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THE BALANCE BETWEEN SUPPLY AND DEMAND OF WATER RESOURCES AND THE WATER-SAVING POTENTIAL FOR AGRICULTURE IN THE HEXI CORRIDOR

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ABSTRACT: The Hexi Corridor is an important base of agriculture development in Northwest China. According to recent statistics, there are $65.94 \times 10^8 m^3$ of water resources available in the Hexi Corridor. At present, net consumption in development and utilization is $43.33 \times 10^8 m^3$. Water supply and demand reach a balance on the recent level of production, but loss of evaporation and evapotranspiration is as much as $25.69 \times 10^8 m^3$. So net use efficiency of water resources is 59%. Based on analyzing balance between water and land considering ecological environment at present, there exists the serious water shortage in the Shiyang River system where irrigation lands have overloaded. There is a comparative balance between supply and demand of water resource in the Heihe River system; and the Sule River system has some surplus water to extend irrigation land. Use of agriculture water accounts for 83.3% and ecological forest and grass for 6.9%. The Hexi Corridor still has a great potential for water saving in agriculture production. Water-saving efficiency of irrigation is about 10% by using such traditional technologies as furrow and border-dike irrigation and small check irrigation, and water-saving with plastic film cover and techniques of advanced sprinkler and drip/micro irrigation etc. can save more than 60% of irrigated water. Incremental irrigation area for water-saving potential in the Hexi Corridor has been estimated as 56% – 197% to original irrigation area. So the second water sources can be developed from water saving agriculture in the Hexi Corridor under Development of the Western Part of China in large scale. This potential can be realized step by step through developing the water-saving measures, improving the ecological condition of oasis agriculture, and optimizing allocation of water resources in three river systems.

KEY WORDS: water resources; balance between supply and demand; water-saving potential of agriculture; Hexi Corridor

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1 AVAILABLE WATER RESOURCES

Situated in Gansu Province, $27.1 \times 10^4 km^2$ in area or amount to 59.7% of Gansu's total area (CHEN, 1992), the Hexi Corridor is a main economic development region and an important marketable grain base whose annual grain yield gains about 2.31 billion kg and therefore supplies the Gansu Province with over 60% marketable grain.

Located in temperate arid zone in Northwest China, the Hexi Corridor has scare rainfall, dry climate and strong evaporation. So its agriculture completely depended on irrigation and most of water supply originated from the southern Qilian Mountain where precipitation, glacier and snow melted water formed the river runoff.

The inland river basins in the Hexi Corridor include the Shiyang River system, the Heihe River system and the Sule River system from east to west. There are 60 inland rivers in the Corridor and the lower reaches of the Heihe River runs into the Inner Mongolian Plateau. Runoff volume of rivers is from $0.01 \times 10^8 m^3$ to $16.12 \times 10^8 m^3$. Among them, runoff volume of 24 rivers in the hydrological observation accounts for 91.2% of the total surface water resources.

1.1 Surface Water Resources

Whole water resources in the Hexi Corridor consist

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of surface and ground water. The surface water which mainly originated from the southern Qilian Mountain can be divided into the station-controlled river flow, the non-station-controlled stream flow and the front-mountains runoff, their surface runoffs respectively amount to 91.2%, 5.8% and 3.0% of the surface water resources in Hexi Corridor. Among three river systems (Table 1) in the Hexi Corridor, the Shiyang River system makes up $15.87\times10^8 m^3$, the Heihe River system $36.83\times10^8 m^3$ and the Sule River system $17.22\times10^8 m^3$, and the total add up to $69.92\times10^8 m^3$.

According to statistical data, the water volume flowing out from the Qilian Mountain area is $68.5\times10^8 m^3$ because of consumption in the mountains (Table 2), of which the Shiyang River system is $15.55\times10^8 m^3$, the Heihe River system $36.22\times10^8 m^3$ and the Sule River system $16.73\times10^8 m^3$.

Table 1 The surface water resource in the Hexi Corridor

	Shiyang River				Heihe River				Sule River				Hexi Corridor			
	Record	Survey	Calculate	Total	Record	Survey	Calculate	Total	Record	Survey	Calculate	Total	Record	Survey	Calculate	Total
Runoff volume ($10^8 m^3$)	14.8	0.49	0.58	15.87	33.01	2.86	0.96	36.83	15.94	0.69	0.59	17.22	63.75	4.04	2.13	69.92
% of total	93.3	3.1	3.6	100	89.6	7.8	2.6	10	92.6	4.0	3.4	100	91.2	5.8	3	100

Table 2 Surface water flowing out from the mountains in the Hexi Corridor

	Shiyang River			Heihe River			Sule River			Hexi Corridor		
	Surface runoff	Consumption in mountains	Total	Surface runoff	Consumption in mountains	Total	Surface runoff	Consumption in mountains	Total	Surface runoff	Consumption in mountains	Total
Runoff volume ($10^8 m^3$)	15.55	0.32	15.87	36.22	0.61	36.83	16.73	0.49	17.22	68.5	1.42	69.92
% of total	98.0	2.0	100	98.0	2.0	100	97.2	2.8	100	98.0	2.0	100

1.2 Groundwater Resources

In the Hexi Corridor, the natural groundwater resources mainly come from the leakage of the river courses, the channels and fields. These belong to the section of repeated with surface water. In addition, a part of phreatic water of valleys in mountain mouths and the rainfall infiltration in the plain area also formed the groundwater that is not included in the surface water resources. According to statistics of the hydrogeological department of the Gansu province, the total groundwater volume in the Hexi Corridor is about $4.94\times10^8 m^3$ (Table 3), of which the Shiyang River system occupies $1.32\times10^8 m^3$, the Heihe River system $2.49\times10^8 m^3$ and the Sule River system $1.13\times10^8 m^3$.

Table 3 Groundwater non-repeated with surface water in the Hexi Corridor ($10^8 m^3$)

	Shiyang River	Heihe River	Sule River	Hexi Corridor
Rainfall feeding	0.48	1.12	0.82	2.42
Side feeding	0.82	1.37	0.31	2.52
Total	1.32	2.49	1.13	4.94

1.3 Total Water Resources Available for the Hexi Corridor

In the Hexi Corridor, total water resources available, which exclude the consumption in the Qilian Mountain area, are the surface water flowing out from the mountain area adding the non-repeated ground water (Table 4), of which, the Shiyang River system makes up $16.87\times10^8 m^3$, the Heihe River system $38.71\times10^8 m^3$, which includes $7.50\times10^8 m^3$ of water flowing into the lower reaches of the Heihe River, and the Sule River system $17.86\times10^8 m^3$. The total water resources are $73.44\times10^8 m^3$ and resources available for the Hexi Corridor are $65.94\times10^8 m^3$. The surface water and groundwater occupy 92.5% and 7.5% respectively.

According to the present situation, in the Hexi Corridor water volume per capita is about $1420 m^3$ and per ha is $11\ 235 m^3$. For three river systems, the Shiyang River are $725 m^3$ per capita and $5580 m^3$ per ha, the Heihe River are $1665 m^3$ per capital and $11010 m^3$ per ha and the Sule River are $4000 m^3$ per capita and $26\ 445 m^3$ per ha.

2 ANALYSIS OF THE BALANCE BETWEEN DUPPLY AND DEMAND OF WATER RESOURCES

2.1 The Balance Between Supply and Demand of Water Resources

The surface water flowing out from the mountains is channeled into canals and farmlands by reservoir regu-

Table 4 Available Water resources in the Hexi Corridor

	Shiyang River			Heihe River			Sule River			Hexi Corridor		
	Surface	Ground	Total	Surface	Ground	Total	Surface	Ground	Total	Surface	Ground	Total
Water volume(10^8m^3)	15.55	1.32	16.87	36.22	2.49	38.71	16.73	1.13	17.86	68.50	4.94	73.44
% of the total	92.2	7.8	100	93.6	6.4	100	93.7	6.3	100	93.3	6.7	100
Water per capita(m^3)	725			1665			4000			1420		
Water per ha(m^3)	5580			11010			26445			11235		

lation and water conservancy works, about 30% of the surface runoff is transformed into groundwater from river courses, which accounts to $23.23 \times 10^8m^3$. A part of farmland irrigation, industry and municipal use of water were still supplied by channeling spring water and pumping groundwater in the Hexi Corridor. Up to the middle of the 1990s, there had been 120 large, middle and small reservoirs with total water storage of $10.02 \times 10^8m^3$ and 11 868km of main and branch canals with pavement of 70%. The water delivery efficiency of canal systems reaches to 55% – 60%, and the water-use efficiency within farmlands is 83%. There were about 21 300 tub wells with electricity power of 273 700 kW and 18 891 pumping stations for irrigation with power 235 700Kw. Therefore water supply completely depends on the water resources available for the Corridor.

The main users of water in the Hexi Corridor are agriculture, industry, municipal supply, drinking of human being and livestock in rural region and irrigated forest and grass. Based on present irrigated farmlands and net consumption quota of irrigation, water use survey for industry, population of towns and villages and each drinking standard, livestock number and drinking water quota, irrigated areas of forest and grass lands, evaporation from surface area of water bodies and groundwater, the present consumption volume of water is calculated. Among these, water consumption for agriculture accounts for 88.3%, for industry for 6.8% (DU, 1997), for municipal supply and for drinking water in the rural region for 2.9% and for irrigated forest and grass for 6.9%. For calculating and analyzing the balance between supply and demand of water resources, the paper takes water resources available for the Corridor as supply items and the net utilization as consumption ones (Table 5).

Table 5 Water balance calculation(10^8m^3)

River system	Resources		Evaporation		Net consumption					Balance
	Surface	Groundwater	Water body	Groundwater	Agriculture	Industry	Ecological	Municipal	Drinking	Shortage or surplus
Shiyang River	15.55	1.32	0.33	2.33	14.96	1.26	0.64	0.32	0.28	–3.25
Heihe River	36.22	2.21	2.21	11.34	16.3	1.31	1.51	0.21	0.31	5.52(–1.98)
Sule River	16.73	0.44	0.44	9.04	4.46	0.78	0.85	0.07	0.07	2.15
Sum	68.5	2.98	2.98	22.71	35.72	3.35	3.00	0.66	0.66	4.42
Total	73.44		25.69		43.33					4.42
%	100		35.0		59.0					6.0

Note: (1) The number within brackets is the water shortage for supply of Ejina oases according to water allocation scheme between Gansu Province and Inner Mongolia Autonomous Region.

(2) Net consumption water is determined on existing irrigation areas and net irrigation quota for agriculture, irrigated forest and grassland areas and net quota for ecological forest and grass lands, survey for industry. The municipal net consumption water is calculated by the division standards of cities and towns, such as 50L/(p·d) for Wuwei, 60L/(p·d) for Zhangye, 50L/(p·d) for Jiuquan and 100L/(p·d) for Jinchang, and municipal census in 1994. Countryside drinking water is calculated by census and the division standards of 30L/(p·d) for Wuwei, 50L/(p·d) for Zhangye, 35L/(p·d) for Jiuquan and 35L/(p·d) for Jinchang. Livestock drinking water is calculated by the division standards of a big stock 50L/p·d and small one 15L/p·d for Wuwei, big 50L/(p·d) and small 10L/(p·d) for Zhangye, big 40L/(p·d) and small 17L/(p·d) for Jiuquan and big 35L/(p·d) and small 10L/(p·d) and the numbers of livestock statistics in the end of 1993.

The results show that the net consumption of water resources is $17.46 \times 10^8m^3$ in the Shiyang River system, but loss of lower effective evaporation as much as $2.66 \times 10^8m^3$. The water shortage is $3.25 \times 10^8m^3$ (Table 5) if not consider rehabilitating ecological environment of the Minqin region. So the contradictory of supply and demand is evident, the ratio between supply and demand is about 0.81∶1, especially, in its lower reaches in Minqin Basin, the water resources is seriously short and the groundwater in it was overexploited. The results also showed that the net use of the Heihe River system is $19.64 \times 10^8m^3$, the lower effective loss of evaporation amounts to $13.6\times10^8 m^3$, the surplus which mainly supply to Ejina oases of the lower reaches is $5.5\times10^8 m^3$. Although there is a balance stage between supply and demand in the Heihe River system (GAO, 1991), but it still has little water shortage and the ratio is 1∶1. It can be found that the net water use in the Sule River system is $6.23\times10^8 m^3$ and the lower effective loss is $9.48\times10^8 m^3$. There is surplus water of $2.15\times10^8 m^3$ and the ratio of supply and demand is 1.3∶1.

At present, the net water consumption in the whole corridor is $43.33\times10^8 m^3$, supply and demand of water reach a weak balance on the recent level of production, the ratio is 0.96∶1. Based on above analysis, although it has physical water shortage, but the lower effective loss amounts to 35.0% of total water resources in the Hexi Corridor and the net utilization efficiency of water resources is 59% under the economic development and environment conditions at present.

2.2 The Balance Between Water and Land in the Hexi Corridor

According to detailed survey of land use status in Gansu Province in 1992, the Hexi Corridor has 65.38×10^4ha of cultivated land (LI, 1998), of which the Shiyang River system is 30.27×10^4ha, the Heihe River system 28.36×10^4ha and the Sule River system 6.75×10^4 ha. In addition, the Hexi Corridor has also rain-fed farmland of 23.01×10^4ha, wasteland suitable for agriculture amounts to 31.15×10^4ha. So like other inland river regions of northwest China, the land development has great potential of land resources in the Hexi corridor.

Based on the present level of agriculture production, adopting the theory of water balance, the balance equations between land and water in every river system are set up in the Corridor. In the equations in Table 6, when the water volume $W>0$, it means that irrigation land have overloaded, when $W=0$, water and land are on a balance stage and when $W<0$ there is surplus water to increase irrigation land. These are respectively represented in the Shiyang River, the Heihe River and the Sule River systems.

Table 6 The interrelationship of water and land balance in the Hexi Corridor

	Shiyang River	Heihe River	Sule River
Equation	$W=3.25+0.495S$	$W=-0.15-0.5775S$	$W=-2.15+0.66S$

W: Balance water volume of agriculture irrigation (10^8 m^3);
S: Variable of irrigation area (10^4ha)

At present, the calculated results and existing balance between water and land (Table 7) show that irrigated lands have overloaded by 6.5×10^4ha in the Shiyang River system, a basically balance if no considering a water deficit to the down stream in the Heihe River system, and some surplus water in the Sule River system which could extend 3.33×10^4ha of irrigation area. That means the irrigation areas could not be extended in large scale according to traditional agriculture and the carrying capacity of water resources has reached critical limit in the corridor under the present production level of water use.

Table 7 The balance of water and land in the Hexi Corridor

River system	Irrigation for farmalnd		Irrigation for forest and glass		Present balance	
	Irrigated area ($\times10^4$ha)	Net consumption (m^3 per ha)	Irrigated area ($\times10^4$ha)	Net consumption (m^3 per ha)	Water volume ($10^8 m^3$)	Area ($\times10^4$ha)
Shiyang River	30.27	4950	1.45	4425	−3.25	−6.53
Heihe River	28.36	5775	3.19	4725	0.15	0.26
Sule River	6.75	6600	1.89	4500	2.15	3.33
Total	65.38	5505	6.52	4575	−0.95	−2.94

3 THE POTENTIALOF WATER SAVING FOR AGRICULTURE

Going to the road of water-saving agriculture is one of effective ways of increasing the efficiency of water resources utilization and alleviating the shortage of water resources (XIAO, 1996). Its main measures can be adopted such as decreasing the loss of leakage in canals by pavement, reducing the irrigating water quota by using new techniques and controlling the ineffective loss of evapotraspiration so as to enhance the efficiency of water resources utilization.

According to the analysis on actual crop irrigated quota in the Hexi farmlands from 1990 to 1993, the average net irrigation quota in Shiyang River system is 5850 m3 per ha, the Heihe River system is $6975m^3$ per ha and the Sule River system is $7950m^3$ per ha. Irrigation experiment result shows that the net consumption quota is 3750m^3 per ha for wheat and 4500m^3 per ha for maize and much less than present quota (Table 8). According to practice of traditional irrigation, it can be concluded that water-saving efficiency of normal irrigation technique is about 10% and water-saving by using advanced techniques with plastic firm cover to wheat and maize can save more than 30% of irrigation water, so these techniques of water-saving are potential for popularizing perspective in crop irrigation and suitable for national conditions.

According to irrigation experiments of wheat and maize, net consumptive water in the wheat field are 33% for soil evapotranspiration and 67% for leaf transpiration, in the maize field are 39% for soil and 61% for leaf (LI, 1992). Based on experiments on site of the wheat fields of Wuwei, Zhangye and Jiuquan, net consumptive water for leaf transpiration during the crop growth period is only 2820 to 3555m^3 per ha. In comparison with the net quota of present irrigation, the loss of evapostranspiration in the field occupies 52% -55% of the irrigation water, the efficiency of water use in the crop field is about 45% -48%. At present, the net coefficient of water delivery from canal to field is 0.48 and the effective use rate of water resources from canal to crop absorption is only 0.23. It is obvious that there is big potential in the water-saving agriculture of the Corridor.

Table 8 The potential of saving-water agriculture in the Hexi Corridor (m^3 per ha)

	Shiyang River	Heihe River	Sule River	Situation
Average water volume	5580	11010	26445	
Net irrigation quota	5850	6975	7950	at present
Normal technique quota	5190	5805	7425	before 2000
Plastic firm cover quota	2700 - 3000 for wheat; 4665 - 4845 for maize			after 2000
Net quota in future	4500	5400	6750	after 2000
Irrigation experiment quota	3750 for wheat; 4500 - 5295 for maize			

According to traditional saving-water technologies in the Hexi Corridor from 1990 to 1993, if substituting furrow irrigation, border-dike irrigation(<0.033ha) or small check irrigation(<0.1ha) for flood irrigation, the water-saving efficiency can get to 10%, and if farming with plastic firm cover, the water-saving efficiency can reach as high as 60%. Advanced irrigation techniques taken, such as spring irrigation, surge irrigation on film, trip irrigation and micro-irrigation by infiltration etc., still have great potential for water saving and perspective for popularizing (WU, 2000), but the more invests are needed. In general, surge irrigation (including in border check or ditch) can save 10% - 30% of water than normal watering, irrigation on film can also decrease 30% of water volume than ground one, the spring irrigation can save 30% of water than flooding and water saving efficiency of trip/micro irrigation can get as high as 50% -70%.

On the basis of water balance calculation above, raising the water-saving efficiency and increasing the carrying potential of water are analyzed and the relations of water and land balance (Table 9) were set up in order to utilize water more efficiently. From these relations, we can see that the potential of saving-water in the Hexi Corridor is great and this can take as a main direction of water rational utilization in future. So the second water sources can be developed from water saving of agriculture.

After taking the water-saving irrigation measures, the development potential of water resources is indicated by the percentage(X) of the ratio of incremental irri-

Table 9 The potential of water-saving irrigation in the Hexi Corridor

Water-saving efficiency	Shiyang River		Heihe River		Sule River	
	Water balance equation	Incremental area of farmland	Water balance equation	Incremental area of farmland	Water balance equation	Incremental area of farmland
0	$W = 3.27 + 0.495S$	-6.61	$W = -0.15 + 0.4575S$	0.26	$W = -2.16 + 0.60S$	3.27
10%	$W = 1.77 + 0.4455S$	-3.97	$W = -1.75 + 0.5205S$	3.36	$W = -2.61 + 0.594S$	4.39
20%	$W = 0.28 + 0.396S$	-0.71	$W = -3.35 + 0.462S$	7.25	$W = -3.05 + 0.528S$	5.77
30%	$W = -1.22 + 0.3465S$	3.52	$W = -4.95 + 0.405S$	12.22	$W = -3.5 + 0.462S$	7.57
40%	$W = -2.72 + 0.297S$	9.16	$W = -6.56 + 0.3465S$	18.93	$W = -3.95 + 0.396S$	9.97
50%	$W = -4.22 + 0.2475S$	17.05	$W = -8.16 + 0.2895S$	28.33	$W = -4.39 + 0.33S$	13.30

Note: W—balance water volume of irrigation agriculture (10^{8}m^3); S—increment of irrigation area (10^{4}ha) gation area to original irrigation area. The relationship between saving-water efficiency (Y) and the potential of water resources (X) is non-linear (Fig. 1). Its mathematics models are arranged in Table 10. The correlative coefficient between X and Y is 0.98 ($\alpha = 0.01$).

Table 10 The relations between saving-water efficiency and potential of water resources in the Hexi Corridor

River system	Non-linear models of efficiency and potential
Shiyang River	$X = -21.8531 + 86.7437Y - 5.0764Y^2 + 287.9630Y^3$
	$Y = 0.2187 + 7.9728 \times 10^{-3}X - 8.2066 \times 10^{-5}X^2 + 5.1910 \times 10^{-7}X^3$
Heihe River	$X = 0.8294 + 111.1257Y + 0.9127Y^2 + 359.2593Y^3$
	$Y = -7.9583 \times 10^{-3} + 9.6385 \times 10^{-3}X - 7.0358 \times 10^{-5}X^2 + 2.4323 \times 10 - 7X^3$
Sule River	$X = 48.4270 + 163.3916Y + 1.0315Y^2 + 531.4818Y^3$
	$Y = -0.3987 + 0.0102X - 4.3608 \times 10^{-5}X^2 + 7.7091 \times 10^{-8}X^3$

From the above non-linear models, we can determine the potential (X) of the carrying capacity of water resources according to achieving the water-saving degrees (Y), or can determine the needful water-saving degrees based on the developing the scale of irrigation area for safeguarding the balance between supply and demand of water resources and coordinating development of water and land resources. Incremental irrigation area for water-saving potential can be estimated as 56% –197% to original irrigation area if achieving the water-saving degree of 50% on the present base in the Hexi Corridor. The water saving degree of above 20% is needed by taking some measures if water resources utilization can reach the relative balance between water and land in the Shiyang River system. And after adopting water saving measures of irrigation to save water of 12%, the surplus water of the Corridor can supply and meet the requirement of the Ejina oases of the lower reaches in the Heihe River system. There is a little surplus water for extending irrigation and adopting water-saving measures also is very important for improvement environment and future development in the Sule River system.

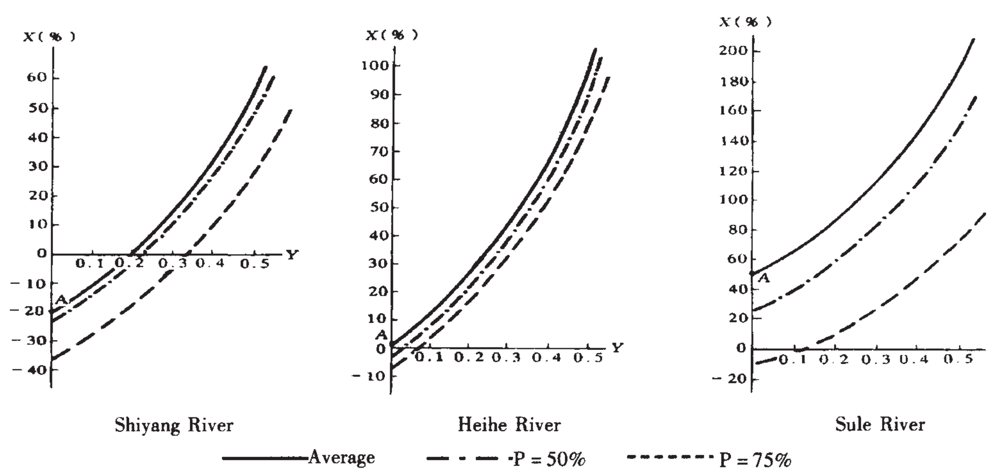

Fig. 1 The relationship between raising the saving water of irrigation (%) and the carrying capacity potential of increasing irrigation areas of water supply

This potential can be realized step by step through carrying out various water-saving measures, improving the ecological condition by constructing concentrated type of oases, combining utilization of surface water and groundwater, decreasing and restraining evaporation of water surface and evapotranspiration of groundwater and optimizing allocation of water resources to agriculture, forestry, livestock breeding and ecological environment construction in three river systems.

4 CONCLUSIONS

Based on above analysis, we concluded that water resources in the Hexi Corridor, which are not exploited fully, has great potential by adopting advanced water-saving technologies. This potential can be carried out step by step under the following conditions: developing the field irrigation technologies and ensure the stable water-saving measures, improving the ecological agriculture of oases in the river systems, and optimizing allocation of water resources. The study also showed that at present the stress and shortage of water resources in the Hexi Corridor mainly caused by the low efficiency and waste of water use. According to the water-saving degrees, such as plastic firm cover in wheat the water-saving efficiency can gain 60%, then water-saving potential can be estimated for the Corridor agriculture. The potential of water resources can be increased by 56% of irrigation area in the Shiyang River system, 112% in the Heihe River system, 197% in the Sule River system for agriculture when reaching water saving degree of 50% according to long-term average of water resources. So it is very important to popularize the advanced water-saving technologies, such as drip/micro irrigation, irrigation by infiltration and plastic firm cover etc, so as to enhance the efficiency of water resources utilization. Therefore we can exploit the second water source from saving water of agriculture in the Hexi Corridor.

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