ENVIRONMENTAL SCIENCE & POLICY 27 (2013) 32–54

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.elsevier.com/locate/envsci

Roles of science in institutional changes: The case of desertification control in China

Lihua Yang [a,b,*], *Jianguo Wu* [c,b], *Pengyun Shen* [a]

[a] *School of Public Administration & Workshop for Environmental Governance and Sustainability Science, Beihang University, No. 37 Xueyuan Rd, Beijing 100191, China*

[b] *Sino-US Center for Conservation, Energy, and Sustainability Science, Inner Mongolia University, Hohhot 010021, China*

[c] *School of Life Sciences and Global Institute of Sustainability, Arizona State University, Tempe, AZ, USA*

ARTICLE INFO

Keywords:
Application of science
Institutional change
Desertification
Knowledge
Scientists

ABSTRACT

Although the importance of science, in both desertification control and other types of environmental governance, has been emphasized by many studies, little is known about how science influences institutional changes. Based on a method combining surveys, interviews, observation, and a meta-analysis of the literature, this study explored the roles of science in institutional changes associated with desertification control in northern China. There are five major results of this study: (1) the application of science significantly improved the outcome of desertification control by influencing several aspects of institutional changes; (2) the major aspects of the institutional changes were identified (major actors in desertification control, desertification control methods, types of property rights, and laws and regulations); (3) the effects of applied scientific desertification control measures (SDCM) had more impacts on institutional changes than the extents of adoption and implementation of the measures; (4) six scientific areas had the greatest effects on institutional changes of desertification control were observed (agricultural science and technology, land development and construction planning, agricultural pest control, knowledge of forestry, knowledge of combating desertification and dust storms, and general knowledge of climate); and (5) the most important factors influencing the application effects of science on institutional change in desertification control were governmental behaviors, governmental attitudes toward the application of science, understanding of local knowledge, local conditions, local people, and effectiveness in science and technology transformation and extension. These findings shed new light on the influence of scientific measures on institutional changes by addressing large-scale, chronic environmental problems, such as desertification control in China and in other arid lands around the world.

1. Introduction

Numerous studies have shown that science (primarily natural science and technology) may play an important role in desertification control (Bauer and Stringer, 2009; Reynolds et al., 2007; Thomas, 1997; Winslow et al., 2011; Xia and Fan, 2000; Yang, 2009, 2010; Yang et al., 2010; Yang and Wu, 2009, 2010). Marx and Engels (1968) argued that technology plays a definite role on the institutional structure of a society. Lin (1989) also indicated that technological advancement is one of four important sources of institutional disequilibrium. Changes in technology not only shape institutional structure but also affect the efficiency of particular institutional

* *Corresponding author at*: School of Public Administration & Workshop for Environmental Governance and Sustainability Science, Beihang University, No. 37 Xueyuan Rd, Beijing 100191, China. Tel.: +86 15910950699.

E-mail addresses: journeyyang@yahoo.cn, Lihua.yang@buaa.edu.cn, journeyyang@yahoo.com.cn (L. Yang).

1462-9011/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.envsci.2012.10.017

arrangements. For example, Anderson and Hill (1975) pointed out that the privatization and leasing of public grazing land in the American West was induced by the innovation of low-cost and barbwire fencing. Day (1967) and Binswanger (1978) reported that tractors and other farm machinery reduced supervision cost, and resulted in a shift from sharecropping to owner operations (or from sharecroppers to wage workers).

On the one hand, institutional arrangements may hinder or promote the adoption and implementation of science-based measures in environmental governance (McNie, 2007; Lidskog and Sundqvist, 2002; Garcia and Charles, 2008; Bauer and Stringer, 2009; Yang and Wu, 2010; Akhtar-Schuster et al., 2011). On the other hand, scientific knowledge can significantly influence the process of institutional change (Miller et al., 2010; North, 1990; Ruttan, 1978, 1984; Ruttan and Hayami, 1984). However, the interactions between science and institutional dynamics are yet to be fully understood. This is especially true as to how science influences the institutional changes in desertification control because little has been done on this topic.

Our previous research (Yang and Wu, 2012) suggests that knowledge-driven institutional change may have played a significant role in combating the desertification in northern China during the last six decades; however, because of the lack of data at that time, we were not able to address the question of how science actually influenced these institutional changes. Thus, the main objective of this study was to analyze the roles that science, when applied to desertification control, played in institutional changes. Specifically, we attempted to address the following two research questions:

(1) Does science significantly influence institutional changes during combating desertification, and in what respects?
(2) What are the key factors impeding or promoting the roles of science, and how can these roles be improved?

Based on the assumption that both scientific application and institutional change are heterogeneous, the hypotheses of this study are: (1) the extent of adoption and implementation of scientific measures (i.e., how much science has been applied in desertification control) and its effect (i.e., the effectiveness of the scientific application) influence the effectiveness of institutional changes in desertification control; (2) the key factors impeding or promoting the roles of science have different effects on the effectiveness of institutional changes in desertification control. To answer these questions and to test the hypothesis, we conducted a series of analyses based on field studies in China, which for decades has been one of the countries most severely affected by large-scale desertification (Wu and Ci, 2002).

2. Study area and research methods

2.1. Study region

We chose 12 counties in three adjacent provinces in northern China for the field studies. Among these counties, there are two in Gansu, two in Ningxia, and eight in Inner Mongolia (Fig. 1). These counties are located at 99°51′E–121°35′E, 36°59′N–49°46′N with four in the arid zones, two in the transitional zones between the arid and semi-arid regions, two in the semi-arid zones, and three in the transitional zones between the semi-arid and semi-humid regions. These counties have population densities of 2–69 per km^2, an annual average temperature ranging from −0.5 to 9.5 °C, an annual average precipitation of 115–460 mm, an annual average evaporation of 1714–2644 mm, and an annual wind speed of 2.3–4.2 m per second (Table 1). Land conversion, groundwater pumping for agriculture, and wind (as the major physical erosive force) are often considered to be major causes of desertification in these areas (CCICCD, 2000, 2002). Furthermore, the Chinese Academy of Sciences (CAS) has operated laboratories and field stations in all of these counties for many years; some of these laboratories and field stations were founded as far back as the 1950s.

2.2. Data acquisition

This study is based on a combination of four types of data: surveys, interviews, observations, and archives. The random surveys were conducted from March to December in 2011, with 4194 valid responses overall (Table 2a and b). Considering that many of the old farmers could not read, we first randomly distributed the questionnaires to high school students, who often came from all of the townships within the county and were trained to help their family members, neighbors, and relatives in answering the questions. If there was more than one high school within the county, we included all of the high schools or chose the school with students that represented the population of most of the townships within the county. Because multiple social actors and organizations participated in desertification control projects in China (Yang, 2009, 2010; Yang et al., 2010; Yang and Wu, 2010), the survey respondents included farmers, as well as middle school teachers and students, desert control station staff, government officials, and businessmen (Table 2b). This method has been practiced for many years and in multiple studies (Yang, 2009, 2010, 2012; Yang et al., 2010; Yang and Wu, 2010) and has proven to be a valid and efficient method for collecting data in rural China.

Face-to-face interviews were conducted from June 2006 to February in 2008 in Minqin, Linze, and Zhongwei and from July to August in 2011 in the other counties, with 118 interviewees from approximately 20 to more than 60 years old to complement the survey data (Table 2c). The interviewees included both volunteers (e.g., farmers or general citizens) and people recommended by the offices of the county bureaus, research institutes (e.g., desert control stations), and businesses. The interview questions were similar to the survey questions, but they were open-ended. We ensured that the identity of any respondent would not be revealed in any circumstance by keeping the interview results confidential.

The participatory and non-participatory observations were conducted during the same period of the interviews, and they were mainly used to acquire some intuitive and direct understandings of the activities and functions of the desert control stations, scientific applications in desertification control, types of property right arrangements, and desert control results; some issues were also raised by the interviewees. Furthermore, in each county, we visited the Bureau of Forestry, the Bureau of Environmental Protection, the desert

Fig. 1 – The twelve research sites and jurisdictions.

control station, typical areas of desertification control, and famous natural reserves (Table 2d and Fig. 2).

Various archives were collected during this study, including county annals, government gazettes, government documents, research reports, and published and non-published literatures. These archives were used to complement the survey and interview data and to provide some background information for research design and data analysis, and they provided a validity check for the research findings.

2.3. *Conceptual background and analytical framework*

Institutions are sets of formal or informal behavioral rules within which individuals interact and through which policy discourse is mediated (Lin, 1989; North, 1981, 1990, 1994a,b; Ostrom, 1990; Ruttan, 1978; Schultz, 1968; Yang and Wu, 2012). Multiple types and layers of institutions often influence each other and then often make institutions nested in a complex and hierarchical system. North (1981) divided institutions into three levels—constitutional rules, operating rules, and normative behavioral codes. Kiser and Ostrom (2000:60) divided institutions into three related but distinct levels: the constitutional, collective choice, and operative levels. In this study, we considered four aspects of institutions and institutional change related to desertification control: types of property rights, laws and regulations, methods of desertification control, and major actors in desertification control. Property rights were classified into three types: national, collective, and private. ''Laws and regulations'' included the property right arrangements, basic laws on desertification control, laws and regulations on implementing the basic laws, and methods of desertification control. The four methods of desertification control evaluated were mechanical (e.g., high sand dike stabilization with a mechanical sand fence and straw checkerboard dune stabilization), chemical (e.g., chemical dune stabilization), biological (such as biological dune stabilization methods), and agricultural methods (e.g., deep plowing, improved slowing techniques, strip intercropping, remaining crop stubble and other methods used in agricultural production to prevent desertification). The major social actors evaluated by the respondents included farmers and herders, households, communities, the general public, businesses, governments, scholars and research institutes (including experts, technicians, desertification control stations, and universities and colleges), media, religious groups, non-governmental organizations, internationals organizations, and others.

To answer the two research questions, this study mainly explored (a) the impacts of adoption and implementation of SDCM on the institutional changes and (b) the factors that have impeded or promoted the uptake of SDCM (Fig. 3). To address our first research question, we examined the extents to which SDCM were adopted and implemented, the effects of these measures, and the types of science that these measures represent. Then, we explored these factors' relationships with the institutional

Table 1 – Characteristics of the 12 counties.

Counties	Provinces	Dimensions								
		Longitude	Latitude	Climate division	Total area (km^2)	Population density (per km^2)	Annual average temperature (°C)	Annual average precipitation (mm)	Annual average evaporation (mm)	Annual wind speed (m/s)
Linze (2001[a])	Gansu	99°51′E–100°30′E	38°57′N–39°42′N	Arid	3148	41	7.7	115	2212	3.2
Minqin (1994)	Gansu	101°49′E–104°12′E	38°03′N–39°27′N	Arid	16,016	17	7.8	115	2644	2.8
Zhongwei (1995)	Ningxia	104°17′E–105°37′E	36°59′N–37°42′N	Arid	5780	52	9.5	188	1914	2.3
Yanchi (2004)	Ningxia	106°30′E–107°47′E	37°04′N–38°10′N	Arid	8661	18	7.7	<300	>2000	2.8
Dengkou (1998)	IM[b]	106°09′E–107°10′E	40°09′N–40°57′N	Arid	3554	27	7.6	145	2398	3
Ejin Horo (2011)	IM	108°58′E–110°25′E	38°56′N–39°49′N	Arid–semi-arid	5600	28	6.7	348	2563	3.6
Xinbaerhuzuo (2002)	IM	117°33′E–120°12′E	46°10′N–49°47′N	Arid–semi-arid	22,000	2	−0.3	268	1650	2.8
Xilinhot (2004)	IM	115°13′E–117°06′E	43°02′N–44°52′N	Semi-arid	15,179	16	1.6	250–350	1746	3.5
Naiman (2001)	IM	120°19′E–121°35′E	42°14′N–43°32′N	Semi-arid	8159	51	6 to −6.5[c]	366	1973–2082	3.6–4.1
Duolun (2000)	IM	115°51′E–116°54′E	41°46′N–42°36′N	Semi-arid–semi-humid	3773	27	1.9	389	1714	3.6
Wengniute (1993)	IM	117°49′E–120°43′E	42°26′N–43°25′N	Semi-arid–semi-humid	11,882	35	4.5	370	2106	3–4.2
Aohan (1990)	IM	119°30′E–120°53′E	41°42′N–43°02′N	Semi-arid–semi-humid	8294	69	5–7	310–460	2161.7	4

Sources: Fan (1993), He et al. (2004), Lu et al. (2004), PGYC (2011), Wu and Peng (2002), Wu (2001), Zhang (1990), Zhou (1998) and Zhuo (2000).

[a] The year of the source published.
[b] IM refers to Inner Mongolia.
[c] In some counties, because the data come from different sources, we only found the annual average intervals rather than the annual average values of some factors.

changes that occurred regarding desertification control. To address our second question, we first identified the key factors that influenced the adoption and implementation of SDCM, investigated the relationship of these factors with institutional changes, and then explored the means of improving the role of science in combating desertification. The influencing factors were based on the Institutional Analysis and Development (IAD) framework (Ostrom, 2005) and the Product-Institutional Analysis (PIA) framework (Yang, 2009, 2010), in additional to the control variables such as the biophysical conditions of the counties (Table 1) and the types of the respondents (Table 2). We considered (1) the level and quality of science development (Barrera-Bassols et al., 2006; Garcia and Charles, 2008; Lidskog and Sundqvist, 2002; Thomas, 1997; Yang, 2009, 2012), (2) the mechanisms, laws, and regulations of science and technology application and extension (Watson et al., 2008; Yang, 2009, 2010; Yang et al., 2010; Yang and Wu, 2010), (3) interactions among multiple organizations and social actors in desertification control (Pellant et al., 2004; Reynolds et al., 2007; van Rooyen, 1998; Yang, 2009, 2010; Yang and Wu, 2010, 2012), and (4) financial support for science and technology application (Akhtar-Schuster et al., 2011; Campbell, 1992; van Rooyen, 1998; Yang, 2009; Yang and Wu, 2010) (Fig. 3).

2.4. *Measurement*

A six-point scale (range: "very large, large, medium, moderately small, very small, and unknown" or "strongly agree, agree, neutral, moderately disagree, strongly disagree, and unknown") was used to evaluate the extents and effects of adoption and implementation of SDCM, the relevant applied sciences, the problems and improvements that were associated with or could be made to the scientific measures, and the results of desertification control.

Using the same six-point scale, we evaluated the four aspects of institutions and institutional change related to desertification control. However, for the three types of property rights, the four types of laws and regulations, the four methods of desertification control, and the eleven types of social actors, we asked the respondents to choose the type of property rights and the control methods via a single-choice question and the participation of social actors via a multiple-choice question for the 1950s, 1960s, 1970s, 1980s, 1990s and 2000s. We then calculated their average responses. Furthermore, we asked the respondents to directly evaluate the influence of scientific applications on these aspects of the institutions and institutional change.

3. Results

3.1. *The impacts of scientific applications on institutional changes*

3.1.1. *Extent of adoption and implementation and effect of SDCM*

On average, more than 40% of the respondents from the 12 counties indicated that both the extent and effect of the application of science in combating desertification were "very large" or "large"; by also including "medium," the percentage

Table 2 – Survey and interview distribution in the 12 counties in northern China (2006–2011).

	Counties												Total
	Linze	Minqin	Zhongwei	Yanchi	Dengkou	Ejin Horo	Xinbaerhuzuo	Xilinhot	Naiman	Duolun	Wengniute	Aohan	
(a) Survey distribution													
The number of sent copies	450	450	450	450	450	450	450	450	450	450	460	450	5410
Response rates (%)	75.78	100	80.00	99.56	72.00	38.89	86.00	93.56	96.00	100	100	100	86.82
The number of valid copies	328	418	345	439	304	150	387	342	424	449	458	362	4406
Valid rate among received copies (%)	96.19	92.89	95.83	97.99	93.83	85.71	100	81.23	98.15	99.78	99.57	80.44	81.44
(b) Types of survey respondents													
Farmers	97	382	130	75	72	53	186	76	70	149	438	256	1984
	(29.57)[b]	(91.39)	(37.68)	(17.08)	(23.68)	(35.33)	(48.06)	(22.22)	(16.51)	(33.18)	(95.63)	(70.72)	(43.42)
Middle schools (teachers and students)	91	8	58	166	99	38	45	99	134	135	11	21	905
	(27.74)	(1.91)	(16.81)	(37.81)	(32.57)	(25.33)	(11.63)	(28.95)	(31.60)	(30.07)	(2.40)	(5.80)	(21.05)
General research institutes[a]	0	1	2	27	2	0	5	3	11	15	0	2	68
	(0)	(0.24)	(0.58)	(6.15)	(0.66)	(0)	(1.29)	(0.88)	(2.60)	(3.34)	(0)	(0.55)	(1.36)
Desert control stations	0	0	0	2	2	0	1	0	2	8	0	0	15
	(0)	(0)	(0)	(0.46)	(0.66)	(0)	(0.26)	(0)	(0.47)	(1.78)	(0)	(0)	(0.30)
Government	14	1	9	15	13	4	14	24	5	32	1	9	141
	(4.27)	(0.24)	(2.61)	(3.42)	(4.28)	(2.67)	(3.62)	(7.02)	(1.18)	(7.13)	(0.22)	(2.49)	(3.26)
Businesses	55	8	48	55	53	10	18	63	14	34	4	28	390
	(16.77)	(1.91)	(13.91)	(12.53)	(17.43)	(6.67)	(4.65)	(18.42)	(3.30)	(7.57)	(0.87)	(7.73)	(9.31)
Rural grassroots organizations	7	9	24	15	4	2	2	4	2	41	0	10	120
	(2.13)	(2.15)	(6.96)	(3.42)	(1.31)	(1.33)	(0.52)	(1.17)	(0.47)	(9.13)	(0)	(2.76)	(2.61)
Organizations of technology development and promotion in rural areas	4	1	0	3	2	0	4	2	3	1	0	1	21
	(1.22)	(0.24)	(0)	(0.68)	(0.66)	(0)	(1.03)	(0.58)	(0.71)	(0.22)	(0)	(0.28)	(0.47)
Universities	1	1	5	18	0	0	4	4	12	0	0	0	45
	(0.31)	(0.24)	(1.45)	(4.10)	(0)	(0)	(1.03)	(1.17)	(2.83)	(0)	(0)	(0)	(0.93)
Religious groups	0	0	2	4	0	0	0	2	2	0	0	0	10
	(0)	(0)	(0.58)	(0.91)	(0)	(0)	(0)	(0.58)	(0.47)	(0)	(0)	(0)	(0.21)
Other public institutes	25	1	25	10	20	16	10	40	3	13	3	26	192
	(7.62)	(0.24)	(7.25)	(2.28)	(6.58)	(10.67)	(2.58)	(11.70)	(0.71)	(2.90)	(0.66)	(7.18)	(5.03)
Non-governmental organizations	5	0	5	4	3	6	1	3	2	1	0	2	32
	(1.52)	(0)	(1.45)	(0.91)	(0.99)	(4)	(0.26)	(0.88)	(0.47)	(0.22)	(0)	(0.55)	(0.94)
News media	1	0	1	2	0	1	0	3	5	0	0	0	13
	(0.31)	(0)	(0.29)	(0.46)	(0)	(0.67)	(0)	(0.88)	(1.18)	(0)	(0)	(0)	(0.32)
International organizations	0	0	4	2	0	0	1	0	15	0	0	1	23
	(0)	(0)	(1.16)	(0.46)	(0)	(0)	(0.26)	(0)	(3.54)	(0)	(0)	(0.28)	(0.48)
Others	28	6	32	41	34	20	96	19	144	20	1	6	447
	(8.54)	(1.44)	(9.27)	(9.33)	(11.18)	(13.33)	(24.81)	(5.56)	(33.96)	(4.46)	(0.22)	(1.66)	(10.31)
(c) Interview distribution													
Farmers or residents	4	6	5	1	1	2	2	1	1	1	1	1	26
Scholars, experts and technicians	3	11	4	4	2	3	0	4	5	0	2	4	42

Government officials	1	11	1	3	6	3	3	4	1	3	5	4	45
Businessmen	0	0	0	0	0	0	0	0	2	0	2	0	4
Religious groups or NGOs	0	1	0	0	0	0	0	0	0	0	0	0	1
Total	8	29	10	8	9	8	5	9	9	4	10	9	118
(d) Observation distribution													
Numbers	4	11	7	2	9	2	2	2	5	3	2	3	52

[a] ''Types of organizations'' refer to people in these organizations.
[b] Numbers in the brackets are the percentages among the valid copies.

increased to 70% (Table 3a and b). The correlation coefficient (Pearson's) between the extent and effect of the scientific application rated as ''very large'' or ''large'' by respondents was 0.361 (at a 0.249 significance level); the correlation coefficient was 0.796 (at a 0.003 significance level), if ''medium'' was included. Many interviewees, including an official in Wengniute Banner and two experts in Aohan Banner, also emphasized the effects of science and said that it had been even more important and significant recently with the development of science and technology. Furthermore, they indicated that the extent to which SDCM were adopted and implemented correlated with their effects, but a thorough adoption and implementation of these measures did not necessarily lead to high major effects because of many other factors, such as government intervention, climate factors, and natural conditions (especially water). An expert in Wengniute even emphasized that the application of science had more impacts in the areas with poor natural conditions than in areas with good conditions. An expert in the Experimental Center of Desert Forestry in Dengkou County also noted that science and technology each had their own scopes and applicabilities.

3.1.2. *Types of sciences*

Although the respondents in different counties emphasized different sciences among 16 types of knowledge, the six types of scientific knowledge with the greatest average application extent evaluated by ''very large'' and ''large'' were as follows: agricultural science and technology, agricultural pest control, zoology or animal biology, knowledge of forestry, knowledge of combating desertification and dust storms, and general knowledge of climate. The six types with the greatest application effect were agricultural science and technology, land development and construction planning, agricultural pest control, knowledge of forestry, knowledge on combating desertification and dust storms, and general knowledge of climate (Table 4). Many interviewees also emphasized that nonscientific land development and construction planning was one of the major reasons for the recent desertification of the rapid, ongoing industrialization and urbanization in China, and thus, the science regarding land development and construction planning was much-needed in desertification control.

3.1.3. *The impact of scientific application on institutional change*

Although the survey respondents from different counties had various evaluations, more than 30% of the respondents indicated that the total impact of scientific application on institutional change was ''very large'' or ''large;'' but if ''medium'' was included, the percentage increased to 71.7% (Table 5). The order of the impacts on the different aspects of institutional change from the greatest to least was ''the major actors in desertification control,'' ''methods of desertification control,'' ''types of property rights,'' and ''laws and regulations''. Furthermore, the order of the impacts on the four types of laws and regulations from the greatest to least were the basic laws of desertification, methods of desertification control, laws and regulations regarding property right arrangements, and laws and regulations regarding implementing the basic laws. Many interviewees had similar ideas. For example, an expert in Wengniute Banner indicated that scientific application had

Fig. 2 – Examples of observation sites. (a) Inner Mongolia Grassland Ecosystem Research Station, the Chinese Academy of Sciences (CAS) in Xilinguole. (b) National Forestry Administration Desertification Monitoring Network Naiman Desertification Research Station and Naiman Desertification Research Station, Cold and Arid Regions Environment and Engineering Research Institute, CAS. (c) Forestry Public Security Bureau of Naiman Banner. (d) National Forest Farm of Desertification Control in Aohan Banner. (e) State-Owned Desertification Control Station in Xinjie Township, Ejin Horo Banner. (f) Experimental Center of Desert Forestry, Chinese Academy of Forestry Sciences in Dengkou County. (g) National Grassland Nature Research in Xinlinguole. (h) The typical area of desertification control in Bayinburide Village, Xinbaerhuzuo Banner. (i) The Yanchi County Area of the Sino-German Financial Cooperation Project of Comprehesive Desertification Control in Northern China.

important impacts on the methods and mechanisms of desertification control and also on the participatory actors in desertification control. However, there was almost no significant influence on the property right arrangements because they were mainly controlled by the government. Furthermore, some interviewees, such as a forestry factory director in Naiman Banner, indicated that clear property rights were a necessary condition rather than a sufficient condition for combating desertification.

The Pearson's correlation coefficient between the extent of scientific application and the total evaluation of the impact of scientific application on institutional change rated as "very large" or "large" by respondents is less than the correlation coefficient of the effect of scientific application; if "medium" was included, both of these coefficients increased with the total evaluation of the impact of scientific application, but the coefficient of the extent of scientific application was still less than the coefficient of the effect (Table 7). Furthermore, the order of the correction coefficients, from the greatest to the least, of the extent and effect of scientific application with the impacts of the scientific application on the four aspects of institutional change was as follows: the methods of desertification control, the major actors in desertification control, the laws and regulations, and the types of property rights (Table 7).

3.1.4. *The relationship with results of desertification control*

Except for the extent of adoption and implementation of SDCM and the impact of the scientific application on the types

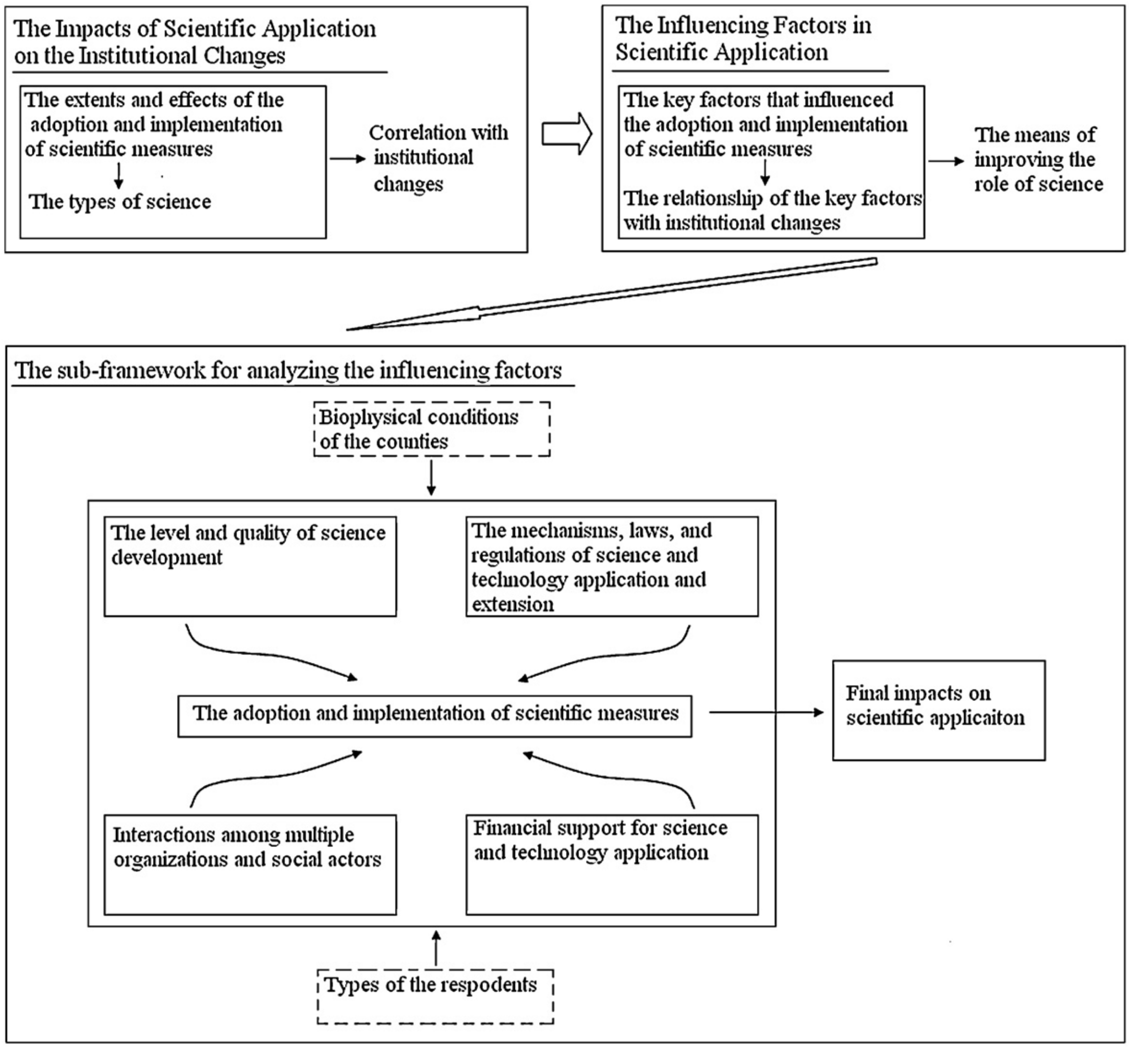

Fig. 3 – Analytical framework.

of property rights, the other aforementioned variables (effects of the scientific application, impact of the scientific application on the methods of desertification control, laws and regulations, major actors in desertification control, and the total evaluation of the impact of scientific application on institutional change) all had high correlations with the results of desertification (Table 8a and b).

3.2. *Problems of scientific application and their improvements*

3.2.1. *Problems influencing scientific application*

Among all of the 16 choices for the problems influencing the scientific application, 11 choices were emphasized by more than 30% of the survey respondents for the choices deemed "very important" or "important," but more than 25% of the survey respondents indicated that all 16 choices were "very important" or "important." The six most highlighted problems were (1) the government bureaucracy and corruption, (2) the lack of scientific knowledge of local conditions, (3) the lack of effective communication between the scientists and local people, (4) the inadequate attention of the local government to the function of science and technology in desertification control, (5) the lack of science suited for the local conditions, and (6) the lack of effective systems of science and technology transformation, extension and application (Table 9). The interviewees also emphasized these problems. For example, a Mongolian person in Xilinhaote City noted that the local people in fact were the real experts on desertification control, and the scientists should respect them and learn from them. He also argued that the major problems of scientific application in desertification control were a combination of local contexts and the mechanism by which the scientific measure is applied. Even many government officials, such as the director of the County Bureau in one county and the director of the Environmental Bureau in one city, realized the importance of local knowledge.

3.2.2. *Improvements to scientific application*

With the exception of the sixth choice (the others), the 15 other choices for the improvements to scientific application were identified by more than 47% of the survey respondents, who indicated that the choices were "very important" and "important." The six most highlighted improvement methods

Table 3 – Extents and effects of scientific application in desertification control as rated by the survey respondents in the 12 counties (2011).

Types and options	Average	Counties											
		Linze (%)	Minqin (%)	Zhongwei (%)	Yanchi (%)	Dengkou (%)	Ejin Horo (%)	Xinbaerhuzuo (%)	Xilinhot (%)	Naiman (%)	Duolun (%)	Wengniute (%)	Aohan (%)
(a) Extents of scientific application													
Very large	8.8	13.0	2.1	16.0	5.0	15.7	9.0	6.6	10.5	5.0	6.2	10.8	5.1
Large	23.2	39.9	16.5	38.0	11.7	27.0	41.8	9.1	18.2	9.2	28.5	22.9	16.0
Accumulation[a]	40.0	52.8	18.6	54.0	16.7	42.8	50.7	15.7	28.7	14.3	34.6	33.7	21.1
Medium	38.0	25.9	48.6	31.9	55.5	27.7	25.4	47.9	37.3	33.6	30.4	43.6	48.0
Total[b]	70.0	78.8	67.3	85.9	72.2	70.4	76.1	63.6	66.0	47.9	65.0	77.4	69.1
(b) Effects of scientific application													
Very large	7.9	6.7	3.0	11.1	4.3	7.7	4.3	32.1	6.1	7.4	4.9	1.4	5.2
Large	22.0	33.3	15.4	32.9	13.3	34.4	13.0	15.8	26.8	7.6	28.8	20.5	21.8
Accumulation	29.5	40.0	18.5	40.0	17.6	42.1	17.4	47.8	32.9	15.0	33.8	21.8	27.0
Medium	39.5	33.7	51.8	38.5	50.2	31.8	46.1	30.2	32.2	16.0	37.1	57.3	48.5
Total	69.3	73.7	70.2	82.5	67.9	73.8	63.5	78.0	65.1	31.0	70.9	79.1	75.6

[a] The total percentage of "very large" and "large" as rated by survey respondents.
[b] The total percentage of "very large" "large" and "medium" as rated by survey respondents.

were (1) improving the knowledge of scientists on the local conditions, (2) improving the attention of the central government to the function of science and technology in desertification control, (3) improving the attention of the local government to the function of science and technology in desertification control, (4) reducing the government bureaucracy and corruption and increasing its efficacy, (5) improving the effective communication between the scientists and local people, especially farmers and pastoralists, and (6) improving the attention of society to the function of science and technology in desertification control (Table 10). Of these six improvements, four corresponded to the most important aforementioned problems (the second and sixth improvements did not), although they existed in an order different from their relative position above. The interviewees, including a very famous professor at the Naiman Desertification Research Station, also identified the importance of government support, especially for the extension of scientific and technological research.

3.3. *Correlation coefficients of the biophysical conditions of the counties and the types of the respondents with the research variables*

Although not all the biophysical conditions of the counties and types of the respondents (control variables in the study) were significantly correlated with the research variables covered in Tables 3–6, 9 and 10, their correlation coefficients indicated: (1) except for the three elements of the biophysical conditions (latitude, population density, annual average evaporation), which had no significant correlation with any research variables, three elements of the biophysical conditions had negative correlation with some of the research variables, and three elements had positive correlation with some, although these elements had different numbers of significant coefficients with the research variables; (2) except for four types of survey respondents (desert control stations, rural grassroots organizations, organizations of technology developments and promotion in rural areas, religious groups), which had no significant correlation with the research variables, six types of the survey respondents had negative correlation with some of the research variables, and five types of the survey respondents had positive correlation with some, although the types of respondents had different numbers of significant coefficients with the research variables (Table 11).

4. Discussion

4.1. *Significance of scientific application on institutional change*

4.1.1. *Differences of scientific application to desertification control*

The large survey percentage of "very large," "large," and "medium" responses indicated that, in general, both the extents and effects of scientific application in desertification control were significant, but the relatively small percentage of "very large" and "large" responses indicated that both the extents and effects still had room for improvement. Furthermore, the

Table 4 – Types of knowledge used in desertification control rated by survey respondents in the 12 counties (2011).

Types of knowledge	Average (order)		Linze (%)		Minqin (%)		Zhong-wei (%)		Yanchi (%)		Dengkou (%)		Ejin Horo (%)		Xinbaer-huzuo (%)		Xilinhot (%)		Naiman (%)		Duolun (%)		Weng-niute (%)		Aohan (%)	
	D[a]	E[b]	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E	D	E
1. Agricultural science and technology	32 [1]	31.8 [1]	42.0 [2]	36.1 [6]	32.6 [1]	31.5 [3]	46.3 [1]	45.4 [2]	27.7 [3]	23.7 [11]	42.6 [2]	39.9 [2]	29.3 [2]	30.4 [6]	22.3 [9]	31.5 [5]	31.8 [6]	36.3 [5]	11.2 [5]	10.8 [4]	27.7 [2]	30.5 [3]	29.5 [3]	35.7 [1]	31.9 [2]	30.0 [4]
2. Agricultural pest control	30.9 [2]	31.2 [3]	43.2 [1]	39.5 [1]	32.1 [2]	32.3 [2]	43.1 [3]	41.9 [5]	26.9 [5]	27.6 [4]	37.5 [4]	38.1 [4]	28.8 [3]	31.2 [4]	24.5 [7]	34.1 [1]	33.5 [5]	37.3 [2]	12.5 [3]	9.2 [8]	25.3 [5]	29.7 [5]	24.4 [5]	26.8 [4]	31.5 [3]	26.9 [7]
3. Zoology or animal biology	30 [3]	28.5 [7]	38.0 [6]	38.3 [2]	31.0 [5]	28.5 [7]	37.2 [9]	36.0 [12]	26.2 [6]	24.3 [9]	33.3 [6]	33.3 [9]	30.9 [1]	19.4 [14]	28.9 [4]	33.4 [2]	34.7 [4]	31.5 [9]	11.7 [4]	9.0 [9]	30.6 [1]	30.6 [2]	30.0 [1]	27.2 [3]	28.3 [5]	30.4 [1]
4. Knowledge of forestry	29.5 [4]	30.9 [4]	37.8 [7]	35.1 [7]	28.8 [9]	28.0 [8]	41.5 [5]	44.5 [3]	27.2 [4]	24.1 [10]	39.2 [3]	39.9 [2]	23.4 [4]	32.9 [2]	21.0 [10]	27.3 [10]	34.8 [3]	36.7 [3]	8.3 [12]	10.0 [5]	26.0 [3]	33.2 [1]	29.8 [2]	30.5 [2]	28.8 [4]	28.3 [5]
5. Knowledge on combating desertification and dust storms	29 [5]	29.2 [5]	35.4 [10]	35.1 [7]	29.1 [8]	29.3 [6]	44.3 [2]	47.2 [1]	32.3 [2]	28.1 [2]	42.7 [1]	40.4 [1]	20.6 [9]	25.7 [9]	28.7 [5]	28.5 [9]	36.9 [1]	42.2 [1]	16.7 [2]	5.8 [16]	24.9 [6]	25.5 [9]	14.3 [10]	21.3 [9]	25.4 [8]	21.8 [11]
6. General knowledge of climate	28.8 [6][c]	29.2 [5]	27.3 [14]	31.8 [13]	29.4 [7]	26.1 [11]	38.9 [6]	41.2 [8]	35.4 [1]	32.2 [1]	33.0 [7]	38.1 [4]	20.0 [11]	25.0 [11]	40.4 [1]	32.7 [4]	35.6 [2]	36.6 [4]	18.4 [1]	15.0 [2]	22.7 [9]	17.9 [16]	18.0 [6]	23.4 [8]	33.3 [1]	30.2 [3]
7. Hydraulic engineering knowledge	25.8 [7]	27.7 [9]	34.9 [11]	36.4 [5]	28.3 [10]	28.0 [7]	42.9 [4]	34.6 [13]	21.1 [13]	20.7 [15]	32.1 [8]	33.8 [8]	23.4 [4]	32.9 [3]	30.7 [2]	27.0 [12]	25.3 [13]	31.4 [10]	8.6 [13]	9.5 [7]	25.9 [4]	28.8 [6]	13.6 [12]	26.5 [6]	27.0 [7]	22.9 [10]
8. Local and indigenous knowledge	25.4 [8]	26.8 [10]	32.4 [12]	32.8 [11]	30.5 [6]	32.3 [1]	36.7 [13]	39.9 [9]	24.2 [8]	25.9 [5]	29.0 [10]	28.7 [12]	21.3 [7]	30.0 [7]	28.3 [6]	25.6 [13]	25.6 [12]	29.9 [13]	8.8 [8]	9.8 [6]	23.3 [7]	24.1 [10]	26.2 [4]	18.2 [11]	23.2 [10]	24.6 [8]
9. Specific knowledge on local desertification	24.5 [9]	26.5 [11]	26.5 [16]	33.1 [10]	31.8 [3]	29.8 [5]	37.1 [11]	44.0 [4]	24.7 [7]	22.4 [13]	31.2 [9]	35.4 [6]	17.1 [13]	27.1 [8]	20.1 [12]	23.4 [16]	31.4 [8]	35.4 [6]	7.3 [14]	7.8 [12]	23.0 [8]	23.8 [11]	16.9 [7]	15.1 [13]	23.5 [9]	20.1 [14]
10. General knowledge of environmental governance	24.3 [10]	25.4 [12]	37.1 [9]	29.6 [15]	21.0 [12]	24.2 [13]	36.8 [12]	41.6 [7]	20.7 [14]	18.9 [16]	36.3 [5]	32.6 [10]	20.6 [9]	22.9 [13]	19.6 [13]	25.3 [14]	31.7 [7]	33.9 [7]	10.2 [6]	8.5 [10]	20.6 [13]	28.2 [7]	13.6 [12]	19.3 [10]	21.3 [14]	20.2 [13]
11. Poultry and livestock disease control	24.2 [11]	28.5 [7]	37.7 [8]	37.5 [3]	31.5 [4]	31.1 [4]	37.2 [9]	38.8 [10]	21.2 [12]	25.5 [6]	21.5 [14]	30.0 [11]	14.4 [15]	27.1 [8]	17.3 [15]	29.3 [7]	29.6 [10]	31.1 [3]	5.1 [16]	7.4 [13]	22.0 [11]	30.0 [4]	15.9 [9]	26.8 [4]	27.3 [6]	27.2 [6]
12. Land development and construction planning	22.9 [12]	31.3 [2]	38.9 [3]	36.0 [3]	28.3 [10]	27.1 [10]	37.9 [7]	41.8 [6]	14 [16]	27.7 [3]	25.2 [12]	34.6 [7]	21.2 [8]	33.3 [1]	18.9 [14]	33.0 [3]	31.3 [9]	33.9 [7]	6.1 [15]	28.6 [1]	17.4 [15]	25.9 [8]	9.2 [15]	23.9 [7]	22.5 [12]	30.3 [2]
13. Knowledge of laws and regulations	22.8 [13]	24.5 [13]	32.3 [13]	33.4 [9]	19.1 [14]	22.0 [14]	31.7 [15]	31.4 [16]	21.6 [11]	22.9 [12]	26.1 [11]	26.9 [13]	22.0 [6]	30.7 [5]	20.6 [11]	29.0 [8]	29.2 [11]	30.3 [12]	8.7 [10]	8.0 [11]	21.2 [12]	22.1 [12]	16.8 [8]	17.1 [12]	22.3 [13]	19.7 [15]
14. Understanding on local social relations	21.1 [14]	22.4 [15]	27.1 [15]	27.4 [16]	18.9 [15]	19.9 [15]	33.3 [14]	36.2 [11]	21.7 [10]	24.5 [8]	20.7 [15]	26.7 [14]	17.1 [13]	19.4 [14]	29.4 [3]	27.2 [11]	23.8 [15]	28.0 [15]	8.8 [8]	7.0 [14]	22.7 [9]	20.7 [13]	13.7 [11]	12.3 [14]	22.6 [11]	19.3 [16]
15. Knowledge of social management	20.3 [15]	21.8 [16]	38.3 [5]	30.2 [14]	16.4 [16]	18.8 [16]	29.3 [16]	33.6 [14]	24.0 [9]	21.7 [14]	22.4 [13]	22.6 [15]	19.9 [12]	19.3 [16]	23.2 [8]	23.5 [15]	24.9 [14]	29.8 [14]	8.7 [10]	6.8 [15]	18.5 [14]	19.8 [15]	7.5 [16]	12.1 [15]	19.3 [15]	23.9 [9]
16.Others	18.6 [16]	23.3 [14]	38.6 [4]	32.5 [12]	19.9 [13]	26.1 [11]	37.3 [8]	33.3 [15]	16.2 [15]	24.7 [7]	14.0 [16]	19.8 [16]	10.3 [16]	23.9 [12]	15.7 [16]	30.0 [6]	22.7 [16]	27.9 [16]	9.9 [7]	12.5 [3]	11.3 [16]	20.6 [14]	12.6 [14]	7.8 [16]	14.3 [16]	21.0 [12]

[a] Extents of scientific application.
[b] Effects of scientific application.
[c] [1]–[16] refers to the rank.

Table 5 – Impact of scientific application on institutional change as rated by the survey respondents in the 12 counties (2011).

Types and options	Average	Counties											
		Linze (%)	Minqin (%)	Zhongwei (%)	Yanchi (%)	Dengkou (%)	Ejin Horo (%)	Xinbaerhuzuo (%)	Xilinhot (%)	Naiman (%)	Duolun (%)	Wengniute (%)	Aohan (%)
(a) The impact of scientific application on methods of desertification control													
Very large	9.1	17.9	3.5	15.6	4.4	10.7	5.6	14.3	11.9	8.5	8.7	2.0	5.7
Large	26.0	35.8	16.4	40.0	14.2	32.5	29.0	21.4	36.0	15.1	25.9	21.7	24.4
Accumulation	35.1	53.6	19.9	55.6	18.6	43.2	34.6	35.7	47.8	23.6	34.6	23.7	30.1
Medium	39.0	30.3	52.0	34.1	49.9	31.6	45.8	28.6	26.6	33.6	41.6	48.4	44.9
Total	74.0	83.9	72.0	89.6	68.5	74.8	80.4	64.3	74.5	57.2	76.2	72.1	75.0
(b) The impact of scientific application on types of property rights													
Very large	10.1	10.6	10.4	12.8	3.8	17.0	7.1	12.7	13.8	8.3	9.0	3.0	12.1
Large	22.7	23.9	17.6	28.5	16.5	21.6	27.0	12.7	24.7	17.0	23.5	32.5	27.2
Accumulation	32.8	34.5	27.9	41.3	20.2	38.6	34.1	25.4	38.5	25.3	32.5	35.5	39.3
Medium	39.8	33.1	50.3	37.0	50.4	26.1	33.3	56.7	27.0	37.7	36.7	50.6	38.4
Total	72.5	67.6	78.2	78.4	70.6	64.7	67.5	82.0	65.5	63.0	69.2	86.1	77.7
(c) The impact of scientific application on laws and regulations[a]													
Very large	10.7	11.4	9.0	14.6	9.7	10.7	7.1	15.1	18.9	7.0	9.9	2.2	12.5
Large	20.8	25.7	19.7	28.6	20.2	23.5	21.0	23.4	22.5	10.6	19.6	13.9	21.1
Accumulation	31.6	38.0	28.7	43.2	29.9	34.2	28.1	38.5	41.4	17.5	29.5	16.1	33.6
Medium	30.7	31.8	38.3	31.4	34.7	25.0	19.0	23.3	23.5	25.6	36.5	39.9	39.6
Total	62.3	69.8	67.0	74.5	64.5	59.1	47.1	61.8	65.0	43.0	66.0	56.0	73.3
(d) The impact of scientific application on major actors of desertification control													
Very large	14.4	14.8	7.0	21.8	7.5	14.4	25.3	29.4	13.3	7.9	17.4	3.3	10.7
Large	26.1	37.7	23.0	36.3	12.8	24.6	35.6	32.3	25.2	12.3	21.9	21.5	29.7
Accumulation	40.5	52.5	30.0	58.1	20.3	38.9	60.9	61.7	38.9	20.2	39.4	24.5	40.3
Medium	37.6	31.4	49.6	34.6	50.4	31.7	25.3	13.7	29.9	37.4	44.5	61.0	41.3
Total	78.1	83.9	79.6	92.7	70.7	70.7	86.2	75.5	68.8	57.6	83.9	85.8	81.7
(e) The total impact of scientific application on institutional change[b]													
Very large	11.1	13.7	7.5	16.2	6.4	13.2	11.3	17.9	14.5	7.9	11.3	2.6	10.3
Large	23.9	30.8	19.2	33.4	15.9	25.6	28.2	22.5	27.1	13.8	22.7	22.4	25.6
Accumulation	35.0	44.7	26.6	49.6	22.3	38.7	39.4	40.3	41.7	21.7	34.0	25.0	35.8
Medium	36.8	31.7	47.6	34.3	46.4	28.6	30.9	30.6	26.8	33.6	39.8	50.0	41.1
Total	71.7	76.3	74.2	83.8	68.6	67.3	70.3	70.9	68.5	55.2	73.8	75.0	76.9

[a] The numbers in this table are the average values of the evaluation of the impact of scientific application on four types of laws and regulations presented in Table 6.

[b] The numbers in this table are the average values of the evaluation of the impact of scientific application on four aspects of institutional change provided in this table (a)–(d).

Table 6 – Impact of scientific application on the four types of laws and regulations as rated by the survey respondents in the 12 counties (2011).

Types and options	Average	Counties											
		Linze (%)	Minqin (%)	Zhongwei (%)	Yanchi (%)	Dengkou (%)	Ejin Horo (%)	Xinbaerhuzuo (%)	Xilinhot (%)	Naiman (%)	Duolun (%)	Wengniute (%)	Aohan (%)
(a) The impact of scientific application on laws and regulations on property rights arrangements													
Very large	13.3	13.5	9.4	18.5	15.9	9.6	8.0	22.2	21.2	13.4	6.9	5.1	16.2
Large	18.2	27.3	20.1	26.8	19.4	24.8	18.4	7.8	20.3	7.5	18.1	8.1	20.2
Accumulation	31.6	40.8.	29.5	45.2	35.5	34.4	26.4	30.1	41.5	20.9	25	13.1	36.4
Medium	30.6	28.6	38.3	29.8	32.8	25.7	20.8	11.4	25.3	27.4	41.1	43.3	42.3
Total	62.1	69.4	67.8	75	68.1	60.1	47.2	41.5	66.8	48.3	66.1	56.5	78.7
(b) The impact of scientific application on basic laws on desertification control													
Very large	8.4	8.6	7.0	8.7	7.3	7.3	6.3	16.4	15.6	5.0	7.6	0.9	9.8
Large	24.2	25.5	19.8	33.7	24.5	24.3	21.3	30.1	27.6	13.5	20.0	24.7	24.9
Accumulation	32.5	34.1	26.8	42.4	31.8	31.7	27.6	46.4	43.2	18.5	27.6	25.6	34.7
Medium	31.3	33.1	40.2	33.4	34.1	24.8	20.5	25.6	21.6	25.25	38.3	41.1	37.3
Total	63.8	67.2	67.0	75.8	65.9	56.4	48.0	72.0	64.8	43.6	65.9	66.7	72.0
(c) The impact of scientific application on laws and regulations on implementing the basic laws													
Very large	8.7	9.2	8.3	11.0	6.6	8.3	7.1	12.1	17.7	4.1	9.3	0.7	10.3
Large	21.3	28.0	19.8	27.7	18.5	22.0	19.7	37.5	20.6	11.4	18.8	11.8	19.6
Accumulation	30.0	37.2	28.2	38.7	25.2	30.3	26.8	49.6	38.3	15.5	28.1	12.5	29.9
Medium	31.4	33.8	33.2	33.9	40.0	27.1	19.7	22.7	25.3	25.9	38.2	36.5	39.9
Total	61.4	71.0	61.4	72.6	65.2	57.3	46.5	72.3	63.6	41.4	66.3	49.0	69.8
(d) The impact of scientific application on methods of desertification control													
Very large	12.3	14.3	11.1	20.3	9.0	17.7	7.1	9.5	21.0	5.3	15.8	2.1	13.8
Large	19.8	25.5	19.1	26.0	18.2	22.7	24.4	18.3	21.6	9.8	21.5	11.1	19.7
Accumulation	32.1	39.8	30.2	46.3	27.1	40.5	31.5	27.9	42.6	15.1	37.3	13.2	33.4
Medium	29.6	31.6	41.5	28.4	31.7	22.3	15.0	33.4	21.9	23.7	28.2	38.5	39.0
Total	61.7	71.4	71.7	74.6	58.9	62.7	46.5	61.3	64.6	38.8	65.5	51.7	72.5

Table 7 – Correlation between the extents and effects of scientific application with the impact of scientific application on methods of desertification control, on types of property rights, on laws and regulations, on major actors of desertification control, and on institutional change (Pearson's).

Variables		Variables									
		The impact of scientific application on methods of desertification control		The impact of scientific application on types of property rights		The impact of scientific application on laws and regulations		The impact of scientific application on major actors of desertification control		Total evaluation of the impact of scientific application on institutional change	
		Coef.[c]	Sig.[d]	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Extents of scientific application	Accumulation[a]	0.734**	0.007	0.665*	0.018	0.330	0.295	0.574	0.051	0.689*	0.013
	Total[b]	0.860**	0.000	0.360	0.251	0.494	0.103	0.821**	0.001	0.823**	0.001
Effects of scientific application	Accumulation	0.752**	0.005	0.387	0.214	0.736**	0.006	0.631*	0.028	0.762**	0.004
	Total	0.615*	0.033	0.625*	0.030	0.711**	0.010	0.742**	0.006	0.867**	0.000

[a] The accumulation of percentages of "very large" and "large" rated by survey respondents.
[b] Total number of percentages of "very large", "large" and "medium" rated by survey respondents.
[c] Coef. = coefficients. It is also applied in other tables.
[d] Sig. = significance. It is also applied in other tables.
* $P < 0.05$ (2 tailed).
** $P < 0.01$ (2 tailed).

large correlation coefficient between the extents and effects of scientific application of "very large," "large" and "medium" indicated that the extents and effects of scientific application were correlated, but their smaller coefficient for the "very large" and "large" responses indicated that the large extent of scientific application did not equate to major effects. These findings were consistent with the arguments of the interviewees. Many studies (Bauer and Stringer, 2009; Reynolds et al., 2007; Thomas, 1997; Xia and Fan, 2000) had proposed improving the participation of science, scientists, scholars, and more in desertification control and environmental governance and had the a priori assumption that significant participation would lead to major effects. However, our findings indicated that, although both the participation extents and effects are important, only the improvements of participation extent cannot lead to major participation effects. Thus, we need to not only distinguish the participation effects and participation extent, but we also need to pay more attention to the effects. Furthermore, we must further study the other factors influencing the scientific application effects in desertification control.

4.1.2. *Most important sciences in desertification control*

Although the existing literature has stressed the important role of science in desertification control (Bauer and Stringer, 2009; Reynolds et al., 2007) and its scientific contributions (Thomas, 1997), as well as developed the types of desert science (Xia and Fan, 2000), the major types of sciences applied in desertification control have not been carefully studied. Our study clarified the important sciences with the greatest application extents and effects. This is valuable for policymaking and for the implementation of desertification control. Furthermore, the differences between the sciences with the greatest application extents and with the greatest effects indicated that the scientific application in desertification control should be adjusted based on their effects. While the science of land development and construction planning had not been included in the six most important types of sciences with the greatest extents, it was deemed the second-most important science with the greatest effect. Although zoology or animal biology was the second science with the greatest extent, it was not included in the six most important sciences with the greatest effect. This suggested that, to improve the success rate of desertification control, we should pay more attention to the science of land development and construction planning rather than to zoology or animal biology. Although previous studies (e.g., Yang et al., 2010) showed that agricultural technicians had little impact on land amelioration in China, this study indicated that agricultural science and technology was deemed the most important science with both the greatest extent and the greatest effect. Furthermore, agricultural pest control was the second-most important science with the greatest extent and the third-most important science with the greatest effect. The findings of this study suggested: (1) the impact of agricultural science and technology and the impact of agricultural technicians on land amelioration were two different things and could not be used to measure each other, (2) the little impact of agricultural technicians on land amelioration did not significantly restrict the impact of agricultural science and technology in desertification control, and (3) researchers should go further to explore the mechanisms of the application and extension of agricultural science and technology and clarify the major positive actors in the process of its application extension in the future.

4.1.3. *Significance of scientific application in institutional change*

Faced by complex linkages between the scientific application and the results of desertification control, the role of scientific application in the institutional changes of desertification control needs to be studied. Both the survey respondents and the interviewees indicated that scientific application significantly influenced the institutional change of desertification control, and the percentages of the survey respondents, who indicated that scientific application significantly influenced

Table 8 – Correlation of scientific application with the results of desertification control as rated by the survey respondents in the 12 counties (2011).

Options	Average	Counties											
		Linze (%)	Minqin (%)	Zhongwei (%)	Yanchi (%)	Dengkou (%)	Ejin Horo (%)	Xinbaerhuzuo (%)	Xilinhot (%)	Naiman (%)	Duolun (%)	Wengniute (%)	Aohan (%)
(a) Results of desertification control													
Very large	8.8	8.6	3.9	16.1	7.2	4.9	11.2	29.6	5.2	8.1	5.9	1.8	2.9
Large	21.8	37.5	10.4	29.6	22.0	22.8	16.8	25.6	24.4	12.7	28.4	15.3	15.5
Accumulation	30.5	46.2	14.3	45.7	29.1	27.7	28.0	55.2	29.6	20.8	34.3	17.1	18.4
Medium	38.4	30.2	43.8	35.7	43.0	42.3	39.2	24.7	39.2	35.0	40.5	42.1	45.2
Total	68.9	76.4	58.1	81.4	72.1	70.0	67.2	79.9	68.8	55.8	74.8	59.2	63.6

Variables	Variables: Results of desertification control			
	Accumulation[a]		Total[b]	
	Coefficients	Significance	Coefficients	Significance
(b) Correlation coefficients of extent of scientific application, effects of scientific application, evaluation of the impact of scientific application on four aspects of institutional change, and total evaluation of the impact of scientific application on institutional change with results of desertification control (Pearson's)				
Extent of scientific application	0.335	0.287	0.464	0.129
Effects of scientific application	0.781**	0.003	0.545	0.067
The impact of scientific application on methods of desertification control	0.656*	0.020	0.505	0.094
The impact of scientific application on types of property rights	0.002	0.994	0.028	0.931
The impact of scientific application on laws and regulations	0.669*	0.017	0.509	0.091
The impact of scientific application on major actors of desertification control	0.725**	0.008	0.380	0.223
Total evaluation of the impact of scientific application on institutional change	0.683*	0.014	0.473	0.120

[a] The accumulation of percentages of "very large" and "large" rated by survey respondents.
[b] Total number of percentages of "very large", "large" and "medium" rated by survey respondents.
* $P < 0.05$ (2 tailed).
** $P < 0.01$ (2 tailed).

Table 9 – Problems of scientific application in desertification control rated by survey respondents in the 12 counties (2011).

	Average (order)	Linze (%)	Minqin (%)	Zhongwei (%)	Yanchi (%)	Dengkou (%)	Ejin Horo (%)	Xinbaerhuzuo (%)	Xilinhot (%)	Naiman (%)	Duolun (%)	Wengniute (%)	Aohan (%)
1. Government bureaucracy and corruption	37.8 [1]	37.2	56.5	41	27.1	46.7	34	39.2	46.6	15.9	36.3	31.1	42.2
2. Scientists' inadequate knowledge of local conditions	36.1 [2]	30.9	50	42.8	25.9	39.3	42.4	46.7	32.0	40	30	17.3	35.9
3. Lack of effective communication between scientists and local people, especially farmers and herdsmen	35.2 [3]	36.9	48.4	42.6	25.7	38.1	34	38.8	39.8	14.3	34.8	31.7	37.1
4. Inadequate attention of local government to the function of science and technology in desertification control	34.8 [4]	33.3	48.9	41	27.1	44.9	34	43.4	41.8	13.1	31.7	19.1	39.7
5. Lack of science suited to local conditions	34.5 [5]	34.3	47.3	39.9	27.8	41.2	29.3	48.6	34.2	14.3	33.2	25.1	39.2
6. Lack of effective systems of science and technology transformation, extension and application	34.4 [6]	36.6	42.2	39.6	22	44.4	34.8	41.7	39.1	9.4	38	30	35.2
7. Low quality of farmers and pastoralists	33.0 [7]	38.4	36.5	42.4	21.8	38.4	33.3	35.5	37.6	17.8	35.7	23.3	34.8
8. Imperfect laws and regulations of science and technology application	32.7 [8]	41.6	41.9	40	18.8	39.6	30.5	41.8	37.5	12.3	32	22.9	33.8
9. Inadequate attention of society to the function of science and technology in desertification control	31.9 [9]	42.2	43.2	34.3	16.2	44.9	34	35.6	33.5	13.6	29	23.4	33.2
10. Low financial support for science and technology application	31.9 [9]	36.8	41.6	47.7	21.5	39.7	24.1	35.6	35.9	9.4	30.6	22.6	36.7
11. Inadequate attention of the central government to the function of science and technology in desertification control	31.4 [11]	33.2	36.5	42.1	30.5	36.7	34.8	35	32.0	15.9	25.6	13.2	41.1
12. Lack of respect of government and scientists for local people	29.3 [12]	28.5	42.7	35.3	26	28.1	34.3	35.1	28.2	12.8	25.9	20.3	34.4
13. Low levels of science and technology development	26.9 [13]	31.3	29.7	37.1	21.3	31.4	22.7	32.1	32.2	12.8	22.8	23.2	26.3
14. Local people's non-cooperation	26.8 [14]	32.3	29.7	33.3	22	23.9	30	44.2	26.2	14	21.1	13.3	31.7
15. Scientists' sabotage	26.6 [15]	25.4	36.2	33.7	24.5	28.3	27.7	34.1	24.5	12.2	23.9	19.1	29.1
16. Others	25.8 [16]	30	25.5	34.4	24.6	31.6	23.4	34.6	25.1	23.2	15	8.3	33.3

Table 10 – Improved methods of scientific application in desertification control rated by survey respondents in the 12 counties (2011).

	Average (order)	Linze (%)	Minqin (%)	Zhongwei (%)	Yanchi (%)	Dengkou (%)	Ejin Horo (%)	Xinbaerhuzuo (%)	Xilinhot (%)	Naiman (%)	Duolun (%)	Wengniute (%)	Aohan (%)
1. Improving scientists' knowledge on local conditions	56.7 [1]	66.7	62.6	57.7	31.9	63.7	44.3	44.3	54.6	17.1	57.6	51.9	45.0
2. Improving the attention of the central government to the function of science and technology in desertification control	52.3 [2]	70.0	62.0	59.1	33.0	72.2	41.1	42.3	61.9	17.4	61.9	49.5	57.1
3. Improving the attention of local government to the function of science and technology in desertification control	52.2 [3]	64.5	62.8	59.1	35.6	72.1	43.3	45.0	63.5	13.1	63.2	49.7	53.9
4. Reducing government bureaucracy and corruption and improving its efficacy	50.7 [4]	64.9	62.2	55.6	31.7	68.6	50.0	45.2	63.1	12.3	58.8	46.5	49.6
5. Improving the effective communication between scientists and local people, especially farmers and pastoralists	50.3 [5]	66.0	59.0	56.9	32.8	63.7	41.8	51.1	61.8	13.1	55.9	52.7	48.5
6. Improving the attention of society to the function of science and technology in desertification control	49.5 [6]	64.9	58.9	57.5	23.6	69.1	47.5	43.6	58.7	13.8	58.3	53.1	45.0
7. Improving the respect of government and scientists for local people	49.3 [7]	68.4	60.4	57.1	32.5	64.6	44.7	42.8	56.6	11.0	56.0	50.1	47.1
8. Improving the systems of science and technology transformation, extension and application	49.1 [8]	63.0	47.5	58.4	28.6	70.4	48.2	46.5	55.2	14.3	58.0	53.9	45.4
9. Developing more science suited to local conditions	49.1 [8]	66.7	55.5	53.4	30.7	69.5	47.5	43.0	56.1	13.4	56.3	48.9	48.2
10. Improving scientists' efforts	48.8 [10]	61.9	57.7	57.5	27.1	65.5	48.9	50.0	56.7	12.9	55.7	47.9	43.3
11. Improving the financial support for science and technology application	48.6 [11]	64.6	57.7	58.7	25.9	68.6	42.4	48.9	57.3	11.3	56.6	47.6	43.9
12. Improving local people's cooperation	48.6 [11]	68.1	54.9	55.0	31.6	67.1	47.5	42.7	58.1	11.0	55.7	46.7	45.0
13. Improving the levels of science and technology development	48.0 [13]	59.7	49.2	55.6	26.8	69.1	41.8	46.5	58.8	14.8	57.0	49.7	47.1
14. Improving the laws and regulations of science and technology application	47.9 [14]	67.3	51.1	52.6	27.3	68.6	40.7	44.2	55.9	15.4	56.8	45.9	48.5
15. Improving the quality of farmers and pastoralists	47.4 [15]	63.8	51.4	55.7	27.5	65.5	48.9	44.3	56.2	13.0	55.3	41.3	45.7
16. Others	35.1 [16]	51.5	35.5	46.0	28.8	27.0	33.3	30.2	45.2	20.3	38.6	24.9	39.7

Table 11 – Correlation between the biophysical conditions of the counties and types of the respondents with the other variables as rated by the survey respondents in the 12 counties (Pearson's).

Variables	Coefficients																
	Biophysical conditions						Types of the respondents										
	Longitude	Climate division	Total area	Annual average temperature	Annual average precipitation	Annual wind speed	Farmers	Middle schools	General research institutes	Government	Businesses	Universities	Other public institutes	NGOs	News media	International organizations	Others
Total numbers of coefficients	22	4	1	8	23	27	1	1	4	1	20	20	15	1	17	30	23
1. Extents and effect of scientific application (see Table 3)																	
(1) Accumulated[a] extents of scientific application			−0.638*										0.589*	0.631*			
(2) Total[b] extents of scientific application	−0.585*			0.772*													−0.596*
(3) Total effects of scientific application						0.754**									−0.810**	−0.779**	−0.660*
2. Extents of the 16 types of knowledge used in desertification control (see Table 4)																	
(1) Agricultural science and technology	−0.705*			0.782**	−0.649*						0.631*						−0.589*
(2) Agricultural pest control	−0.731**			0.726**	−0.701*						0.693*						
(3) Zoology or animal biology	−0.577**					0.709**										−0.778**	−0.647*
(4) Knowledge of forestry	−0.606*			0.673*	−0.584*											−0.597*	−0.656*
(5) Knowledge on combating desertification and dust storms	−0.617*	0.657*			−0.703*						0.828**						
(6) General knowledge of climate	−0.216																
(7) Hydraulic engineering knowledge	−0.604*				−0.622*												
(8) Local and indigenous knowledge	−0.641*			0.603*	−0.697*										−0.608*	−0.620*	
(9) Specific knowledge on local desertification	−0.628*			0.598*	−0.663*						0.617*						
(10) General knowledge of environmental governance	−0.658*				−0.69*						0.873**		0.638*				
(11) Poultry and livestock disease control	−0.636*				−0.631*												−0.600*
(12) Land development and construction planning	−0.676*				−0.711*												
(13) Knowledge of laws and regulations	−0.589*										0.818**		0.706*				
(14) Knowledge of social management	−0.686*	0.631*			−0.607*						0.775**						
3. Effects of the 16 types of knowledge used in desertification control (see Table 4)																	
(1) Agricultural science and technology						0.596*											−0.577*
(2) Agricultural pest control	−0.607*				−0.63*	0.581*					0.620*					−0.698*	
(3) Zoology or animal biology						0.602*									−0.651*	−0.673*	
(4) Knowledge of forestry						0.608*					0.598*		0.597*			−0.640*	
(5) Knowledge on combating desertification and dust storms	−0.592*				−0.621*						0.747**						
(6) General knowledge of climate											0.718**						
(7) Hydraulic engineering knowledge	−0.539*					0.638*						−0.592*	0.591*			−0.731**	
(8) Local and indigenous knowledge	−0.74**	0.616*		0.672*	−0.655*												
(9) Specific knowledge on local desertification	−0.687*	0.592*			−0.681*						0.707*		0.598*				
(10) General knowledge of environmental governance											0.664*						
(11) Poultry and livestock disease control	−0.6*					0.656*										−0.732**	−0.620*
(12) Land development and construction planning											0.661*		0.673*				
(13) Knowledge of laws and regulations											0.634*		0.686*			−0.620*	
4. Four aspects of institutional changes (see Table 5)																	
(1) Accumulated impact of scientific application on methods of desertification control											0.736**		0.709**				

(2) Total impact of scientific application on methods of desertification control	−0.590*		0.687*												
(3) Accumulated impact of scientific application on types of property rights								−0.674*			−0.639*	0.650*			
(4) Total impact of scientific application on types of property rights						0.816*	−0.863*						−0.637*		
(5) Accumulated impact of scientific application on laws and regulations										0.717**		0.621*			
(6) Accumulated impact of scientific application on major actors of desertification control												0.583*			
(7) Total impact of scientific application on major actors of desertification control					0.601*										−0.593*
(8) Accumulated "total impact of scientific application on institutional change"										0.602*		0.749**			
(9) Total "total impact of scientific application on institutional change"					0.62*								−0.640*		−0.689*
5. Four types of laws and regulations (see Table 6)															
(1) Accumulated impact of scientific application on laws and regulations on property rights arrangements										0.808**		0.615*			−0.698*
(2) Total impact of scientific application on basic laws on desertification control													−0.647*		
(3) Accumulated impact of scientific application on methods of desertification control									0.639*	0.784**		0.694*			
(4) Total impact of scientific application on methods of desertification control													−0.586*		−0.603*
6. Problems of scientific application in desertification control (see Table 9)															
(1) Government bureaucracy and corruption														−0.658*	−0.579*
(2) Lack of effective communication between scientists and local people, especially farmers and herdsmen					0.598*						−0.594*		−0.599*	−0.702*	−0.593*
(3) Inadequate attention of local government to the function of science and technology in desertification control				−0.578*											
(4) Lack of science suited to local conditions													−0.679*	−0.583*	
(5) Lack of effective systems of science and technology transformation, extension and application					0.067*						−0.685*		−0.648*	−0.772**	
(6) Imperfect laws and regulation of science and technology application				−0.656*											
(7) Inadequate attention of society to the function of science and technology in desertification control				−0.706*				−0.668*			−0.700*			−0.606*	
(8) Low financial support for science and technology application				−0.645*											
(9) Low levels of science and technology development				−0.661*											
(10) Scientists' sabotage													−0.578*		
7. Improvements of scientific application in desertification control (see Table 10)															
(1) Improving scientists' knowledge on local conditions				−0.616*	0.61*						−0.700*		−0.604*	−0.727**	−0.660*
(2) Improving the attention of the central government to the function of science and technology in desertification control					0.625*						−0.677*		−0.576*	−0.690*	−0.679*
(3) Improving the attention of local government to the function of science and technology in desertification control					0.68*						−0.661*		−0.604*	−0.761**	−0.702*
(4) Reducing government bureaucracy and corruption and improving its efficacy					0.692*						−0.708**			−0.786**	−0.654*

Table 11 (*Continued*)

Variables	Coefficients																
	Biophysical conditions						Types of the respondents										
	Longitude	Climate division	Total area	Annual average temperature	Annual average precipitation	Annual wind speed	Farmers	Middle schools	General research institutes	Government	Businesses	Universities	Other public institutes	NGOs	News media	International organizations	Others
(5) Improving the effective communication between scientists and local people, especially farmers and pastoralists						0.682^{*}						-0.669^{*}			-0.606^{*}	-0.782^{**}	-0.650^{*}
(6) Improving the attention of society to the function of science and technology in desertification control					-0.595^{*}	0.624^{*}			-0.618^{*}			-0.773^{**}				-0.714^{**}	-0.614^{*}
(7) Improving the respect of government and scientists for local people						0.674^{*}						-0.682^{*}			-0.591^{*}	-0.773^{**}	-0.690^{*}
(8) Improving the systems of science and technology transformation, extension and application.						0.658^{*}						-0.730^{**}				-0.724^{**}	
(9) Developing more science suited to local conditions						0.682^{*}						-0.731^{**}				-0.770^{**}	-0.635^{*}
(10) Improving scientists' efforts						0.64^{*}			-0.587^{*}			-0.733^{**}				-0.753^{**}	
(11) Improving the financial support for science and technology application					-0.564^{*}	0.603^{*}						-0.701^{*}			-0.591^{*}	-0.717^{**}	
(12) Improving local people's cooperation						0.675^{*}						-0.679^{*}				-0.772^{**}	-0.627^{*}
(13) Improving the levels of science and technology development						0.643^{**}						-0.717^{**}				-0.711^{**}	
(14) Improving the laws and regulation of science and technology application						0.622^{*}						-0.712^{**}				-0.700^{*}	
(15) Improving the quality of farmers and pastoralists						0.648^{*}						-0.708^{**}				-0.728^{**}	

[a] The accumulation of percentages of ''very large'' and ''large'' rated by survey respondents.

[b] Total number of percentages of ''very large'', ''large'' and ''medium'' rated by survey respondents.

[*] $P < 0.05$ (2 tailed).

[**] $P < 0.01$ (2 tailed).

the institutional change, were greater than the ones for the extents and effects of the scientific application in desertification control. That is, the significance of scientific application on institutional change was highlighted. Previous studies (Reynolds et al., 2007; Thomas, 1997; Xia and Fan, 2000) stressed the importance of scientific application in desertification control and even the institutional barriers it faced (Akhtar-Schuster et al., 2011; Bauer and Stringer, 2009; Lidskog and Sundqvist, 2002; Rametsteiner et al., 2011; Winslow et al., 2011), but they had not systematically studied the influence of scientific application on institutional change. Our findings emphasized its influence on institutional change and indicated that this influence might be significant. North (1994a: 1) even noted that understanding institutional change "is essential for further progress in the social sciences in general and economics in particular." The importance of knowledge and technical change in institutional change has also been stressed by many researchers (North, 1990; Ruttan, 1978, 1984; Ruttan and Hayami, 1984; Yang, 2009, 2010; Yang and Wu, 2010). The case study outlined in this paper provides support for this assertion and develops it by highlighting the role of scientific application in the institutional change related to desertification control. Furthermore, this study indicated that scientific application had the greatest influence on the institutional change regarding the major actors in desertification control and the least influence on the laws and regulations. The influences on the methods of desertification control and on the types of property rights were in the middle. Furthermore, the findings demonstrated that, among the four types of laws and regulations, scientific application had the greatest impact on the change of basic laws of desertification and the least impact on the laws and regulations in implementing the basic laws, with the impacts on the changes of desertification control methods and laws and regulations regarding property right arrangements in the middle. These findings provided us with valuable instructions to improve the influence of scientific application on institutional change.

The large correlation coefficient between the extent and effect of scientific application and the total evaluation of the impact of scientific application on institutional change indicated that the large scientific application extents and effects often lead to the significant impact of scientific application on institutional change. The effect of scientific application often had a more important influence on institutional change than did the extent of the application. This was consistent with our assumption and the common sense of people. That is, to change institutions, more attention should be paid to scientific application extents and effects, especially to the effects. Among the four aspects of institutional change, the coefficients of both the scientific application extents and effects with the institutions of the desertification control methods were the largest. The coefficients of the types of property rights were the smallest, while the coefficients for the institutions regarding the major actors in desertification control and regarding the laws and regulations in the middle. The differences between this order and the order of the directly perceived impacts of the respondents on the different aspects of intuitional change suggested a difference between most of the influenced aspects of the long-term instructional change and the aspects of the institutional change possibly influenced by certain scientific application extents and effects or by the sensitivities of the different aspects of institutional change to the scientific application. This is also useful for policymaking and implementation for the scientific application in desertification control. The policymakers and implementers can adjust their policies and policy implementation methods according to both the sensitivities of the different aspects of institutional change and the targeted impacts.

4.1.4. *Relationship between scientific application and desertification control outcome*

Despite many studies emphasizing the functions of science (Reynolds et al., 2007; Thomas, 1997; Xia and Fan, 2000) and knowledge (Chasek et al., 2011; Reed et al., 2011) in desertification control and their influences on the results of desertification control, there has been little research into the relationship between the desertification control results and the institutional changes driven by the applications of science or knowledge. The high and significant correlation between the results of desertification control and the impact of scientific application (and its different aspects) on institutional change indicated that scientific application influenced the results of desertification control by influencing its institutional change and its different aspects, except for the types of property rights. China has three main types of property – public, collective, and private – but the lands were only public and collective. The property rights of the land are often stable and controlled by the government and the collective communities, as emphasized by multiple interviewees. Thus, our finding is reasonable. Furthermore, the relatively low and insignificant coefficient between the results of desertification control and the degree of scientific application demonstrated that the influence of the scientific application effects on the desertification control results were more than the scientific application extent. This suggested again that the policymakers and implementers should pay more attention to the scientific application effects rather than extents.

4.2. Key factors influencing scientific application and its improvements

4.2.1. *Major influencing factors*

More than 25% of the survey respondent emphasis for all 16 listed problems indicated that all of them are important factors influencing scientific application. However, among the six most highlighted problems, two were about government, and the factor of "government bureaucracy and corruption" was rated the most influential. These findings, along with the assertions of the interviewees, indicated that the government behaviors had strongly influenced scientific application, and the government itself was the problem, be it through their bureaucratic and corrupted behaviors or through their inadequate attention to scientific application. However, these findings were different from the ones from other counties that were not dominated by the government (Chittenden, 2011; Corburn, 2007; Gaur and Gaur, 2004; Nelson et al., 2008; Pellant et al., 2004; Reed et al., 2007; van Rooyen, 1998); these other counties often emphasized the self-governance of scientific communities, citizen participation, and democratic collaboration among the various social members and organizations.

Furthermore, among the six most important factors, the lack of understanding of the local conditions and people described three of them: the lack of knowledge of scientists of the local conditions (No. 2); the lack of communication between the scientists and local people (No. 3); and lack of science suited to local conditions. This finding was consistent with previous studies for the importance of local knowledge, local conditions, and local people (Davis, 2005; Mukhopadhyay, 2008; Mwangi and Ostrom, 2009; Nelson et al., 2008; Norton et al., 1998; Ostrom, 1990; Reed et al., 2007; Roba and Oba, 2008; Thomas and Twyman, 2004; Stringer et al., 2009; Winslow et al., 2011). The least important factor among the six was the lack of effective systems for the science and technology transformation, extension and application. This is also consistent with previous studies (Yang, 2009, 2010; Yang et al., 2010; Yang and Wu, 2010) and the contentions of the interviewees, such as the Mongolian people in Xinlinhaote City.

4.2.2. *Major improvements*

All of the listed improvements were highlighted by more than 47% of the survey respondents. That is, the survey respondents highly agree with all of them. Corresponding to the most important problems, both of survey respondents and the interviewees highlighted the improvements of the government behaviors and the understanding of the local conditions and local people. However, the six most important improvements were slightly different from the problems. For example, "government bureaucracy and corruption" was the most identified problem, but "reducing government bureaucracy and corruption" was deemed to be the fourth-most important improvement. While "improving scientists' knowledge on local conditions," "improving attention of central government on the function of science and technology", and "improving attention of local government on the function of science and technology" were deemed to be the three most important improvements. The fifth improvement was about the communication between the scientists and local people.

Furthermore, the improvements stressed the social attention and support for the function of science and technology (the sixth-ranked factor), which was not included in the six most serious problems. The increased emphasis for "scientist knowledge on local conditions," "the attention of the central government", and "the attention of local government" compared to "reducing government bureaucracy and corruption" indicated that the survey respondents had more trust and hopes for changes in the behaviors of scientists than for the government officials, as well as for changes in the attention of the central and local government officials than for reducing their bureaucracy and corruption. That is, if the government officials could improve their allocated attention and support for the function of science and technology, some of the bureaucracy and corruption could be tolerated (because the survey respondents knew that they could not change the bureaucracy and corruption of government officials in China). Furthermore, the increased emphasis on "the attention of central government" compared to "the attention of local government" demonstrated that the respondents also put more trust and hope in the central government than in the local government. All of these findings demonstrated some unique characteristics of a society with powerful government agencies (Bian and Logan, 1996; Jahiel, 1998). Such findings are different from those that would be found in other, more democratic societies.

4.3. *Influences of biophysical conditions and types of respondents on the roles of science*

Several conclusions can be drawn from the correlations between the biophysical conditions of the counties/respondent types and the research variables:

(1) The elements of the biophysical conditions of the counties and the types of the respondents could negatively or positively influence the perceived roles of science on institutional change in desertification control. Among the six correlated elements of the biophysical conditions, longitude, total area, and annual average precipitation had a negative influence on some of the research variables, while the influences of climate division (higher divisions indicate more arid regions), annual average precipitation, and annual wind speed were positive. Among the 11 correlated types of the respondents, middle schools, general research institutes, universities, news media, international organizations, and others had negative influence on some of the research variables, while the influences of farmers, government, businesses, other public institutes, and NGOs were positive.
(2) Different elements of the biophysical conditions and types of the respondents influenced different types of the research variables; there was no any element of the biophysical conditions or type of the respondents systematically influenced all the research variables. But among the six correlated elements of the biophysical conditions, annual wind speed, annual average precipitation, and longitude had more significant influence on the roles of sciences than the other elements; among the 11 correlated types of the respondents, businesses, universities, other public institutes, news media, international organizations, and others had more influence.
(3) Although both higher longitudes and annual temperatures reduced the extents and effects of some types of sciences used in desertification control, only higher longitudes reduced the total extents of scientific application. Furthermore, the respondents from businesses often had more positive assessments on the extents and effects of the types of sciences used in desertification control, but their assessments were not significantly correlated with the accumulated or total extents and effects of scientific application.
(4) The respondents from other public institutes had a more positive attitude on the accumulated impact of scientific application on institutional change and on the four aspects of institutional changes than the other types of respondents. The respondents from the counties with higher annual wind speed often had a more positive attitude on the improvements of scientific application in desertification control, but the respondents from universities, international organizations, others, and news media often had a more negative attitude on the improvements of scientific application.
(5) Although there was no any single element of the biophysical conditions or type of the respondents systematically influenced all the research variables covered in the study, the elements of biophysical conditions and the

types of the respondents could influence the assessments of the research variables together. For example, because the elements of the biophysical conditions and the types of the respondents with negative influences often had higher values and because the elements and the types with positive influences often had lower values, Naiman always had low values (Tables 3, 4, 6, 9 and 10).

In conclusion, the biophysical conditions of the counties and the types of respondents both influenced the perceived roles of science in institutional changes in desertification control in a number of ways. Because of the large number of diverse biophysical conditions, the large sample size of various respondent types, and the supplemental study cases based on interviews, observations, archives, and the literature, our findings on the perceived roles of science in institutional changes in desertification control were robust.

Acknowledgements

The study was supported by the National Natural Science Foundation of China (71073008). The authors would like to thank Professor Elinor Ostrom for comments and suggestions on an earlier version of the paper. We also would like to thank Wensheng Chen and Teng Zhang for their help with fieldwork and data collection.

REFERENCES

Akhtar-Schuster, M., Thomas, R.J., Stringer, L.C., Chasek, P., Seely, M.K., 2011. Improving the enabling environment to combat land degradation: institutional, financial, legal and science-policy challenges and solutions. Land Degradation and Development 22, 299–312.

Anderson, T.L., Hill, P.J., 1975. The evolution of property rights: a study of the American West. Journal of Law and Economics 18, 163–179.

Barrera-Bassols, N., Zinck, J.A., Van Ranst, E., 2006. Symbolism, knowledge and management of soil and land resources in indigenous communities: ethnopedology at global, regional and local scales. Catena 65, 118–137.

Bauer, S., Stringer, L.C., 2009. The role of science in the global governance of desertification. The Journal of Environment Development 18 (3), 248–267.

Bian, Y., Logan, J.R., 1996. Market transition and the persistence of power: the changing stratification system in urban China. American Sociological Review 61, 739–758.

Binswanger, H.P., 1978. The Economics of Tractors in South Asia: An Analytical View. Agricultural Development Council, New York and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India.

Campbell, A., 1992. Landcare in Australia: taking the long view in tough times. Third Annual Report. National Soil Conservation Program, Canberra.

CCICCD (Secretariat of China National Committee for the Implementation of the United Nations Convention to Combat Desertification), April 2000. Presented at China National Report on the Implementation of United Nations Convention to Combat Desertification and National Action Programme to Combat Desertification, Beijing, China.

CCICCD (Secretariat of China National Committee for the Implementation of the United Nations Convention to Combat Desertification), April 2002. Presented at China National Report to Implement the United Nations Convention to Combat Desertification (UNCCD), Beijing, China.

Chasek, P., Essahli, W., Akhtar-Schuster, M., Stringer, L.C., Thomas, R., 2011. Integrated land degradation monitoring and assessment: horizontal knowledge management at the national and international levels. Land Degradation and Development 22, 272–284.

Chittenden, D., 2011. Commentary: roles, opportunities, and challenges—science museums engaging the public in emerging science and technology. Journal of Nanoparticle Research 13, 1549–1556.

Corburn, J., 2007. Community knowledge in environmental health science: co-producing policy expertise. Environmental Science and Policy 10, 150–161.

Davis, D.K., 2005. Indigenous knowledge and the desertification debate: problematising expert knowledge in North Africa. Geoforum 36, 509–524.

Day, R.H., 1967. The economics of technological change and the demise of the sharecropper. American Economic Review 57, 427–449.

Fan, Y., 1993. County Annals of Wengniute. Inner Mongolia People's Publishing House, Hohhot, Inner Mongolia (in Chinese).

Garcia, S.M., Charles, A.T., 2008. Fishery systems and linkages: implications for science and governance. Ocean and Coastal Management 51, 505–527.

Gaur, M.K., Gaur, H., 2004. Combating desertification: building on traditional knowledge systems of the Thar Desert communities. Environmental Monitoring and Assessment 99, 89–103.

He, G., Zhang, B., Yang, Z., 2004. Ecological Construction County Annals of Yanchi. Ningxia People's Publishing House and Ningxia People's Education Press, Yinchuan, Ningxia (in Chinese).

Jahiel, A.R., 1998. The organization of environmental protection in China. The China Quarterly 156, 757–787.

Kiser, L.L., Ostrom, E., 2000. The three world of action: a metatheoretical synthesis of institutional approaches. In: McGinnis, M.D. (Ed.), Polycentric Games and Institutions: Readings from the Workshop in Political Theory and Policy Analysis. The University of Michigan Press, Ann Arbor, pp. 56–88.

Lidskog, R., Sundqvist, G., 2002. The role of science in environmental regimes: the case of LRTAP. European Journal of International Relations 8 (1), 77–101.

Lin, J.Y., 1989. An economic theory o f institutional change: induced and imposed change. Cato Journal 9 (1), 1–33.

Lu, J., You, L., Chen, H., Zhou, J., Lu, Z., 2004. Assessment of ecological security and adjustment of land use in Xilinhaote City of Inner Mongolia. Resources Science 26 (2), 108–114.

Marx, K., Engels, F., 1968. Selected Works. International Publishers, New York.

McNie, E.C., 2007. Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. Environmental Science and Policy 10, 17–38.

Miller, K., Charles, A., Barange, M., Brander, K., Gallucci, V.F., Gasalla, M.A., Khan, A., Munro, G., Murtugudde, R., Ommer, R.E., Perry, R.I., 2010. Climate change, uncertainty, and resilient fisheries: institutional responses through integrative science. Progress in Oceanography 87, 338–346.

Mukhopadhyay, D., 2008. Indigenous knowledge and sustainable natural resource management in the Indian desert. In: Lee, C., Schaaf, T. (Eds.), The Future of Drylands. UNESCO, Paris, France, pp. 161–170.

Mwangi, E., Ostrom, E., 2009. A century of institutions and ecology in east Africa's rangelands: linking institutional robustness with the ecological resilience of Kenya's Maasailand—essays in honour of Konrad Hagedorn. In:

Beckmann, V., Padmanabhan, M. (Eds.), Institutions and Sustainability: Political Economy of Agriculture and the Environment. Springer, New York, pp. 195–221.
Nelson, R., Howden, M., Smith, M.S., 2008. Using adaptive governance to rethink the way science supports Australian drought policy. Environmental science and policy 11, 588–601.
North, D.C., 1981. Structure and Change in Economic History. Norton, New York.
North, D.C., 1990. Institutions, Institutional Change and Economic Performance. Cambridge University Press, Cambridge, NY.
North, D.C., 1994. Institutional change: a framework of analysis. Working Paper. Series: Economic History. No. 9412001. http://129.3.20.41/eps/eh/papers/9412/9412001.pdf (online).
North, D.C., 1994b. Economic performance through time. American Economic Review 84 (3), 359–368.
Norton, J.B., Pawluk, R.R., Sandor, J.A., 1998. Observation and experience linking science and indigenous knowledge at Zuni, New Mexico. Journal of Arid Environments 39, 331–340.
Ostrom, E., 1990. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, Cambridge, NY.
Ostrom, E., 2005. Understanding Institutional Diversity. Princeton University Press, Princeton, NJ.
Pellant, M., Abbe, B., Karl, S., 2004. Restoring the grate basin desert, USA: integrating science, management, and people. Environmental Monitoring and Assessment 99, 169–179.
PGYC (People's Government of Yijinhuoluo County), 4 May 2011. The Report Materials for the Objectives and Responsibility of Yinjinhuoluo County (Yijinhuoluoqi Fangsha Zhisha Mubiao Zeren Huibao Cailiao). Yijinhuoluo, Inner Mongolia (in Chinese).
Rametsteiner, E., Pülzl, H., Alkan-Olsson, J., Frederiksen, P., 2011. Sustainability indicator development—science or political negotiation? Ecological Indicators 11, 61–70.
Reed, M.S., Buenemann, M., Atlhopheng, J., Akhtar-Schuster, M., Bachmann, F., Bastin, G., Bigas, H., Chanda, R., Dougill, A.J., Essahli, W., Evely, A.C., Geeson, N., Fleskens, L., Glass, J.H., Hessel, R., Holden, J., Ioris, A.A.R., Kruger, B., Liniger, H.P., Mphinyane, W., Nainggolan, D., Perkins, J., Raymond, C.M., Ritsema, C.J., Schwilch, G., Sebego, R., Seely, M., Stringer, L.C., Thomas, R., Twomlow, S., Verzandvoort, S., 2011. Cross-scale monitoring and assessment of land degradation and sustainable land management: a methodological framework for knowledge management. Land Degradation and Development 22, 161–171.
Reed, M.S., Dougill, Y.A.J., Taylor, M.J., 2007. Integrating local and scientific knowledge for adaptation to land degradation: Kalahari Rangeland management options. Land Degradation and Development 18 (3), 249–268.
Reynolds, J.F., Smith, D.M.S., Lambin, E.F., Turner, B.L., Mortimore, M., Batterbury, S.P.J., Downing, T.E., Dowlatabadi, H., 2007. Global desertification: building a science for dryland development. Science 316, 847–851.
Roba, H.G., Oba, G., 2008. Integration of herder knowledge and ecological methods for land degradation assessment around sedentary settlements in a sub-humid zone in northern Kenya. The International Journal of Sustainable Development and World Ecology 15, 251–264.
Ruttan, V.W., 1978. Induced institutional change. In: Binswanger, H.P., Ruttan, V.W. (Eds.), Induced Innovation: Technology, Institutions, and Development. Johns Hopkins University Press, Baltimore, pp. 327–357.
Ruttan, V.W., 1984. Social science knowledge and institutional change. American Journal of Agricultural Economics 66 (5), 549–559.
Ruttan, V.W., Hayami, Y., 1984. Toward a theory of induced institutional innovation. Journal of Development Studies 20 (4), 203–223.
Schultz, T.W., 1968. Institutions and the rising economic value of man. American Journal of Agricultural Economics 50, 1113–1122.
Stringer, L.C., Dyer, J.C., Reed, M.S., Dougill, A.J., Twyman, C., Mkwambisi, D., 2009. Adaptations to climate change, drought and desertification; insights to enhance policy in southern Africa. The Environmental Science and Policy 12, 748–765.
Thomas, D.S.G., 1997. Science and the desertification debate. Journal of Arid Environments 37 (4), 599–608.
Thomas, D.S.G., Twyman, C., 2004. Good or bad range land? Hybrid knowledge, science and local understandings of vegetation dynamics in the Kalahari. Land Degradation and Development 15, 215–231.
van Rooyen, A.F., 1998. Combating desertification in the southern Kalahari: connecting science with community action in South Africa. Journal of Arid Environments 39, 285–297.
Watson, I.W., Norton, B.E., Novelly, P.E., Russell, P.J., 2008. Chapter 3: Integration of regulation, extension, science, policy and monitoring improves land management in the rangelands of western Australia. In: Lee, C., Schaaf, T. (Eds.), The Future of Drylands. UNESCO, Paris, pp. 599–614.
Winslow, M.D., Vogt, J.V., Thomas, R.J., Sommer, S., Martius, C., Akhtar-Schuster, M., 2011. Science for improving the monitoring and assessment of dryland degradation. Land Degradation and Development 22 (2), 145–149.
Wu, B., Ci, L.J., 2002. Landscape change and desertification development in the Mu Us Sandland, Northern China. Journal of Arid Environments 50, 429–444.
Wu, Y., Peng, Q., 2002. County Annals of Xinbaerhuzuo. Inner Mongolia Culture Publishing House, Hailaer, Inner Mongolia (in Chinese).
Wu, Z., 2001. County Annals of Naiman. Fangzhi Publishing House, Beijing (in Chinese).
Xia, X., Fan, S., 2000. Research progress of desert science in China. Chinese Science Bulletin 45 (24), 2209–2213.
Yang, L., 2009. Scholar-participated governance: combating desertification and other dilemmas of collective action. Dissertation. Arizona State University, Phoenix, AZ.
Yang, L., 2010. Scholar participated governance: combating desertification and other dilemmas of collective action. Journal of Policy Analysis and Management 29 (3), 672–674.
Yang, L., 2012. Building a knowledge-driven society: scholar participation and governance in large public works projects. Management and Organization Review, http://dx.doi.org/10.1111/j. 1740-8784.2011.00279.x.
Yang, L., Lan, Z., Wu, J., 2010. Roles of scholars in the practice of combating-desertification: a case study in northwest China. Environmental Management 46, 154–166.
Yang, L., Wu, J., 2009. Scholar-participated governance as an alternative solution to the problem of collective action in social–ecological systems. Ecological Economics 68 (8–9), 2412–2425.
Yang, L., Wu, J., 2010. Seven design principles for promoting scholars' participation in combating desertification. International Journal of Sustainable Development and World Ecology 17 (2), 109–119.
Yang, L., Wu, J., 2012. Knowledge-driven institutional change: an empirical study on combating desertification from 1949 to 2004 in northern China. Journal of Environmental Management 110, 254–266.
Zhang, N., 1990. County Annals of Aohan. Inner Mongolia People's Publishing House, Hohhot, Inner Mongolia (in Chinese).
Zhou, P., 1998. County Annals of Dengkou. Inner Mongolia People's Publishing House, Hohhot, Inner Mongolia (in Chinese).
Zhuo, K., 2000. County Annals of Duolun. Inner Mongolia Culture Publishing House, Hailaer, Inner Mongolia (in Chinese).