Chapter 3

Cropping Choices and Farmers' Options

Irrigation being the main cause of aquifer depletion, agriculture is the first candidate to contribute to its solution. Options of agricultural planting structure in Beijing-Tianjin-Hebei region are analyzed using various planting scenarios. The analysis shows that when addressing only the region's self-sufficiency in food, planted area can be reduced by 26%, eradicating over-pumping but decreasing farmers' revenue by 50%. No realistic agricultural strategy can eliminate over-pumping in North China Plain without water transfers from the South. Farmers' reaction to policies plays an important role regarding their efficiency. The implementation status and effects of seasonal land fallowing in Hebei Province were evaluated in a field survey of 560 farm households showing that the subsidy is welcome, and farmers are eager to participate in the program. However, more than half of the farmers will go back to winter wheat growing if the subsidy is decreased or discontinued. The groundwater game "Save the Water" was played with farmers in Guantao. Results showed that the farmers are not so much led by profit optimization as by customs and inertia against change. They, however, reacted strongly to the visualized decline of groundwater levels, which indicates that appropriate information may induce behavioral change.

Electronic supplementary material The online version of this chapter (https://doi.org/10.1007/978-981-16-5843-3_3) contains supplementary material, which is available to authorized users.

3.1 Options of Optimizing Crop Structure in Hebei-Beijing-Tianjin Region

3.1.1 Introduction

The Beijing-Tianjin-Hebei (BTH) Plain is the area of most serious groundwater depletion in China (Feng et al. 2013, 2018). In the piedmont plain of the Taihang Mountains the groundwater level dropped most rapidly. It is estimated that its shallow aquifer under present abstractions could be depleted to its physical limit within the next 80 years (Zhang et al. 2016). Hebei Plain has become one of the most vulnerable areas in China and possibly worldwide (Wang et al. 2015).

Food production in the BTH area, the main cause of groundwater overexploitation, increased continuously and today exceeds the region's total food requirements by far. The grain surplus in the region is 49% of the total grain production, if only considering the food grain requirement. It is 9% of the total production if the requirements of the region for feed grain used in the production of meat, eggs and milk are also included. Meanwhile, the surplus amounts of fruit, vegetables, eggs, milk and aquatic products are all more than 50% of the respective production in BTH region (Fig. 3.1). According to the national estimates on water resources and water use, the BTH region overexploited groundwater resources on average by 6.7 Bio. m³/year between 2005 and 2015. Since 2014, the imports of surface water through the SNWT project have to a large part replaced groundwater use by households and industry, leaving a deficit mainly due to agricultural groundwater use. It is estimated to be about 4.4 Bio. m³/year (or 65% of the overexploitation between 2005 and 2015), which still makes both water resources use and agricultural production unsustainable.

Irrigation of the intensifying cropping system has become the main cause for serious groundwater depletion. Before the 1970s, Hebei Plain was a dry-land farming area dominated by wheat and millet, without any problem of groundwater overexploitation. Since the 1970s, however, with the improvement of irrigation conditions, the planting system gradually developed in intensity from one harvest per year via

Fig. 3.1 Annual food supply, demand and surplus of households in Beijing-Tianjin-Hebei region (in 10,000 tons) *Source* (Luo 2019)

Fig. 3.2 Development of crop production according to sown area (in 10,000 hectares)(left) and annual yield (in 10'000 tons) (right) of crops in Beijing-Tianjin-Hebei region between 1980 and 2015 *Source* (Luo 2019)

three harvests in two years, and four harvests in three years into a high-intensity irrigated agricultural production mode, which is dominated by a winter wheat-summer maize double cropping system with two harvests in a year (Xiao et al. 2013; Wang et al. 2012; Mo et al. 2009).

The planting structure of crops has changed remarkably in the past 35 years. It has become simpler with respect to the crop variety while the crop yield has greatly improved (Fig. 3.2). A planting mode dominated by wheat, maize, fruit, and vegetables evolved. The water consumption of well-watered winter wheat, the main food crop, is approximately 420–430 mm (Shen et al. 2013; Zhang et al. 2011), but the precipitation in its growth season is less than 150 mm (1963–2013), leading to a water deficit of approximately 270–280 mm. For the economic crops, such as vegetables and fruit, the precipitation is also less than their water consumption during the growth period. Green house planting can consume considerably more water per year than any other cropping pattern (including double cropping of winter wheat and summer maize) due to its water intensive vegetable and fruit cultures and its multiple cropping all year round.

As the scale of irrigation expanded, groundwater consumption also increased (Cao et al. 2013). In the period of 1984–2008, 139 Bio. m³ of groundwater have been consumed by grain production in Hebei Province (Yuan and Shen 2013). In the BTH region, the current irrigated planting area has exceeded the carrying capacity of the region's water resources. Therefore, a reduction in the irrigated planting area has become the key to achieving the required massive water saving on a regional scale. Its implementation is an urgent task.

Reducing or replacing high water consumption crops (such as winter wheat, vegetables, and fruit) is the most efficient way to save water. There are two ways to downsize the irrigation area: one is to de-intensify the cropping system, changing the conventional winter wheat and summer maize double cropping system to a cropping system of for example three harvests in two years (Luo et al. 2018); the other

is to optimize the planting structure in terms of economic output under different constraints (Luo 2019).

In this study, the bearing capacity of water resources, the food requirements of BTH region and the self-sufficiency of the region in the main agricultural products were considered as constraints. Four scenarios with different objectives for optimization were defined. Using the Elitist Non-dominated Sorting Genetic Algorithm (NSGA-II), the planting structure was optimized with respect to economic benefits for each of the four objectives, quantifying the optimal planting structure, its water use, and its crop production. The goal was to explore a sustainable planting structure in a tradeoff between water resources requirements and agricultural production, providing a policy basis for the sustainable utilization of water resources and regional food security in the BTH region.

3.1.2 Optimization Scenarios

Four simulation scenarios for optimizing the planting structure were defined. The results are described in terms of water use, land use, and the value of economic output. Apart from the first scenario, which could be reached by 2030 given current trends, the scenarios are not predictions but rather benchmarks, against which actual policy can be calibrated. Therefore, no time scales for their implementation are given.

Scenario I (current development trend): This scenario assumes that the planting structure of crops will evolve according to current trends without being affected by a macro-control and management policy.

Scenario II (self-sufficiency in the main agricultural products): In this scenario, the planting structure of crops will depend on the needs defined by self-sufficiency of BTH region in the main agricultural products (excluding rice).

Scenario III (maximum grain output under the constraints of water resources): In this scenario, the planting structure of crops aims at the maximum grain output scale which can be supported by the water resources available in the area in view of satisfying national grain security requirements.

Scenario IV (coordination of grain crops, cash crops and water needs): In this scenario, the optimized planting structure will be constrained by the scale needed to ensure grain self-sufficiency of the area (total amount of wheat and rice) while maximizing the economic output.

Detailed information on the formulation of the objectives can be found in (Luo 2019; Luo et al. 2021). The following sections will discuss scenario by scenario the results, which are summarized in Table 3.1.

Table 3.1 Optimization scenarios of planting structure in Beijing-Tianjin-Hebei (BTH) region (Luo 2019; Luo et al. 2021)

Scenarios	Current status	Optimization results			
	S0	S1	S2	S3	S4
Total planting area (10^6 ha)	10.17	9.93	7.48	7.35	9.55
Irrigation water consumption (10^9 m ³ /year)	12.3	11.3	6.6	5.6	10.5
Economic benefit (10^9 CNY/year)	239.9	239.1	118.6	117.7	213.7

Note: S1—Current trend scenario; S2—regional self-sufficiency in agricultural products; S3—maximum grain output; S4—coordination of grain crops, cash crops and water need

3.1.3 Scenario Analysis of Planting Structure Optimization

Scenario of the current development trend

The first scenario (S1) predicts the future crop planting structure based on current trends in the BTH region. The scenario will result in 2% reduction in the sown area of major crops in the Hebei Plain.

Under the current development trend scenario, the future planting structure will be more water efficient. Major crops in the BTH region can reduce water consumption in total by 1.0 Bio. m³/year compared to the current total amount (Table 3.1). In addition, the total grain output will increase by 5% with no significant change in economic benefits. The reduction in irrigation water use can reduce groundwater overexploitation to some extent, but it is still far from solving the problem of groundwater overexploitation in the BTH-region.

Scenario of self-sufficiency in the main agricultural products

The maximum potential for water conservation resulting from scenario S2 is an important reference for the formulation of any agricultural and water policy in the BTH region. Under this scenario, the sown area of major crops in the region will be reduced to 7.48 Mio. ha, a reduction of 2.69 Mio. ha (or 26%) compared to the current status. The total grain output will decrease by 11%.

The total amount of water saved by major crops relative to the current planting structure is 5.7 Bio. m³/year, which may be the maximum potential for water conservation in the BTH region, when only the region's local demand for major food crops is considered.

Comparing to the estimated overexploitation of the BTH region, regional self-sufficiency can solve the problem of groundwater over-abstraction without additional surface water import by the SNWT Project. In this scenario, the economic benefit will decrease by about 50%, while a balance between exploitation and replenishment of groundwater used for farming will be achieved. This scenario can eliminate agricultural groundwater overexploitation.

Scenario of maximum grain output under water resources constraints

The maximum wheat production, which can be supported by regional water resources (S3), is an important basis for determining the maximum scale of agricultural production under a balanced groundwater budget. Based on the national data on current water resources, the mean regional water resources available in the BTH region are 18.8 Bio. m³/year (average 2005–2015). To maximize wheat production, other major crops with water deficits during the growth period (including vegetables, fruit, cotton, oil crops and potatoes) are constrained by the food consumption needs of the area to ensure that maximum water resources are left for wheat irrigation. Under this scenario, the maximum wheat planting scale that can be supported by regional water resources is 1.48 Mio. ha, equivalent to about 60% of the status quo wheat planting scale.

In this scenario, regional water resources are used as the limit of water consumption to balance exploitation and replenishment of groundwater. The total sown area of crops will decrease by 28% and the total grain output by 13%. The economic output will be reduced, while water saving will balance out the estimated regional overexploitation by agriculture, resulting in a sustainable use of regional agricultural water resources.

Scenario of coordination of grain crops, cash crops and water requirements

The coordinated development of grain crops, cash crops and water use (S4) has long been an issue of great concern in the optimization of planting structures. The scenario optimizes the planting structure by demanding self-sufficiency in food crops for the region (total demand for rice and wheat, where the rice deficit is converted into wheat), groundwater protection, and economic benefits as the critical criteria for the development. The results show a 6% reduction in the crop planting scale relative to the current cropping structure. Wheat, rice, vegetables, and fruit roughly maintain a scale similar to the current planting structure, which can meet the regional requirement for food (wheat and rice), save water and largely secure economic benefits. Therefore, the current planting structure is a relatively reasonable planting structure if one does not take restrictions on water resources into account.

The scenario can save 1.8 Bio. m³/year of water relative to the current planting structure. It can mitigate the problem of groundwater overexploitation, but the water saved is much less than the estimated 4.4 Bio. m³/year of overexploitation. Therefore, other water sources are still required for a balanced groundwater budget, while meeting the demand for food crops and economic output.

3.1.4 Conclusion and Discussion

The water deficits of the major crops—wheat, vegetables, and fruit—account for about 90% of the total groundwater consumption in farming. Different planting structure scenarios can alleviate groundwater overexploitation with the amount of

water saved ranging from 1.0 Bio. m³/year to 6.7 Bio m³/year. The sown area of major crops must be reduced by 2% to 28%, and the scale of winter wheat, a major crop of high groundwater consumption, by 8% to 41% of the current scale. Changes in food production over the scenarios range from 5% increase to 13% decrease, while the reduction in direct economic output in farming ranges from 0.3% to 51%.

Overall, self-sufficiency in the main agricultural products (S2) can meet the regional self-sufficiency in agricultural production and water saving under this scenario is sufficient to achieve a balance between exploitation and replenishment in agricultural water use. Maximum food output under water resource constraints (S3) results in a planting structure scenario with a relatively high degree of sustainability in agricultural water use and a relatively high regional grain self-sufficiency. The two scenarios (S2 and S3) are the preferred optimized planting structures for the BTH region.

The above scenarios provide reference thresholds for restructuring of the planting system to achieve sustainable use of agricultural water resources. They show how big the contribution of agricultural restructuring to sustainable groundwater use can theoretically be and what this means in terms of production and farmers' income. Sustainability in groundwater resources could be reached by agricultural restructuring alone, but it would come with a high price tag regarding farmers' income. In comparison to an income loss on the order of 100 Bio. CNY/year, the cost of additional 2–3 Bio. m³/year of SNWT-water at a price of 2–3 CNY/m³ seems affordable. It also must be noted that no scenario can achieve the national goals of grain security **and** a balanced groundwater budget at the same time without additional water imports through the SNWT project.

In practice, the adoption of an optimized crop structure will depend on farmers' behavioral traits as well as yield and market forces and willingness to pay for the water resources. To a certain degree the process can be steered by the state through subsidies, be it on agricultural products, fallowing, water saving technology, or through the water price itself.

3.2 Farmers' Feedback in a Household Survey on Seasonal Land Fallowing

A large-scale field survey was conducted in four prefectures in Southern Hebei Province from April 2018 to September 2019 by the China Center for Agricultural Policy (CCAP) of Peking University. The four prefectures (Cangzhou, Handan, Hengshui, and Xingtai) participated in the Seasonal Land Fallowing Program (SLFP) from the start and account for nearly 90% of the implementation area of Seasonal Land Fallowing (SLF). In addition, these four prefectures are the most serious regions of groundwater overdraft in Hebei Province. Within these four prefectures, 7 counties (Yanshan, Pingxiang, Qinghe, Gucheng, Jizhou, Qiuxian and Guantao, shown in Fig. 3.3) were selected to conduct a field survey. Within each county, two townships

Fig. 3.3 Location of sample counties for the field survey in four prefectures (Cangzhou, Hengshui, Xingtai and Handan) in Hebei Province

and within each township, two villages were chosen for the survey, one village which participated in the SLF project and another village which did not. In each village, 20 farm households were randomly selected for conducting a face-to-face interview. The final sample included 560 households in 28 villages of 14 townships in 7 counties and 4 prefectures. Among the 28 surveyed villages, 14 villages participated in the SLF and 14 did not. Among the 560 households surveyed, 249 participated and 311 did not.

3.2.1 Effects of Seasonal Land Fallowing

Relatively high targeting efficiency

According to the policy guidelines, pilot sites participating in the SLF should satisfy the following four conditions:

1. They should be located in a groundwater overdraft zone.
2. Irrigation should mainly depend on groundwater.
3. They should grow winter wheat.
4. Land considered for fallowing should cover a coherent area of at least 50 mu (3.3 ha).

The survey’s results show that most pilot sites participating in the project satisfied the four requirements. For example, all sample villages participating in the project are located in groundwater overdraft zones in accordance with the definition given by Hebei Province. Among 14 villages, 6 villages are not only located in *General Overdraft Zones of Shallow Groundwater* but in *Serious Overexploitation Zones of Shallow Groundwater*. 8 villages belong to the *Serious Overexploitation Zone of Deep Groundwater*. The definition of the Overdraft Zones can be found in (Hebei Government 2017). In addition, 77% of cultivated land in the sample villages mainly use groundwater for irrigation. Most cultivated land (93%) of the participating villages is concentrated and it is not hard to find a coherent plot larger than 50 mu. About 70–80% of plots within the SLFP were planted with winter wheat before participating. This also means that between 20 and 30% of plots did not plant winter wheat before participating in the SLFP.

Reduction of water use

Our first-hand survey data prove that the SLF can reduce farmers’ groundwater use. We compared the changes in water use (Tables 3.2 and 3.3) between SLF households who started to participate in the SLFP in the winter of 2017/2018 and non-SLF households, both before and after the SLFP. We found that the SLF households, who started to participate in SLF in the winter of 2017, reduced their annual water use by 15.7% (735 m³/ha) in 2019 (Table 3.2). Comparing the same two years, the

Table 3.2 Comparison of annual water use per hectare of non-SLFP households and SLFP households who participated in the SLFP in winter of 2017

	SLFP households			Non-SLFP households		
	2017	2019	Change	2017	2019	Change
Annual agricultural water use per hectare (m ³ /ha)	4680	3945	−735	6375	6675	300
Annual agricultural groundwater use per hectare (m ³ /ha)	3855	3120	−735	6060	6375	315

Source SLFP survey in 2019

Table 3.3 Comparison of annual water use per hectare of non-SLFP households and SLFP households who participated in the SLFP in the winter of 2018

	SLFP households			Non-SLFP households		
	2018	2019	Change	2018	2019	Change
Annual agricultural water use per hectare (m ³ /ha)	4440	3600	−840	6435	6675	240
Annual agricultural groundwater uses per hectare (m ³ /ha)	4275	3510	−765	6120	6375	255

Source SLFP survey in 2019

annual water use of non-SLF households increased by about 4.7% (300 m³/ha) due to differences in precipitation in the years compared. Consequently, it can be estimated that the project led to an annual reduction of **total** water use and **groundwater** use by 20.4 and 24.3% respectively. Similarly, it can be estimated that **total** water use and **groundwater** use of households who started to participate in the SLF in the winter of 2018 (Table 3.3) both decreased by approximately 22%. Hebei Provincial Government claims that SLF can decrease annual irrigation water use by 2700 m³/ha (180 m³/mu), while the Action Plan 2019 and the evaluation report used a more realistic number of 120–140 m³/mu. However, since farmers only participated in the SLF with part of their arable land, the water saving per hectare of SLF households' total area is much lower than the above values.

3.2.2 Challenges of Implementing SLFP

Despite the progress made in SLFP, there are some problems challenging its effective implementation in the long term.

Some participating farmers were not qualified

Some participating farmers retired land themselves before the SLFP started. These farmers had already spontaneously fallowed land before being involved in the SLFP. Participating farmers should have had at least one plot of land on which winter wheat had been grown before, to be subsidized under the policy (Table 3.4). The table shows

Table 3.4 Farmers share of winter wheat area in total sown area the year before participation

	Share of winter wheat area in total sown area of a farmer interviewed (%)			Total
	0	Between 0 and 100	100	
Number of farmers	54	92	103	249
Share of farmers (%)	22	37	41	100

Source SLFP survey in 2019

that about one fifth of the farmers did not fulfill this requirement.

Fallowing land is economical for some farmers irrespective of a subsidy. The survey found that these farmers tended to stop growing winter wheat years ago, partly due to higher income from off-farm work. Another common reason is that they grow crops of higher economic value such as cotton instead of the wheat–maize succession. This means that some farmers, who should not have participated according to the project's policy, crowded out other farmers who would have really fallowed wheat—and thus saved water—through their participation.

Fallowing land was underused

The government encouraged farmers to grow green manure crops such as oilseed rape and alfalfa on land retired in winter and spring. However, only a fraction of the arable land involved in the SLF has been planted with such crops. Most fallowed land remains uncultivated, which may affect its fertility and result in a decline of production. In the NCP, the wind erodes the soil surface, especially in winter and spring when there is no plant cover and the winds are strong. Among a total of 2374 plots subsidized under the SLF project, 93.81% carried no crops in winter and 3.58% lay fallow for the full year. Only 2.61% of the plots carried some crops in winter, mainly oilseed rape.

Planting green manure crops helps to maintain and improve soil fertility while reducing water use. However, farmers rarely do so. There are several reasons. First, many farmers lack experience in planting green manure crops and publicity and scientific guidance provided by local government (on county or township level) are insufficient. Second, green manure crops generate costs for seeds, labor, and other items. It takes a long time for green manure crops to be converted into fertilizer in the soil, so in the short term the effect on improvement of soil fertility is slight or even not apparent at all. In addition, due to the late sowing time, seedlings of green manure crops may die through frost.

In conclusion, the willingness of farmers to plant green manure crops is very low, leaving the fallowed land underused. By forgoing the opportunity of improving soil fertility, the potential of SLF is not fully utilized.

Subsidy does not reflect the varying opportunity cost of land fallowing among farmers

The subsidy for fallowing is always 500 CNY/mu/year (7,500 CNY/ha), irrespective of the local circumstances, which means that the subsidy may be lower than farmers' expectation in some places and higher in others. Some studies show that the opportunity cost of SLF varies with the yield or the price of wheat. The yield of wheat in turn is affected by many factors such as soil quality and the availability of irrigation water. Therefore, compensation for fallowing in different areas should be adjusted according to the local conditions for agricultural production, in order to achieve fairness and efficient incentives for farmers in any area to be involved in SLF.

Policy sustainability is doubtful

Many farmers commented that if the policy ends, their retired land would be used to plant winter wheat again. In fact, the purpose of this policy is to encourage farmers to retire their winter wheat plots even if no subsidy can be provided in the future. The survey shows that 57.1% of households will plant winter wheat again after quitting participation in the SLFP.

When the subsidy decreases, the willingness of households to participate in the SLFP will decrease or even cease to exist (Table 3.5). When asked in the survey, the share of farmers willing to participate in the SLFP declined from 77% to less than 1% when the subsidy decreased from 500 CYN/mu/year to 100 CNY/mu/year. The issue is even more pronounced among participating farmers, 92.8% of which are content to take part in the policy under the current compensation standard. The willingness to participate decreased to 33.3% for a slightly lower subsidy of 400 CNY/mu/year, and none of the farmers was willing to participate if the subsidy declined to 100 CNY/mu/year (Table 3.5). So, farmers are very sensitive to the amount of subsidy. This implies that under the constraints of the government's budget for SLF, the sustainability of the policy needs to be carefully addressed.

After the SLFP, more than half of the participating farmers claim they no longer have the incentive to fallow land without subsidy, partly because their income is very low and fallowing land has still some—albeit small—impact on their income. When there is no more subsidy, they will plant winter wheat again to compensate for the loss of the subsidy. Take for example the allocation of time after fallowing land: in most cases, the time allocation was not affected by fallowing of land. Only 10% of farmers respond that the time they engaged in off-farm work contributing to their income increased (Table 3.6). This indicates that for most farmers, fallowing land has little impact on their life. They will adopt the previous planting mix and plant winter wheat when there is no subsidy.

In conclusion, the SLFP has without doubt brought about real water saving. It could be more efficient by adjusting amounts of subsidy to local conditions and by avoiding free riding. The most crucial point is its financial sustainability over time. At an avoidance cost of about 3 CNY per cubic meter of water saved it is a rather expensive measure (see also Box 5.1).

Table 3.5 Percentage of farmers willing to participate in SLF as a function of subsidy level (from CNY 100 to 500 per mu per year)

	Number of farmers	Subsidy (CNY/mu/year)				
		100	200	300	400	500
Non participant	311	1.6	6.1	8.7	15.1	64.3
Participant	249	0.0	6.4	13.3	33.3	92.8
Total	560	0.9	6.3	10.7	23.2	77.0

Source SLFP survey in 2019

Table 3.6 Influence on farmers’ time allocation after participating in the SLFP

	Percentage (%)
Without influence	77.5
Leisure time increase	6
Time engaged in agriculture decreases	12.4
Time engaged in agriculture increases	0.8
Time engaged in off-farm work increases	10

Source SLFP survey in 2019

3.3 Farmers’ Reaction to Policy Assessed Through a Groundwater Game

3.3.1 Introduction

During the Sino-Swiss project implementation, one item enthusiastically shared among the project team and the stakeholders was the groundwater game *Save the Water* (referred to as StW for short hereafter), which mimics the agricultural practice in the NCP. The development of StW resulted in two products, namely a board game version (Kocher et al. 2019) (Fig. 3.4) and a digital version (Fig. 3.5), respectively. The digital version is a web-based app, featuring real-time data transmission and the option to customize games. Detailed game instructions can be found in Appendix A-9.

Serious games originated in pedagogical fields (Apt 1970; Michael and Chen 2005) and have been increasingly used in public policy contexts, e.g. related to

Fig. 3.4 The “Save the Water” StW board game

Fig. 3.5 User interface of the digital game “Save the Water” StW. The game can be accessed through the web link <https://savethewater-game.com/game/>

health care (Kato 2010), social morality (Katsarov et al. 2019) and, more recently, natural resources management, e.g. (Morley et al. 2017; Craven et al. 2017). Bots and van Daalen (2007) divide the possible functions of serious games for natural resource management in six categories, namely: (1) Research and analyse policy contexts as systems (game as a laboratory); (2) design and recommend alternative solutions to a policy problem (game as a design studio); (3) provide advice to a client on what strategy to follow in the policy process (game as a practice ring); (4) mediate between different stakeholders (game as a negotiation table); (5) democratize policy development by actively bridging stakeholder views (game as a consultative forum) and; (6) clarify values and arguments pertinent to the policy discourse (game as a parliament). Among those functions—given a sufficient correspondence between game and real natural system—using game as a laboratory allows researchers to draw valid conclusions from observations of the gaming process, which unfolds as players navigate through the game world. In addition, since the game world is a conceptual representation of reality, one can treat a player’s decisions at different stages of a game as a reflection of his/her actual strategy under changing conditions of the real world. In this regard, a gaming episode is comparable with an interview, and hence the serious game may be used as a survey tool for data collection. Questions that one would ask in a questionnaire are now “answered” automatically and stored in a database as a game is played out. Compared with the questionnaire, the playfulness of serious games can make the “survey” process more enjoyable and, consequently, more motivating for farmers to participate in. Inspired by the literature, our team members carried out a field survey in Guantao using the digital StW game, and then

conducted a behavioural analysis based on the game results to better understand Guantao farmers’ decision-making and preferences in their agricultural activities.

3.3.2 Data and Materials

The game survey was conducted in October 2019, covering all eight townships in Guantao. For each township, two villages were selected from which 20 farmers were chosen. In total, 160 farmers were surveyed, including 26 farmers, who also participated in the CCAP’s survey. Their profiles are shown in Fig. 3.6. The age of participants shows a bi-modal pattern, with one group concentrated around 40 years of age and the other around 55. It is consistent with the pattern from the Hebei survey. The majority of farmers received an education of nine years as mandated by China’s national compulsory education program. The typical farm size is about 5 mu per family, and most participants have been farming for twenty to forty years. Despite the small sample size, the farmers’ profiles are consistent with the previous SFLP survey by CCAP.

During the survey, each farmer first received oral instructions about the game rules, followed by a trial under customized easy mode to familiarize themselves with the StW game. At last, they proceeded to play formal games under the supervision

Fig. 3.6 Farmer players’ profiles regarding age, educational level, farm size and farming experience

Fig. 3.7 Photos of farmer participants playing StW in the game-based survey

of students (Fig. 3.7). To compensate for their working hours lost, participants were granted a base subsidy plus an additional reward. This reward was set proportional to gaming results to keep participants motivated until they finish the games. Farmers were required to finish the game at least once. However, it was found that about 37% of players played more than three times.

The analysis of the gaming results has the goal to gain insights about players' underlying decision-making processes, especially the identification of factors that drive certain decisions.

In this work we adopt the decision-tree classification technique (Safavian and Landgrebe 1991; Breiman et al. 1984) for a behavioral analysis. Originating from the data mining field, the decision-tree classification fits a model on a sample by recursively partitioning the data into groups that involve instances of classes as uniform as possible. The structure of the model can be represented as a tree composed of nodes and branches, where the former corresponds to different features of a sample, and the latter are the splits of (sub-)samples. The derived rules are easy to interpret since they are merely “if...else” clauses that are, arguably, similar to the human decision-making process (e.g. Drakopoulos 1994; Drakopoulos and Karayiannis 2004). Therefore, the decision-tree classification can be used to formulate decision heuristics in modeling choice behavior, each rule stating a path of reaching a specific decision.

Table 3.7 List of main variables that characterize the StW game world and will be recorded in a database during a play. “Decision” refers to feasible actions that players can input in the game, while “Events” are external and random disturbances. They both affect the state of the game. Note that the weather conditions determine the amount of precipitation recharge to the aquifer

Category	Variable	Values
Decisions	Crop	Discrete choice among: “single crop”, “double crops”, “vegetables”, “fallowing” ^a
	Farmland	Discrete choice between: “buy field” and “return”
	Amount of irrigation	A crop specific integer between 0 and 5
	Other input	Discrete choice among: “tractor”, “water-saving irrigation”, “greenhouse”, “agricultural insurance”
States	Total capital	A positive integer
	Groundwater storage	An integer between 0 (empty storage) to 288 (the maximum storage)
	Current farm size	An integer between 1 to 36 (the maximum land size)
Events	Weather	“Dry year”, “normal year”, “wet year”
	Neighbouring water use	A positive integer depending on current water table
	Other	“Thunder strike”, “pest damage”, etc.

^aHere “fallowing” means not cultivating any crop on a field. It is different from “seasonal fallowing” practiced in the NCP, where government subsidizes farmers for growing only summer maize instead of summer maize plus winter wheat in a year. In the game, seasonal fallowing corresponds to the choice of single crop

Since in StW most variables are of discrete type, it is straightforward to use decision-tree classification for the analysis, and the derived decision-tree may represent the discrete choice model of a player. Specifically, we use the Python implementation of the classification and regression tree algorithm (CART) (Pedregosa et al. 2011) as the classifier, which has been applied in behavioral studies of different contexts (e.g. Arentze et al. 2000; Su et al. 2017; Schilling et al. 2017; Huang and Hsueh 2010). The algorithm also provides measures for relevant feature importance as well as for the classification accuracy (Menze et al. 2009; Hossin and Sulaiman 2015). Table 3.7 shows a list of the main variables related to decisions, states, and random events in the game.

3.3.3 Results

Figure 3.8 summarizes the final performance of the games of all participants, with each line corresponding to one player. The performance is defined by a number of indicators (see Table 3.8). According to the plot, typical crop choices are single and double crops, with only few farmers growing vegetables. During the game survey, it was noticed that farmers unconsciously linked the game to their farming experience, and selected crop types based on what they actually grew in their farms. Moreover,

Fig. 3.8 Performance of players pooling results from all participants. Each line corresponds to the final performance of an individual player (yellow lines), with the best player who in the end owns the most assets highlighted in blue

Table 3.8 Definition of indicators used for comparing players’ results. Among them, the “totAssets” indicator is used to define a winner within each policy group

Performance indicator	Definition
waterLV	Groundwater level in the last year of the game
NrOfFields	The total number of crop fields in the last year
totAssets	The total value of assets (capital and fixed assets) in the last year
WP	Average economic water productivity during a game
singleCropRatio	The ratio between single crop fields and total fields
doubleCropRatio	The ratio between double crops fields and total fields
vegeCropRatio	The ratio between greenhouse vegetable fields and total fields
sprinklerRatio	The ratio between fields with sprinklers and total fields
tractorRatio	The ratio between fields with tractors and total fields
irrUse	Average irrigation water use per field

only about 12% of players own a greenhouse. The irrigation behavior is also similar to reality, where Guantao farmers are used to irrigate twice for single crop and 3–4 times for double crops.

Regarding economic performance (i.e., totAssets and WP), results are clustered around the low end of the axis. In particular, the economic water productivity (WP) is around 10 and sometimes even negative, meaning that players did not exploit the value of groundwater to its maximum. In the StW game, acquiring more land plots is a key to the success of capital increase, and buying farming equipment such as sprinklers and tractors will further boost productivity. However, in the game farmers are rather conservative: they mostly get only one to two farm fields—similar to real-life households—and the adoption of tractors is low. In comparison, farmer players prefer to invest in sprinklers for saving irrigation cost, as shown by the high sprinkler ratio in the results.

Results of feature importance obtained from decision tree analysis are summarized in Fig. 3.9. For single crop decision (Fig. 3.9a), the crop chosen in the previous

Fig. 3.9 Boxplots of feature importance for single crop decision (a), water saving irrigation (b), adoption of sprinklers (c) and land acquisition (d). the statistics of the box is computed from 50 times of training, each with a different sub-sample. Scores with larger value imply a higher importance in determining a specific decision. The notions of the factors along the x-axis are: “capital”—Money owned at decision-making step; “gw level”—groundwater level at decision-making step; “gw level[%]”—relative groundwater level at decision-making step; “forecast”—forecast weather at decision-making step; “weather”—actual weather at decision-making step; “preMainCrop”—the main crop type in previous step; “NrTractors”—the number of tractors possessed; “NrSprinklers”—the number of sprinklers possessed; “NrGreenHse”—the number of greenhouses possessed

decision time step (i.e., last “year”) appears as a dominating factor. This implies that farmers’ crop decision in this year strongly depends on what they did in the previous year, indicating a strong behavioral inertia. The capital level appears to have less influence on the decision. The second important factor is relative groundwater level, indicating that farmers do take into account groundwater availability in their decision-making process. Informing farmers about groundwater level, therefore, can be useful to promote single cropping (SLF in real life). Secondary to the factor of previous crop choice are capital level and weather forecast, which show a similar importance. This, on one hand, indicates that farmers’ crop decision is not strongly economically motivated. On the other hand, farmers trust the weather forecast and use this information in planning their crop choices, even though the forecast accuracy in the game is uncertain.

Figure 3.9b shows the feature importance of “water saving” behavior. The “water saving” decision includes three situations in the game: (1) use deficit irrigation to save water at the cost of reduced income; (2) use sprinklers in the game to improve irrigation efficiency; and (3) do not irrigate at all. Results show that, in this case, the groundwater level [%] is the main factor that triggers players’ water saving action. The capital level is the second important, possibly because each irrigation induces a cost. Sprinklers are the third important factor, which is expected since it saves irrigation water as defined by the rules: In StW, sprinklers can reduce a crop’s water demand by one unit without affecting its yield.

Turning to the adoption of sprinklers (Fig. 3.9c), the number of sprinklers possessed has the highest importance, which is an intuitive result since it is less likely, even impossible, to buy new sprinklers during a game if one has already acquired many of them. But the results also confirm that the CART algorithm is working as expected. The second and third important factors are the capital and relative groundwater level, respectively. Therefore, if farmers have no sprinkler at all, the capital level will be the main obstacle that prevents them from adopting water saving equipment, while groundwater severity is the second concern. This might explain why programs such as subsidizing water saving equipment are welcomed by farmers, even though they have to pay maintenance cost themselves. Our results also suggest that, informing farmers about the severity of groundwater depletion could help to reinforce farmers’ willingness in accepting programs for subsidizing water-saving equipment.

Regarding the land acquisition decision (Fig. 3.9d), the capital appears as the dominating factor, followed by weather forecast and groundwater level. Possibly because they are linked to groundwater availability for irrigation (In StW, buying new fields allows players to access more groundwater).

3.3.4 Discussion and Conclusions

The analysis of game results shows that farmers’ crop choice has strong inertia and is less motivated by economic factors. The reasons behind such inertia are not clear, and

can possibly be linked to the lack of experience with innovation, high age of farmers, risk averseness fearing failure when growing new crops or just to farmers' planting habits, since in NCP the single/double cropping has a well-established routine using mechanization. However, farmers in NCP do not buy but rather rent agricultural machinery from a company, which not only provides equipment but also service. Currently, smallholder farmers cannot afford to buy those machines themselves. One observation from the previous SLFP survey shows that farmers are willing to give up winter wheat for a subsidy of 500 CNY/mu, but few farmers take advantage of fallowed land to grow other permitted crops such as oilseed rape or alfalfa, even though such a practice can help to maintain the fertility of the soil. Therefore, unless changing crop structure is relatively cost-free (e.g., compensated by subsidy) and operationally easy, it will require a stronger economic incentive to persuade farmers to adopt new crops.

Water-saving irrigating behavior strongly depends on the groundwater level. Moreover, the groundwater level plays an important role in affecting other decisions in the game. Therefore, a proper communication with farmers about the severity of groundwater depletion can help to motivate water-saving behavior. In Guantao, the local water resource bureau has set up posters with historical records of groundwater head to show the declining trend. Also, the StW game can serve as such a communication tool for awareness raising.

The capital level is the main influencing factor for farmers' land acquisition and adoption of sprinklers—if one excludes the number of sprinklers possessed as a candidate determining factor. Therefore, if farmers have sufficient money, they are willing to invest on water-saving equipment. The higher capital level can also encourage farmers to buy new land, but from the results it is found that the land expansion behavior is rather conservative, with mostly only 1–2 new fields acquired during the game.

Using the game as a survey and analysis tool is a new concept proposed in our project, and the field experiments also suggests that farmers' decisions in the game show consistency with their real farming practice. Although the StW game omitted many nuances seen in real agricultural activities, such as the influence of seed quality, extreme weather other than precipitation, time length of irrigation, etc., it is nevertheless able to capture essential farmers' behavioral traits, and to provide directions for further investigation with formal econometric methods.

References

- Apt CC (1970) *Serious games: the art and science of games that simulate life in industry, government and education*. Viking, New York
- Arentze TA, Hofman F, Mourik H, Timmermans HJP, Wets G (2000) Using decision tree induction systems for modeling space-time behavior. *Geogr Anal* 32:330–350. <https://doi.org/10.1111/j.1538-4632.2000.tb00431.x>
- Bots P, van Daalen E (2007) Functional design of games to support natural resource management policy development. *Simul Gaming* 38:512–532. <https://doi.org/10.1177/1046878107300674>

- Breiman L, Friedman J, Stone CJ, Olshen RA (1984) Classification and regression trees. CRC Press
- Cao G, Zheng C, Scanlon BR, Liu J, Li W (2013) Use of flow modeling to assess sustainability of groundwater resources in the North China Plain. *Water Resour Res* 49(1):159–175. <https://doi.org/10.1029/2012WR011899>
- Craven J, Angarita H, Corzo Perez GA, Vasquez D (2017) Development and testing of a river basin management simulation game for integrated management of the Magdalena-Cauca River Basin. *Environ Model Softw* 90:78–88. <https://doi.org/10.1016/j.envsoft.2017.01.002>
- Drakopoulos SA (1994) Hierarchical choice in economics. *J Econ Surv* 8:133–153. <https://doi.org/10.1111/j.1467-6419.1994.tb00097.x>
- Drakopoulos SA, Karayiannis AD (2004) The historical development of hierarchical behavior in economic thought. *J Hist Econ Thought* 26:363–378. <https://doi.org/10.1080/1042771042000263849>
- Feng W, Zhong M, Lemoine JM, Biancale R, Hsu HT, Xia J (2013) Evaluation of groundwater depletion in North China using the Gravity Recovery and Climate Experiment (GRACE) data and ground-based measurements. *Water Resour Res* 49:2110–2118. <https://doi.org/10.1002/wrcr.20192>
- Feng W, Shum CK, Zhong M et al (2018) Groundwater storage changes in China from satellite gravity: an overview. *Remote Sens* 10(5):674. <https://doi.org/10.3390/rs10050674>
- Hebei Government (2017). Notice of the People's Government of Hebei Province: announcement of Groundwater Overdraft Zones, Forbidden and Restricted Groundwater Exploitation Zones. Document Nr. 48 (In Chinese)
- Hossin M, Sulaiman M (2015) A review on evaluation metrics for data classification evaluations. *Int J Data Min Knowl Manag Process* 5:1. <https://doi.org/10.5121/ijdkp.2015.5201>
- Huang CF, Hsueh SL (2010) Customer behavior and decision making in the refurbishment industry—a data mining approach. *J Civ Eng Manag* 16:75–84. <https://doi.org/10.3846/jcem.2010.07>
- Kato PM (2010) Video games in health care: closing the gap. *Rev Gen Psychol* 14:113–121. <https://doi.org/10.1037/a0019441>
- Katsarov J, Christen M, Mauerhofer R, Schmocker D, Tanner C (2019) Training moral sensitivity through video games: a review of suitable game mechanisms. *Games Cult* 14:344–366. <https://doi.org/10.1177/1555412017719344>
- Kocher M, Martin-Niedecken AL, Li Y, Kinzelbach W, Bauer R, Lunin L (2019) “Save the Water”—a China water management game project. In: Jonna Koivisto and Juho Hamari (Eds.) *Proceedings of the 3rd International GamiFIN Conference*, Levi, Finland, pp 265–276. <http://ceur-ws.org/Vol-2359/paper23.pdf>
- Luo JM (2019) Evaluating water saving effects due to planting structure optimization in the Beijing-Tianjin-Hebei plain. Ph. D. thesis. Institute of Genetics and Developmental Biology, CAS, 2019
- Luo JM, Shen YJ, Qi YQ et al (2018) Evaluating water conservation effects due to cropping system optimization on the Beijing-Tianjin-Hebei plain China. *Agric Syst* 159:32–41. <https://doi.org/10.1016/j.agsy.2017.10.002>
- Luo JM, Qi YQ, Huo YW, Dong W, Shen YJ (2021). Optimizing planting structure for groundwater sustainability in Beijing-Tianjin-Hebei region, China: 1. Food supply/demand and water consumption. Submitted to *Agric. Water Manag*
- Menze BH, Kelm BM, Masuch R, Himmelreich U, Bachert P, Petrich W, Hamprecht FA (2009) A comparison of random forest and its Gini importance with standard chemometric methods for the feature selection and classification of spectral data. *BMC Bioinform* 10:213. <https://doi.org/10.1186/1471-2105-10-213>
- Michael DR, Chen SL (2005) Serious games: games that educate, train, and inform. Muska & Lipman/Premier-Trade
- Mo XG, Liu SX, Lin ZH et al (2009) Regional crop yield, water consumption and water use efficiency and their responses to climate change in the North China Plain. *Agr Ecosyst Environ* 134(1):67–78. <https://doi.org/10.1016/j.agee.2009.05.017>

- Morley MS, Khoury M, Savič DA (2017) Serious game approach to water distribution system design and rehabilitation problems. *Procedia Eng* 186:76–83. <https://doi.org/10.1016/j.proeng.2017.03.213>
- Pedregosa F, Varoquaux G, Gramfort A, Michel V, Thirion B, Grisel O, Blondel M, Prettenhofer P, Weiss R, Dubourg V, et al (2011) Scikit-learn: machine learning in python. *J Mach Learn Res* 12:2825–2830. [arXiv:1201.0490v4](https://arxiv.org/abs/1201.0490v4)
- Safavian S, Landgrebe D (1991) A survey of decision tree classifier methodology. *IEEE Trans Syst, Man, Cybern* 21:660–674. <https://doi.org/10.1109/21.97458>
- Schilling C, Mortimer D, Dalziel K (2017) Using CART to Identify Thresholds and Hierarchies in the Determinants of Funding Decisions. *Med Decis Making* 37:173–182. <https://doi.org/10.1177/0272989X16638846>
- Shen YJ, Zhang YC, Scanlon BR et al (2013) Energy/water budgets and productivity of the typical croplands irrigated with groundwater and surface water in the North China Plain. *Agric for Meteorol* 181(01):133–142. <https://doi.org/10.1016/j.agrformet.2013.07.013>
- Su P, Yang J, Li Z, Liu Y (2017). Mining actionable behavioral rules based on decision tree classifier. In: 13th International conference on Semantics, Knowledge and Grids (SKG), IEEE, Beijing, China, pp 139–143. <https://doi.org/10.1109/SKG.2017.00030>
- Wang J, Wang E, Yang XG et al (2012) Increased yield potential of wheat-maize cropping system in the North China Plain by climate change adaptation. *Climatic Change* 113(3):825–840. <https://doi.org/10.1007/s10584-011-0385-1>
- Wang X, Li XB, Tan MH et al (2015) Remote sensing monitoring of changes in winter wheat area in North China Plain from 2001 to 2011. *Trans Chin Soc Agric Eng* 31(8):190–199
- Xiao DP, Tao FL, Liu YJ et al (2013) Observed changes in winter wheat phenology in the North China Plain for 1981–2009. *Int J Biometeorol* 57(2):275–285. <https://doi.org/10.1007/s00484-012-0552-8>
- Yuan ZJ, Shen YJ (2013) Estimation of agricultural water consumption from meteorological and yield data: a case study of Hebei North China. *Plos ONE* 8(3):e58685. <https://doi.org/10.1371/journal.pone.0058685>
- Zhang XY, Chen SY, Sun HY et al (2011) Changes in evapotranspiration over irrigated winter wheat and maize in North China Plain over three decades. *Agric Water Manag* 98(6):1097–1104. <https://doi.org/10.1016/j.agwat.2011.02.003>
- Zhang XL, Ren L, Kong XB (2016) Estimating spatiotemporal variability and sustainability of shallow groundwater in a well-irrigated plain of the Haihe River basin using SWAT model. *J Hydrol* 541:1221–1240. <https://doi.org/10.1016/j.jhydrol.2016.08.030>

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.