X_9)	18.40	12.80	13.00	12.60	21.40	21.80	100.0
X_{10}: $X_9 - X_1$	-0.20	+0.50	0.00	+0.10	-0.30	-0.20	

6.2.2 Regional variation in sensitivity of Peasants' preferred irrigation methods

Tables 6.2.2.1 to 6.2.2.4 summarise the changes in priority ranking of irrigation options under three scenario in four city regions, Xi'an, Xianyang, Baoji, and Weinan.

Across four city-regions, under the scenario of giving 100% weight to economic criterion, except Baoji, weights of using sprinkling and drip-irrigation in other three city-regions may increase more or less. And it appears using manual rain-water and manual irrigation might become less favored across all regions. This result indicates that using water-saving irrigation methods help peasants reduce more water usage during cultivation so that economic input can be reduced correspondingly. It also means if economic growth is prioritized more, Xi'an would be the most sensitive area to this scenario, while Xianyang would be the least sensitive one. Furthermore, peasants from Xi'an, Xianyang, and Weinan may prefer water-saving sprinkling and drip irrigation techniques more, while peasants from Baoji, because of the lack of financial support, they might prefer low-cost well-irrigation even more. Under the scenario of giving 100% weight to social criterion, the regional variation is similar to the overall situation. Weights for sprinkling and drip-irrigation may drop significantly in all four city regions. Especially in Weinan and Xianyang, weights may reduce by a magnitude of 3 percentage points in weighting scheme. Another common place of four city-regions is that the concentration of using rain and river water, while manual-irrigation is the least sensitive one to the scenario. This finding suggests that peasants from individual study area all agree with using water-saving irrigation techniques might, to varying degrees, adverse to their social interests. The result also suggests that if social interest growth is more prioritized, peasants will alter their preferences to other economical and affordable irrigation methods, such as using rain or

pumping water from the river. Under the scenario of giving 100% weight to environmental criterion, there is no surprise to find that weights for sprinkling and drip-irrigation will rise. Four city-regions all show certain degrees of weight increase in weighting scheme, especially Xianyang and Baoji. In contrast, weights of other well-irrigation and surface water irrigation methods will decrease accordingly. Among all, well-irrigation gets the most significant cut down, followed by pumping water from the rivers. Well-irrigation by withdrawing groundwater to supply water, if groundwater is over-exploit, it may cause surface subsidence. As for using river-water, there is a lot of water loses because of evaporation and infiltration if the anti-seepage technology has not been promoted. So improper utilization of these two irrigation methods may adverse to sustainable water-use. The result also indicates that if environmental protection is encouraged more, sprinkling and drip irrigation will be much more advocated. Correspondingly, the usage of well-irrigation and surface water-irrigation would be reduce.

As for the regional variation in terms of the absolute magnitude of changes in priority ranking in irrigation options, it is found that the largest magnitudes of change show up in water-saving irrigation techniques. Using manual irrigation turns out to be the least sensitive irrigation method in the study city-regions.

According to the hypothetical scenario of sustainable development, it is found that the trade-offs in irrigation methods will be mainly existed between natural rainfall, water-saving technique of drip-irrigation, and well-irrigation. Especially in Baoji, the agricultural irrigation weights too heavily toward well-irrigation. There is rarely weight change in Xi'an and Xianyang. The weights for using sprinkling and drip-irrigation in Weinan may drop a little bit, as given in the economic inputs of using sprinkling and drip-irrigation. There is still a gap between the level of rural economic development of Weinan and Xi'an, Xianyang.

Table 6.2.2 1 Trade-offs of weights of irrigation methods (Xi'an) (Unit: Percentage)

Weight scenario for evaluation criteria	Priority ranking of irrigation options and changes						
	well	**rain**	**river**	**manual**	**sprinkling**	**drip**	**Total**
Original (X_1)	14.00	12.80	13.40	12.90	22.80	24.00	100.0
100% weight for economic criterion (X_2)	15.30	11.30	13.60	12.80	22.70	24.30	100.0
X_3: X_2 - X_1	+1.30	-1.50	+0.20	-0.10	-0.10	+0.30	
100% weight for social criterion (X_4)	14.90	13.30	14.70	13.10	21.90	22.10	100.0
X_5: X_4 - X_1	+0.90	+0.50	+1.30	+0.20	-0.90	-1.90	
100% weight for environmental criterion (X_6)	11.00	15.20	12.10	12.90	23.70	25.10	100.0
X_7: X_6 - X_1	-3.00	+2.40	-1.30	0.00	+0.90	+1.10	
X_8: $|X_3|$ +$|X_5|$ + $|X_7|$	5.20	4.40	2.80	0.30	1.90	3.30	
Equal weight for all criteria (X_9)	13.70	13.30	13.50	12.90	22.80	23.80	100.0
X_{10}: X_9 - X_1	-0.30	+0.50	+0.10	0.00	0.00	-0.20	

Table 6.2.2.2 Trade-offs of weights of irrigation methods (Xianyang) (Unit: Percentage)

Weight scenario for evaluation criteria	Priority ranking of irrigation options and changes						
	well	**rain**	**river**	**manual**	**sprinkling**	**drip**	**Total**
Original (X_1)	22.10	10.60	12.00	10.70	21.70	22.80	100.0
100% weight for economic criterion (X_2)	22.60	9.70	12.30	10.50	22.00	22.90	100.0
X_3: X_2 - X_1	+0.50	-0.90	+0.30	-0.20	+0.30	+0.10	
100% weight for social criterion (X_4)	24.70	12.60	12.70	10.50	19.40	20.00	100.0
X_5: X_4 - X_1	+2.60	+2.00	+0.70	-0.20	-2.30	-2.80	
100% weight for environmental criterion (X_6)	18.60	10.60	10.90	11.20	23.30	25.40	100.0
X_7: X_6 - X_1	-3.50	0.00	-1.10	+0.50	+1.60	+2.60	
X_8: $|X_3|$ +$|X_5|$ + $|X_7|$	6.60	2.90	2.10	0.90	4.20	5.50	
Equal weight for all criteria (X_9)	22.00	11.00	12.00	10.70	21.60	22.80	100.0
X_{10}: X_9 - X_1	-0.10	+0.40	0.00	0.00	-0.10	0.00	

Table 6.2.2.3 Trade-offs of weights of irrigation methods (Baoji) (Unit: Percentage)

Weight scenario for evaluation criteria	Priority ranking of irrigation options and changes						
	well	rain	river	manual	sprinkling	drip	Total
Original (X_1)	33.80	13.30	14.10	13.00	13.30	12.50	100.0
100% weight for economic criterion (X_2)	35.10	12.50	14.20	12.80	13.20	12.30	100.0
X_3: X_2 - X_1	+1.30	-0.80	+0.10	-0.20	-0.10	-0.20	
100% weight for social criterion (X_4)	31.70	16.50	14.40	13.00	12.70	11.70	100.0
X_5: X_4 - X_1	-2.10	+3.20	+0.30	0.00	-0.60	-0.80	
100% weight for environmental criterion (X_6)	29.00	13.60	13.60	14.10	14.80	14.80	100.0
X_7: X_6 - X_1	-4.80	+0.30	-0.50	+1.10	+1.50	+2.30	
X_8: $|X_3|$ +$|X_5|$ + $|X_7|$	8.20	4.30	0.90	1.30	2.20	3.30	
Equal weight for all criteria (X_9)	31.90	14.20	14.00	13.30	13.60	12.90	100.0
X_{10}: X_9 - X_1	-1.90	+0.90	-0.10	+0.30	+0.30	+0.40	

Table 6.2.2.4 Trade-offs of weights of irrigation methods (Weinan) (Unit: Percentage)

Weight scenario for evaluation criteria	Priority ranking of irrigation options and changes						
	well	rain	river	manual	sprinkling	drip	Total
Original (X_1)	14.10	13.10	12.20	12.80	23.70	24.10	100.0
100% weight for economic criterion (X_2)	13.80	12.50	11.90	12.60	24.40	24.90	100.0
X_3: X_2 - X_1	-0.30	-0.60	-0.30	-0.20	+0.70	+0.80	
100% weight for social criterion (X_4)	15.80	15.20	13.70	13.80	20.70	20.80	100.0
X_5: X_4 - X_1	+1.70	+2.10	+1.50	+1.00	-3.00	-3.30	
100% weight for environmental criterion (X_6)	13.70	13.10	11.80	12.80	24.10	24.60	100.0
X_7: X_6 - X_1	-0.40	0.00	-0.40	0.00	+0.40	+0.50	
X_8: $|X_3|$ +$|X_5|$ + $|X_7|$	2.40	2.70	2.20	1.20	4.10	4.60	
Equal weight for all criteria (X_9)	14.40	13.60	12.40	13.10	23.10	23.40	100.0
X_{10}: X_9 - X_1	+0.30	+0.50	+0.20	+0.30	-0.60	-0.70	

6.3 Summary

This chapter presents peasants from four major city-regions Xi'an, Xianyang, Baoji, and Weinan in Guanzhong Plain, their preferences of agricultural irrigation methods with respect to various economic, social, and environmental factors. Also the potential trade-offs they might face with if the sustainability of the agricultural food production system requires optimization.

The results indicate that in general, the agricultural irrigation system in Guanzhong Plain mainly adopts water-saving and well-irrigation techniques by peasants. By contrast, water pumping from the rivers, manual irrigation, and using natural precipitation, such irrigation methods are less preferred while economic, social benefits, and environmental impacts are simultaneously considered. As for the regional variation, it is resulted from regional economic disparity. Normally regional economic disparity is caused by different economic base, geographical location, resource endowment, production factors, and industrial structure. Xianyang, from adjacent geographical location, resource endowment, to describing as the existence of satellite city, has shared lots of similarities with Xi'an. It is not surprised to find out that peasants from these two cities share similar ideas. Weinan and Baoji are less developed, while the selection of agricultural irrigation techniques in Weinan seems more advanced than Baoji. Main cause can be attributed to peasants in Weinan do have higher average income than Baoji. The results also show that peasants from different city-regions may adjust their preferences according to their different economic, social demands, and environmental concerns.

Sensitivity analysis suggests that the priorities of agricultural irrigation methods' selection may change if the weights of evaluation attributes are altered. The results show

that pumping water from rivers and manual irrigation are not sensitive. This indicates that such techniques are mature with the support from governments, peasants' preference are basically unconverted. While well-irrigation, natural precipitation, and water-saving irrigation of sprinkling and dripping are sensitive in various degree to economic, social, and environmental decision attributes. The hypothetical scenario results show that if the sustainability of current Central Shaanxi's agricultural irrigation system is required to be optimized, the trade-offs peasants may face with will be mainly between water-saving irrigation techniques of sprinkling and dripping, and well-irrigation.

Chapter Seven

7 Conclusions

7.1 Contributions to the Literature

Conventional agricultural practices have caused widespread environmental degradations over the last several decades, threatening the long term viability of farming globally. Moving towards sustainable agriculture is topped the agenda of most developing countries in initiating agricultural development policies. It is crucial to understand how local peasants perceive various goals associated with sustainable agriculture in order to make the public policies effective because peasants are most affected by any public policies. Taking Guanzhong Plain in Shaanxi, China as a case study, this study has attempted to evaluate the sustainability of agricultural food production system by considering economic, social, and environmental goals simultaneously, and evaluating available options in agricultural land-use and irrigation practices.

The aspects used to evaluate the sustainability of agricultural production system in this study fall into the economic, social, and environmental dimensions. These three dimensions have been well-known and well-used in the literature (Bernués, 2016; Dillon, 2010; Malanson, 2014; Xu, 2012). Under the sustainable dimensions, the selection of decision attributes depends upon the scale of evaluation, because so far there is no consensus about what parameters can be used to accurately calculate or measure the level of sustainability in agricultural production (Below, 2012; Caviglia, 2001; Jain, 2015; Pannell, 1999). This study adopts nine decision attributes under three sustainability criteria draw on the literature.

Compared to other integrated assessment methods, Analytic Hierarchy Process

(AHP) method aims to help decision-makers reach optimized decision by finding one among many options that suit their goal and understanding the best (Satty, 1990; Yin, 2004). AHP has its advantages to deal with the sustainability assessment of agriculture by structuring hierarchical models consider multiple objectives, incorporation imprecise, and uncertain information simultaneously (Karami, 2006; Mosadeghi, 2015; Satty, 1990). According to Zhang (2014a, 2014b), AHP also has a few deficiencies such as the decision-making was relied on subjective judgement, it might be difficult to reach a consensus if there are many decision-makers involved.

An important finding of this study is that peasants value economic benefits more than social benefits and environmental impacts in assessing agricultural sustainability. In particular, peasants under study value crop yield and agricultural income improvement the most. Such a result is expected, as it is generally consistent with the findings in the literature. For example, Wei and Gu (2005) provided a ranking of the sustainability levels of agricultural sub-systems. They suggested that in Hebei Province, agricultural outputs system is prioritized the most, which is closely followed by the agricultural economy system, agricultural technology, and agricultural ecology sub-systems. They indicated that agricultural society sub-system is ranked the least. Gu (2004) and Xu et al. (2012) also found that economic benefits were weighted higher than social and environmental dimensions in assessing agricultural sustainability by peasants in China. However, such a conclusion is not universally applicable, especially in environmentally sensitive areas. For example, in Iran where environmental conditions are much more harsh for agricultural production, environmental impacts have been weighted much more importantly than economic benefits in sustainable agricultural development (Rezaei, 2007).

This study also finds that there are some regional variations in weighting sustainability goals. For instance, peasants in Baoji stress much more economic benefits in their agricultural production than the other three regions, even if all four regions are located adjacently and have similar climate and soil conditions. The result may reflect the variation in economic development as Baoji has a relatively laggard development level of its agricultural economy in comparison to the other three regions. This pattern of regional variation is also revealed in the study by Zhang (2013). She discovered that peasants' agricultural income is influenced by different regional agricultural development levels in Guanzhong Plain. Compared to the other three regions, the level of agricultural development in Baoji is the lowest due to its relatively lower level in economic development, urbanization rate, and agricultural investments and inputs. The finding has also been shown by Li (2007). He evaluated the regional sustainability of agriculture using cluster analysis and sorted ten agricultural regions in Shaanxi into three clusters. The top cluster includes Xi'an, Xianyang, and Weinan which have a more developed agricultural economy with higher socioeconomic inputs. Baoji is the only city in the Guanzhong Plain that fell into the second cluster with a relatively low score in economic, social, and environmental sub-systems.

This study assessed the prioritization of crop land uses by peasants in association with their identified sustainable agricultural goals. The results show that peasants prioritize wheat and corn as the main grain crops, and fruit as the main cash crop. Such crop selection preferences are consistent with natural resource endowments and institutional factors in the study area. Wang (Wang, 2012) conducted an analysis of agricultural food production potential in Guanzhong Plain and concluded that photosynthetic and climatic conditions in

the area are suitable for growing wheat and corn. In particular, Baoji has the biggest productive potential for wheat and corn, followed by Weinan, Xianyang and Xi'an. Besides, Guanzhong Plain is also one of the important grain production bases in China. Governments have encouraged grain producers to grow grain crops by providing direct subsidies. Grain subsidies were first initiated back in 2004. On one hand, it aims at supporting peasants' initiative by increasing agricultural income. On the other hand, it is to increase agricultural land-use efficiency and prevent excessive land abandonment due to out-migration of able-bodied peasants to coastal cities (Gale, 2005).

It is not a surprise that fruit production is prioritized by the surveyed peasants in the study area. According to Geng's study (2011), that Shaanxi has become one of the major fruit production provinces in China because of its unique geographical advantages. The flourishment of fruit production in the region is also related to an important agricultural programme "Grain for Green" that was launched in 1999 in order to control soil erosion and increase vegetation cover. The "Grain for Green" programme requires peasants to convert slope agricultural land to tree plantation. Under the programme, governments in Shaanxi have transferred a huge amount of slope arable land to fruit orchards that can generate higher economic profits (Li, 2012). As such, fruits became the dominant cash crop in the study regions. The development of fruit production has made a great contribution to the development of regional agriculture and rural economy, and to the improvement of peasants' incomes. Studies have shown that peasants have been greatly motivated to produce fruits in the region (Geng, 2011). Given that people's standard of living in China is improving, demands for fruit products are expected to grow significantly. Therefore, the finding of this study indicates that prioritizing fruit production reflects the primary interest

of peasants in income improvement.

In addition to fruit production, this study finds that peasants also prioritize wheat and corn as the main grain crops. This is especially true in Baoji. Such crop selection reflects the values of concerns of peasants beyond income improvement in agricultural production. For instance, growing wheat or corn requires less economic and social inputs than fruit production; higher economic returns from fruit production might also mean higher risk stemming from market fluctuations or natural hazards. This finding is consistent with the results from Wang's (2012) research. In analyzing the driven force of cropland change, Wang indicated that socio-economic factors such as the amount of agricultural labour, amount and suitability of arable land, and agricultural consumption level, affect the selection of cropland use in Guanzhong Plain. Wheat or corn production requires shorter periods of growing time, less land, fewer working days, and less fertilizer inputs than fruit production. It also has a more stable product market backed by the state due to the concern of food security.

Due to varied perceptions, attitudes and values towards sustainable agricultural development, peasants select different options in agricultural land-use practices in the Guanzhong Plain. Such selection of land use mixes results in some wider implications. An over-emphasis on fruit production in more developed agricultural areas might lead to a reduction in grain production, which could threaten food security over the long run at a national level. As fruit production may take many years to mature, the over-supply of fruits might put the region in a risky situation due to market saturation and price fluctuation. In the less developed areas where wheat and corn production is dominantly preferred by peasants, the continuing agricultural subsidies from governments might challenge the long-

term economic viability of agricultural production. In fact, the unbalanced agricultural cropland-use patterns have become one of the major issues in ensuring food security and improving the agricultural economy (Su, 2010). Therefore, attention needs to be paid to optimize agricultural land-use in order to address the possible consequence of current agricultural production practices in the region.

The results of sensitivity analysis in this study indicate that the priorities of crop land use might change if the weights of evaluation criteria are altered. Especially, the rankings of fruit and vegetable is sensitive to weighting of the environmental impacts. However, the rankings of wheat and corn as the most preferred food crop species are not sensitive to any change. Such finding has once again indicated that peasants will not alter the unshakable position of growing wheat or corn as the main food-crop no matter how economic, social, or environmental criteria are weighted. The literature has also showed that even though the planting area of food crops shows a tendency of descending for the past few years, the total yield appears to the increasing (Ma, 2016). The rankings of soybean, canola, and cotton are a little more sensitive than grain crops. The literature, indicating that the expected returns of these crops are smaller than corn and the socioeconomic inputs of these crops are bigger than wheat (Guo, 2014), led to the rankings of soybean, canola, and cotton being more sensitive when considering economic benefits. Their rankings are similarly sensitive as wheat, but they are all more sensitive than corn when considering the environmental impacts. Studies have pointed out that the soil fertility and pH value requirements of growing canola, soybean, cotton, and wheat are relatively higher than growing corn (Guo, 2014; Ren, 2000a).

As for the prioritization of irrigation methods by peasants in association with their

identified sustainable agricultural goals, this study shows that peasants prefer water-saving irrigation techniques including sprinkling, drip irrigation, and well-irrigation. Correspondingly, pumping water from the rivers, manual irrigation, and natural rainfall are less preferred. The choices of irrigation methods conform to the availability of water resources in the region. Guanzhong Plain is one of the water-scarce areas in inland China. Studies indicate that developing water-saving irrigation techniques for sustainable water use have become the top priorities in the past two decades (Li, 2006; Pang, 2006; Ren, 2000b; Yin, 2013). In the study on the potential of agricultural water-saving in Guanzhong Plain, Yin et al. (2013) suggested that the amount of agricultural water-use in Guanzhong area is approximately equal to the available water quantity, and the total re-exploration potential of water is very limited. Using resource-oriented water-saving techniques, such as sprinkling and drip will improve water-use efficiency (Fuchs, 2006), and improving anti-seepage technology for transferring surface water will reduce the water loss during the process of agricultural production (Zeng, 2016). The results of this study also indicate that peasants are fully aware of the advantages of water-saving irrigation techniques and they prefer irrigation techniques that provide stable water supply and require less inputs in agricultural production. The strong awareness of water-saving technologies should give the credit to the advocacy of national and local governments who promote the water saving irrigation. As stated by Sun (Sun, 2013), a large part of peasants in Guanzhong agree that they have been exposed to water-saving technologies and have seen water-saving demonstration sites that are established by the governments.

Well-irrigation is ranked below water-saving irrigation of sprinkling and dripping. Although well-irrigation is given a high priority, it still remains a problematic irrigation

technique. According to Cao (2011), the water-use efficiency of well-irrigation is low during the process of agricultural production in the Guanzhong area. It is often associated with lacking of management regulation, inconsistent water rate, low technology and aged equipment, and the deficiency of ancillary water-carrying facilities. However, well-irrigation is still the irreplaceable agricultural irrigation method for peasants because it has a profoundly long cultural history in agricultural production and enjoys a wide application in Guanzhong Plain (Sun, 2005).

As for using relatively less preferred irrigation methods of using river-water, natural precipitation, and manual irrigation, a few studies have also generated some insights. As stated by Tang (Tang, 2010), more than 200 thousands of hydraulic engineering projects have provided certain amount of water for agricultural production in Guanzhong Plain. However, upstream water-pollution and overuse, as well as silt reservoirs have greatly affected downstream peasants' agricultural irrigation. Tang (2010) also analyzed the efficiency of irrigation water and he suggested outdated irrigation methods with low water-use efficiency such as manual irrigation and free-flooding irrigation are infeasible and unsustainable. It is because such irrigation methods will easily lead to a great waste of water and cause soil salinization and nutrition loss of soil. As for the rain water, Ren (2000b) indicated that high variability of natural precipitation influenced the environmental demand of cropland soil. Summer is the season with intensive precipitation in Guanzhong, yet the mean annual precipitation of Guanzhong Plain is only around 500-800mm. Such natural conditions become the driving force for peasants adopting more stable also affordable irrigation methods.

Combining the characteristics of irrigation methods with different socioeconomic

and geographical conditions, regional variation in peasants' preference of irrigation in this study seems to be reasonable. The result of this study shows that peasants from Xi'an, Xianyang, and Weinan prefer more water-saving techniques of sprinkling and drip-irrigation combined with well-irrigation and other methods, in terms of economic, social, and environmental concerns. While peasants from Baoji overwhelmingly adopt well-irrigation and using river-water and much less prefer water-saving irrigation techniques, even when considering environmental impacts. Tang (2010) and Sun (2013) both backed the reasons for different preferences for irrigation methods across these regions include different economic development level and different stages of agricultural modernization. Sun (Sun, 2013) also suggested that varied education background of peasants, different water price, and water use supervision mode have led to the divergent preferences of irrigation methods. Geographical location makes it possible for peasants from Baoji to be endowed with relatively more water resource than Xi'an, Xianyang, and Weinan (Hou, 2012), making the water price in Baoji lower than that in other three city-regions. Higher water price means peasants from Xi'an, Xianyang, and Weinan have grown stronger awareness of water-saving technologies. It is also indicated that peasants with higher educational background have stronger water-saving consciousness (Sun, 2013). They are more willing to participate in the water conservation and irrigation management (Azizi, 2009).

Due to varied accessibility of water, different economic development levels and attitudes toward sustainable agricultural development, peasants from Guanzhong Plain currently prefer varied irrigation methods in agricultural production. Such preferences of irrigation method present more implications. Water-saving irrigation technology might be

easier to extend in more developed agricultural regions than in less developed regions. For more developed agricultural regions, water is charged according to the amount of flow and duration with more accurate volumetric measurement and strict water-use supervision and monitoring. Such stricter mode of supervision and monitoring and higher water-price prompt peasants to pay more attention to save water in agricultural production. Peasants from less developed agricultural regions might not be easy to accept, psychologically and economically, the transformation of agricultural irrigation. High-tech water-saving irrigation technique means more economic inputs. Generally speaking, poor water-delivery facilities and low efficiency of water-use are the main problems of agricultural utilization of water resources (Tang, 2010). Therefore, attention needs to be paid by the water conservation authorities to optimize agricultural water conservation in order to address possible consequences of current agricultural water-use practices in the study area.

Sensitivity analysis for irrigation methods in this study indicates that the priorities of agricultural watering techniques might also change if the weights of evaluation criteria are altered. The rankings of water-saving irrigation techniques are sensitive to social benefits, and the ranking of well-irrigation is greatly sensitive to the environmental impacts. This finding has indicated that peasants will prefer well-irrigation in consideration of socioeconomic benefits. Many studies have argued that well irrigation is part of a long historical culture and serves as a mechanism to bind peasants together in rural Guanzhong. It is widely used because it requires low socioeconomic inputs (Sun, 2005; Yang, 2011). Also peasants prefer sprinkling and drip irrigation in consideration of the environmental impacts instead of well-irrigation, as the advantages of water-saving irrigation techniques have been widely mentioned (Bjornlund, 2009; Hu, 2012; Levidow, 2014; Xu, 2008).

While pumping water from the rivers and manual irrigation are mature agricultural watering methods, they will be insensitive to any priority change in terms of the focus of sustainable agriculture (Zhang, 2015).

In summary, this research offers an important perspective about how peasants prioritize economic benefits, social benefits, and environmental impacts in agricultural production in rural China. In practicing sustainable agriculture, peasants' preferences for agricultural land-use is mainly focused on wheat, corn, and fruit; their preferences for agricultural irrigation methods are sprinkling and drip techniques in combination with well-irrigation and river-water. By using the Analytic Hierarchy Process (AHP) approach, peasants' trade-offs of agricultural cropland and water use might exist between food crops and cash crops, and between water-saving irrigation and other kinds of less water-saving watering methods. These findings contribute to the literature in suggesting that 1) it is necessary and significant to consider all economic, social, and environmental aspects of agricultural production simultaneously for sustainable development; 2) selecting appropriate economic, social, and environmental decision attributes can help generate insights into peasants' concerns during the process of agricultural production; 3) sensitivity analysis can generate the underlying trade-offs among different cropland uses and water use methods, providing policy-makers with valuable information about peasants' preferences and interests, so that public policies about sustainable agriculture can be implement feasibly and effectively.

7.2 Implication for Public Policies

This case study provides policy-makers and governments with information to formulate and implement public policies about sustainable agriculture in the Guanzhong

Plain and beyond. Because the surveyed peasants have all been involved in agricultural production, their prioritization of the economic, social, and environmental goals, and the trade-offs about cropland uses and choice of irrigation methods need to be fully considered when sustainable agricultural production is concerned. The sustainable development of agricultural production requires long-term efforts to be made by both peasants and governments. On the one hand, peasants need to be informed about the importance of sustainable agricultural production. On the other hand, governments and agricultural authorities should provide peasants with more resources to balance their benefits and address their concerns.

Firstly, this study indicates grain production, especially growing wheat and corn, is prioritized by peasants in the study area. Given the fact that the profit margins in grain-crop farming are generally low and sometimes peasants are even operating at losses when the fluctuation of market price results in negative net returns of grain crops, the continuation of providing financial subsidies might be necessary in order to take away peasants' a few risks so that national food security as well as stability of food supply can be guaranteed.

Secondly, this study identified that soybean is ranked much lower than corn and wheat. For the purpose of sustaining soil productivity, measures should be taken to encourage mixed cropping, such as grain-soybean rotation. Especially for those who might respond to the change for sustainable agriculture policies, encouraging subsidies will ease their worries of income and yield decreasing. As for those peasants do not have experiences for crop rotation, related trainings on the crop-rotation should be provided.

Thirdly, it is important to strengthen water-saving awareness among peasants and provide economic incentives to shift to water saving irrigation methods. Peasants in the

area with lower water-price and less supervision on water waste tend to prefer the low economic-cost irrigation methods. It is important to provide water-saving incentives and technical supports from governments to promote sustainable water use in agriculture. In combination with cropping structure, governments may encourage peasants to adopt less water-input but still high-profit crops.

Finally, the study indicates the current peasants are less concerned about agricultural impacts on the environment but more concerned about economic benefits. It is essential to educate peasants about sustainable agricultural practices, otherwise excessive damage to the environment might jeopardise the economic viability and social harmony over the long haul. It is also important to keep peasants updated about the latest agricultural information. For example, rural peasants, especially those elder and less educated peasants, might lack the latest information on market demand. Timely information on market demands of grain crops or cash crops could help prevent over-supply of produce and the consequences of potential market price fluctuation.

7.3 Future Research Opportunities and Considerations

This study offers only a surface glance at peasants' priorities of agricultural land-use and irrigation methods when considering nine decision attributes under economic, social, and environmental evaluation criteria. Agricultural systems are open and complex system that embraces various sub-systems, and hence decision attributes of sustainable evaluation criteria can vary from different scales of assessment. There is much room to discover more and suitable decision attributes to understand the sustainable agricultural systems across different scales.

Additionally, this study conducted an integrated assessment of sustainable

agricultural production based on peasants' perceptions, and results can provide valuable information about peasants' interests for policy-makers to better implement sustainable ideas in public policies. However, the results of this study are generated from Guanzhong Plain. Findings and implication for public policies of this study might applicable to sustainable agricultural food production systems in other Western inland provinces with similar geographic and environmental conditions, and similar agricultural cropland and irrigation structure, such as those in Shaanxi province, Inner-Mongolia, Gansu, and Xinjiang province. It might not applicable to those Eastern coastal regions with an advanced level of agricultural sustainability, strong agricultural policy-support from governments, and high educational background of peasants, such as Jiangsu, Zhejiang, and Heilongjiang Province. It would be better to combine the practical rural and agricultural situation into the sustainability assessment.

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Appendix One - AHP Questionnaire

In our survey, the intensity of importance of criteria or crop types is expressed by numbers of 1 to 9. Odd numbers 1, 3, 5, 7 and 9 are more often used in pairwise comparing process. The intensity of importance, definition and explanation are presented as follows. Please check mark ("√") under the corresponding number.

The Fundamental Scale for Pairwise Comparisons		
Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favor one element over another
5	Strong importance	Experience and judgement strongly favor one element over another
7	Very strong importance	One element is favored every strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance.		

In AHP survey, the bold font words in the end of the first sentence are goal of the question. Given Element Pairs A & B to each goal, judge their relative importance as below, read off the equivalent number. Use even numbers for intermediate discrimination.
Row A, Column B
If A and B are **equally important** to the goal, then select **1**
If A is **weakly more important** to the goal than B, then select **3**
If A is **strongly more important** to the goal than B, then select **5**
If A is **very strongly more important** to the goal than, B then select **7**
If A is **absolutely (extremely) more important** to the goal than B, then select **9**

1. Evaluation criteria and decision attributes

a. Evaluation criteria. Please select the intensity of importance of criteria for **sustainable food production**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Economic benefits																		Social benefits
Economic benefits																		Environmental impacts
Social benefits																		Environmental impacts

b. Decision attributes in economic benefits. Please select the intensity of importance for **Economic benefits**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Improve yield																		Improve income
Improve yield																		Improve water use efficiency
Improve income																		Improve water use efficiency

c. Decision attributes in social benefits. Please select the intensity of importance for **Social benefits**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Improve household life style																		Improve community cohesion
Improve household life style																		Improve recreation
Improve community cohesion																		Improve recreation

d. Decision attributes in Environmental impacts. Please select the intensity of importance for **Environmental impacts**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Chemical runoff and leaching prevention																		Reducing Water withdrawal from the river
Chemical runoff and leaching prevention																		Soil erosion prevention
Reducing water withdrawal from the river																		Soil erosion prevention

1.2 Crop type options.
a. Improve yield.
Please select the intensity of importance of crop type for **improving yield**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wheat																		Corn
Wheat																		Canola
Wheat																		Soybean
Wheat																		Cotton
Wheat																		Fruit
Wheat																		Vegetable
Corn																		Canola
Corn																		Soybean
Corn																		Cotton
Corn																		Fruit
Corn																		Vegetable
Canola																		Soybean
Canola																		Cotton
Canola																		Fruit
Canola																		Vegetable
Soybean																		Cotton
Soybean																		Fruit
Soybean																		Vegetable
Cotton																		Fruit
Cotton																		Vegetable
Fruit																		Vegetable

b. Improve farm income.
Please select the intensity of importance of crop type for **improving income**

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wheat																		Corn
Wheat																		Canola
Wheat																		Soybean
Wheat																		Cotton
Wheat																		Fruit
Wheat																		Vegetable
Corn																		Canola
Corn																		Soybean
Corn																		Cotton
Corn																		Fruit
Corn																		Vegetable
Canola																		Soybean
Canola																		Cotton
Canola																		Fruit
Canola																		Vegetable
Soybean																		Cotton
Soybean																		Fruit
Soybean																		Vegetable
Cotton																		Fruit
Cotton																		Vegetable
Fruit																		Vegetable

c. Improve water use efficiency.

Please select the intensity of importance of crop type for **improving water use efficiency**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wheat																		Corn
Wheat																		Canola
Wheat																		Soybean
Wheat																		Cotton
Wheat																		Fruit
Wheat																		Vegetable
Corn																		Canola
Corn																		Soybean
Corn																		Cotton
Corn																		Fruit
Corn																		Vegetable
Canola																		Soybean
Canola																		Cotton
Canola																		Fruit
Canola																		Vegetable
Soybean																		Cotton
Soybean																		Fruit
Soybean																		Vegetable
Cotton																		Fruit
Cotton																		Vegetable
Fruit																		Vegetable

d. Improve household life style.

Please select the intensity of importance of crop type for **improving household life style**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wheat																		Corn
Wheat																		Canola
Wheat																		Soybean
Wheat																		Cotton
Wheat																		Fruit
Wheat																		Vegetable
Corn																		Canola
Corn																		Soybean
Corn																		Cotton
Corn																		Fruit
Corn																		Vegetable
Canola																		Soybean
Canola																		Cotton
Canola																		Fruit
Canola																		Vegetable
Soybean																		Cotton
Soybean																		Fruit
Soybean																		Vegetable
Cotton																		Fruit
Cotton																		Vegetable
Fruit																		Vegetable

e. Improve community cohesion.

Please select the intensity of importance of crop type for **improving community cohesion**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wheat																		Corn
Wheat																		Canola
Wheat																		Soybean
Wheat																		Cotton
Wheat																		Fruit
Wheat																		Vegetable
Corn																		Canola
Corn																		Soybean
Corn																		Cotton
Corn																		Fruit
Corn																		Vegetable
Canola																		Soybean
Canola																		Cotton
Canola																		Fruit
Canola																		Vegetable
Soybean																		Cotton
Soybean																		Fruit
Soybean																		Vegetable
Cotton																		Fruit
Cotton																		Vegetable
Fruit																		Vegetable

f. Improve recreation condition.

Please select the intensity of importance of crop type for **improving recreation condition**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wheat																		Corn
Wheat																		Canola
Wheat																		Soybean
Wheat																		Cotton
Wheat																		Fruit
Wheat																		Vegetable
Corn																		Canola
Corn																		Soybean
Corn																		Cotton
Corn																		Fruit
Corn																		Vegetable
Canola																		Soybean
Canola																		Cotton
Canola																		Fruit
Canola																		Vegetable
Soybean																		Cotton
Soybean																		Fruit
Soybean																		Vegetable
Cotton																		Fruit
Cotton																		Vegetable
Fruit																		Vegetable

g. Chemical runoff and leaching prevention.

Please select the intensity of importance of crop type for **preventingchemical runoff and leaching**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wheat																		Corn
Wheat																		Canola
Wheat																		Soybean
Wheat																		Cotton
Wheat																		Fruit
Wheat																		Vegetable
Corn																		Canola
Corn																		Soybean
Corn																		Cotton
Corn																		Fruit
Corn																		Vegetable
Canola																		Soybean
Canola																		Cotton
Canola																		Fruit
Canola																		Vegetable
Soybean																		Cotton
Soybean																		Fruit
Soybean																		Vegetable
Cotton																		Fruit
Cotton																		Vegetable
Fruit																		Vegetable

h. Reducing water withdrawal from the river.

Please select the intensity of importance of crop type for **reducing water withdrawal from river.**

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wheat																		Corn
Wheat																		Canola
Wheat																		Soybean
Wheat																		Cotton
Wheat																		Fruit
Wheat																		Vegetable
Corn																		Canola
Corn																		Soybean
Corn																		Cotton
Corn																		Fruit
Corn																		Vegetable
Canola																		Soybean
Canola																		Cotton
Canola																		Fruit
Canola																		Vegetable
Soybean																		Cotton
Soybean																		Fruit
Soybean																		Vegetable
Cotton																		Fruit
Cotton																		Vegetable
Fruit																		Vegetable

i. Soil erosion prevention.

Please select the intensity of importance of crop type for **preventing soil erosion**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Wheat																		Corn
Wheat																		Canola
Wheat																		Soybean
Wheat																		Cotton
Wheat																		Fruit
Wheat																		Vegetable
Corn																		Canola
Corn																		Soybean
Corn																		Cotton
Corn																		Fruit
Corn																		Vegetable
Canola																		Soybean
Canola																		Cotton
Canola																		Fruit
Canola																		Vegetable
Soybean																		Cotton
Soybean																		Fruit
Soybean																		Vegetable
Cotton																		Fruit
Cotton																		Vegetable
Fruit																		Vegetable

1.3 Water use technology options.

a. Improve yield.
Please select the intensity of importance of water use technology for **improving yield**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Well																		Rain
Well																		River Pump
Well																		Manual
Well																		Sprinkling
Well																		Drip
Rain																		River Pump
Rain																		Manual
Rain																		Sprinkling
Rain																		Drip
River Pump																		Manual
River Pump																		Sprinkling
River Pump																		Drip
Manual																		Sprinkling
Manual																		Drip
Sprinkling																		Drip

b. Improve income.
Please select the intensity of importance of water use technology for **improving income**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Well																		Rain
Well																		River Pump
Well																		Manual
Well																		Sprinkling
Well																		Drip
Rain																		River Pump
Rain																		Manual
Rain																		Sprinkling
Rain																		Drip
River Pump																		Manual
River Pump																		Sprinkling
River Pump																		Drip
Manual																		Sprinkling
Manual																		Drip
Sprinkling																		Drip

c. Improve water use efficiency.

Please select the intensity of importance of water use technology for **improving water use efficiency**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Well																		Rain
Well																		River Pump
Well																		Manual
Well																		Sprinkling
Well																		Drip
Rain																		River Pump
Rain																		Manual
Rain																		Sprinkling
Rain																		Drip
River Pump																		Manual
River Pump																		Sprinkling
River Pump																		Drip
Manual																		Sprinkling
Manual																		Drip
Sprinkling																		Drip

d. Improve household life style.

Please select the intensity of importance of water use technology for **improving household life style**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Well																		Rain
Well																		River Pump
Well																		Manual
Well																		Sprinkling
Well																		Drip
Rain																		River Pump
Rain																		Manual
Rain																		Sprinkling
Rain																		Drip
River Pump																		Manual
River Pump																		Sprinkling
River Pump																		Drip
Manual																		Sprinkling
Manual																		Drip
Sprinkling																		Drip

e. Improve community cohesion.

Please select the intensity of importance of water use technology for **improving community cohesion**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Well																		Rain
Well																		River Pump
Well																		Manual
Well																		Sprinkling
Well																		Drip
Rain																		River Pump
Rain																		Manual
Rain																		Sprinkling
Rain																		Drip
River Pump																		Manual
River Pump																		Sprinkling
River Pump																		Drip
Manual																		Sprinkling
Manual																		Drip
Sprinkling																		Drip

f. Improve recreation condition.

Please select the intensity of importance of water use technology for **improving recreation condition**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Well																		Rain
Well																		River Pump
Well																		Manual
Well																		Sprinkling
Well																		Drip
Rain																		River Pump
Rain																		Manual
Rain																		Sprinkling
Rain																		Drip
River Pump																		Manual
River Pump																		Sprinkling
River Pump																		Drip
Manual																		Sprinkling
Manual																		Drip
Sprinkling																		Drip

g. Chemical runoff and leaching prevention.
Please select the intensity of importance of water use technology for **preventingchemical runoff and leaching**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Well																		Rain
Well																		River Pump
Well																		Manual
Well																		Sprinkling
Well																		Drip
Rain																		River Pump
Rain																		Manual
Rain																		Sprinkling
Rain																		Drip
River Pump																		Manual
River Pump																		Sprinkling
River Pump																		Drip
Manual																		Sprinkling
Manual																		Drip
Sprinkling																		Drip

h. Water withdrawal from river reduction.
Please select the intensity of importance of water use technology for **reducing water withdrawal from river.**

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Well																		Rain
Well																		River Pump
Well																		Manual
Well																		Sprinkling
Well																		Drip
Rain																		River Pump
Rain																		Manual
Rain																		Sprinkling
Rain																		Drip
River Pump																		Manual
River Pump																		Sprinkling
River Pump																		Drip
Manual																		Sprinkling
Manual																		Drip
Sprinkling																		Drip

i. Soil erosion prevention.

Please select the intensity of importance of water use technology for **preventing soil erosion**.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Well																		Rain
Well																		River Pump
Well																		Manual
Well																		Sprinkling
Well																		Drip
Rain																		River Pump
Rain																		Manual
Rain																		Sprinkling
Rain																		Drip
River Pump																		Manual
River Pump																		Sprinkling
River Pump																		Drip
Manual																		Sprinkling
Manual																		Drip
Sprinkling																		Drip

Appendix Two - Family and farm information

1. Please provide your permanent address: _____

2. Year of Birth:_____

3. Gender:_____

4. What is the highest level of education achieved?
       A. Primary School and under
       B. Middle School
       C. High School
       D. College and above

5. How much of your net household income is derived from the use of your land (percentage)?
       A. 0% to less than 25%
       B. 25% to less than 50%
       C. 50% to less than 75%
       D. 75% to less than 100%
       E. 100%
       F. Not applicable

6. How many cultivated-area did you plant in 2014?
       A. Under 10 mu
       B. 11 to 30 mu
       C. 31 to 50 mu
       D. 51 to 100 mu
       E. Over 100 mu