



Tradeoff between groundwater exploitation and food production in the deep groundwater overexploited area of North China Plain

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XVIII World Water Congress International Water Resources Association (IWRA) Beijing, China J September 11-15, 2023



Background and Motivation

-Groundwater overexploitation-Contradiction between groundwaterexploitation and food production

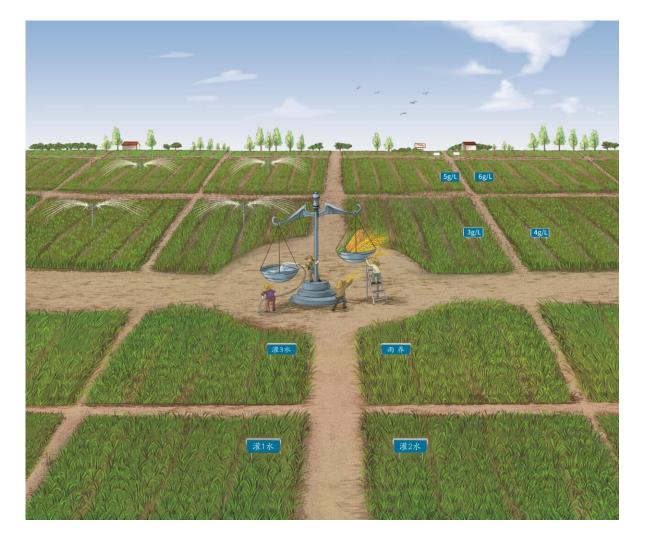
Materials and Methods

-Distributed agro-hydrological model -Scenario simulations and evaluations

Results and Discussion

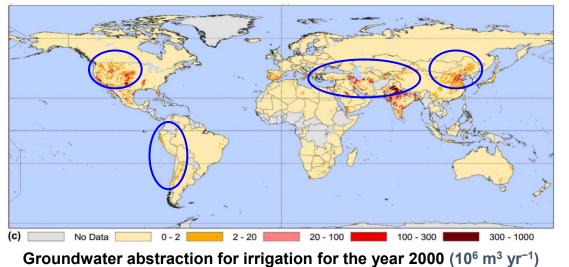
-Limited surface irrigation

- -Saline water irrigation
- -Sprinkler irrigation
- Conclusions
- Acknowledgements



Trade offs between groundwater exploitation and food production

Background and Motivation

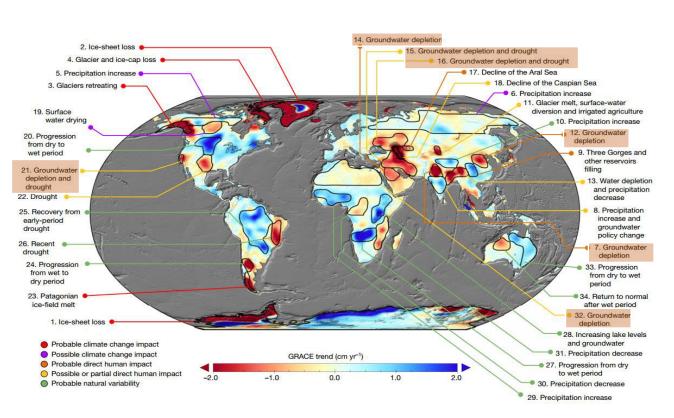


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Source: Wada et al. (2012)

Groundwater provides around 25% of all water withdrawn for irrigation, serving 38% of the world's irrigated land (United Nations, 2022).

About 70% of the pumped groundwater worldwide is used to sustain irrigation and is important for food security (de Graaf et al., 2019).



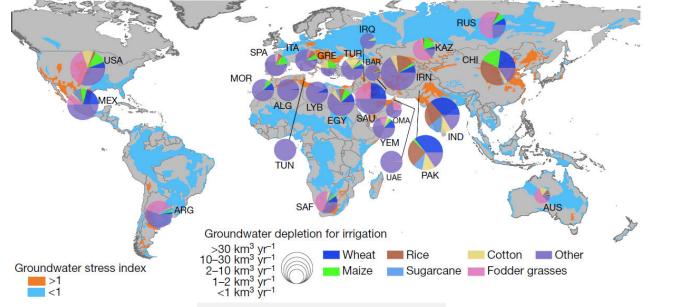
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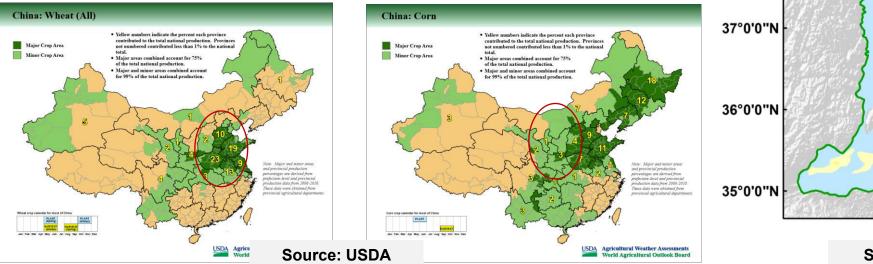
Trends in terrestrial water storage (TWS) obtained on the basis of Gravity Recovery and Climate Experiment (GRACE) satellite observations from April 2002 to March 2016 and the cause of the trend in each outlined study regions

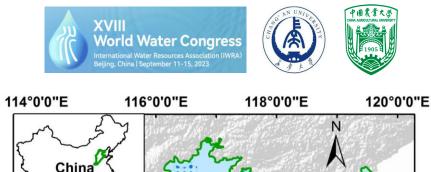
Source: Rodell et al. (2018)

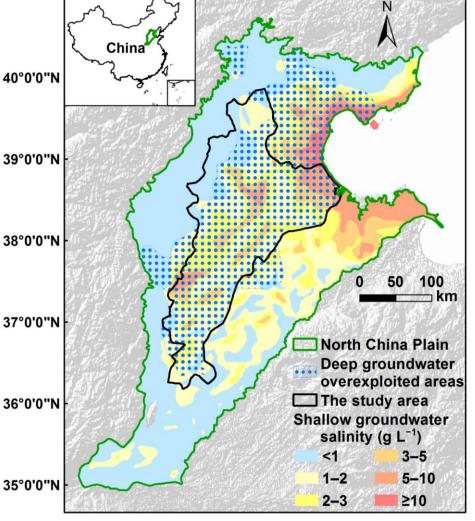
Background and Motivation



Source: Dalin et al. (2017)



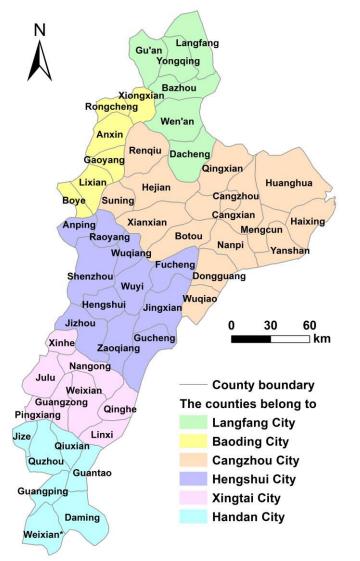




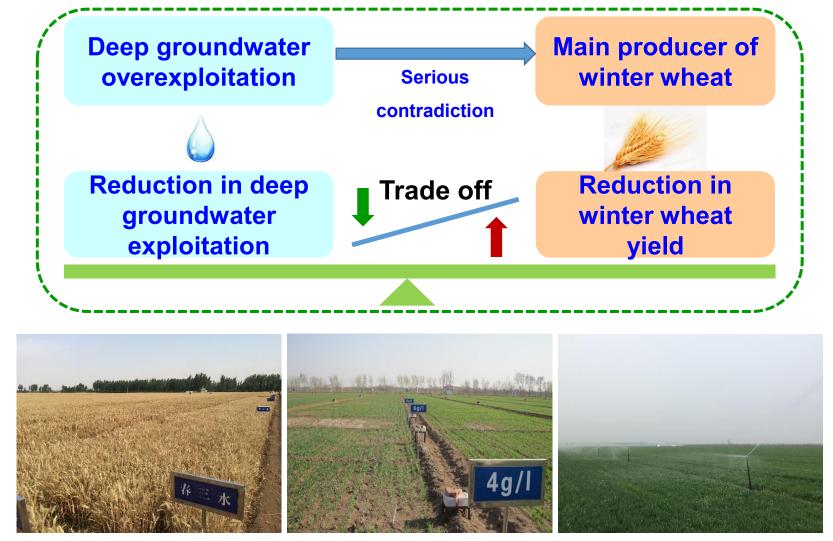
Source: Li and Ren (2021)

Background and Motivation





Source: Li and Ren (2019b)



Limited surface irrigation strategy

Saline water irrigation strategy

Sprinkler irrigation strategy



Experimental evaluation at the experimental station scale,

A need of study

-at the regional scale.

-for different irrigation strategies.

-under the framework of simulation-optimization-evaluation

Materials and Methods





Establishment

Calibration:

-Soil water content

-Crop leaf area index

-Soil salt content

-Crop biomass

-Crop yield

Validation:

-Soil water content

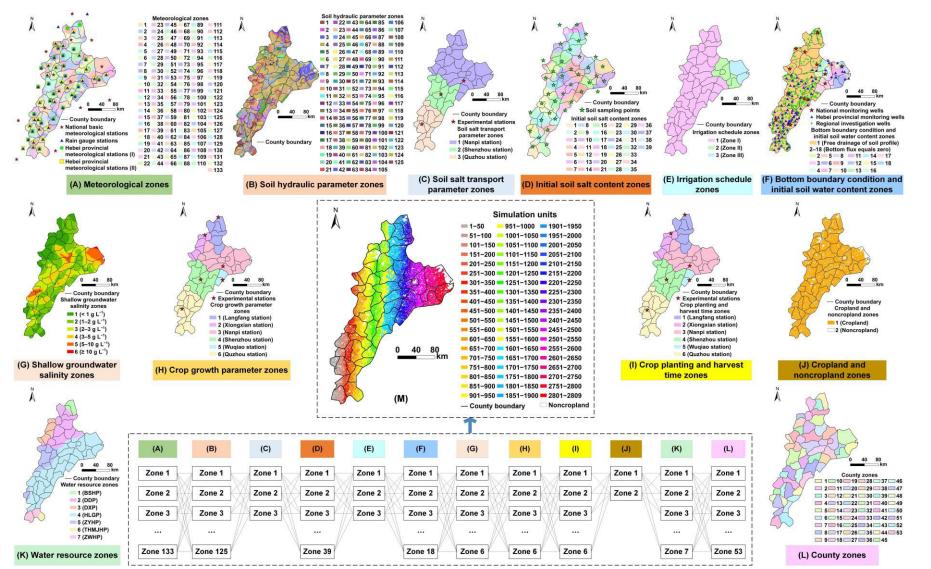
-Evapotranspiration

-Crop leaf area index

-Soil salt content

-Crop biomass

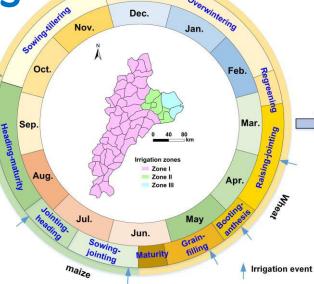
-Crop yield



Source: Li and Ren (2019a)

Materials and Methods

	Scenario	Irrigation frequency	Irrigation timing
1. Same	L1	3	Pre-sowing + recovery-jointing + booting-anthesis
225 mm	L2	3	Pre-sowing + recovery-jointing + early grain-filling
() (100000000) 	L3	3	Pre-sowing + booting-anthesis+ early grain-filling
	L4	2	Pre-sowing + recovery-jointing
150 mm	L5	2	Pre-sowing + booting-anthesis
	L6	2	Pre-sowing + early grain-filling
	L7	1	Pre-sowing
75	L8	1	Recovery-jointing
mm	L9	1	Booting-anthesis
	L10	1	Early grain-filling
0 mm	L11	1	Early grain-filling



Winter

Induction		Winter wheat				Summer maize	
Irrigation zone	PEP	Pre- sowing	Raising- jointing	Booting- anthesis	Early grain- filling	Sowing	Heading
	25%	V	\$	☆	×	×	×
Zone	50%	V	\$	\$	\$	×	×
1	75%	V	\$	\$	☆	\checkmark	×
	95%	V	\$	\$	☆	\checkmark	V
	25%	V	☆	×	×	×	×
Zone	50%	\checkmark	☆	\$	×	×	×
Ш	75%	V	\$	\$	×	×	×
	95%	V	\$	\$	×	V	×
	25%	×	×	×	×	×	×
Zone	50%	×	☆	×	×	×	×
ш	75%	×	☆	×	×	×	×
	95%	×	\$	×	×	×	×

Note: (1) " $\sqrt{"}$ represents freshwater irrigation; " \pm " represents saline water irrigation; and " \star " represents no irrigation. (2) Under scenarios 1, 2, 3, 4 and 5, the irrigation water salinity in the winter wheat growing season was 2.0 g L⁻¹, 3.0 g L⁻¹, 4.0 g L⁻¹, 5.0 g L⁻¹ and 6.0 g L⁻¹, respectively, and the irrigation water salinity at the winter wheat pre-sowing and during the summer maize growing season was still 1.0 g L⁻¹. (3) PEP means precipitation exceedance probability.

Note: 1) the irrigation amount for each application was 75 mm .

Eleven limited surface irrigation scenarios

Fixed sprinkler	Irrigation	Irrigation	Irrigation amount at different stages of winter wheat (mm)						Schedul
irrigation scenario	quota (mm)	frequency	Before winter dormancy	Recovery	Jointing	Booting	Anthesis	Grain- filling	sprinkle irrigatio
Scenario 1 (S1)		6	30	30	30	45	45	45	scenari
Scenario 2 (S2)	225	5	45	-	45	45	45	45	Scenario 7
Scenario 3 (S3)		5	30	-	30	30	30	30	Scenario 8
Scenario 4 (S4)	-	4	30	-	30	-	45	45	Scenario 9
Scenario 5 (S5)		3	-	-	50	-	50	50	Scenario 10
Scenario 6 (S6)	75	2	-	-	30	-	-	45	Scenario 11
	1	1	(A)		1				

Scheduled	Value of f_3 at different DVS of winter whea						
sprinkler irrigation scenario	DVS=0	DVS=0.5	DVS=1.0	DVS=1.5	DVS=2.0		
Scenario 7 (S7)	0.90	0.90	0.70	0.70	0.80		
Scenario 8 (S8)	0.90	0.90	0.75	0.75	0.85		
Scenario 9 (S9)	0.90	0.90	0.80	0.80	0.90		
Scenario 10 (S10)	0.90	0.90	0.85	0.85	0.90		
Scenario 11 (S11)	0.90	0.90	0.90	0.90	0.90		
	(B)						

Eleven sprinkler irrigation scenarios

Note: 1) "-" represents no irrigation at this growth stage; 2) f_3 is a user-defined factor depletion fraction, sprinkler irrigation is applied when the depletion of water in the root zone exceeds fraction f_3 of the available water; 3) DVS represents development stage, which values of 0, 0.5, 1.0, 1.5 and 2.0 indicate the seedling, middle vegetative, anthesis, middle reproductive and mature stages, respectively; and 4) the irrigation amount for each application under the scheduled sprinkler irrigation scenarios was 30 mm.

Summe

Five saline water irrigation scenarios

Source: Li and Ren (2019b, 2021, 2022)

Materials and Methods



	Limited surface irrigation	Saline water irrigation	Sprinkler irrigation
Objective function	$\min z = \sum_{i=0}^{11} p_i x_i$	$\max z = \sum_{i=0}^{5} c_i x_i$	$\max z_j = \sum_{i=1}^{11} WP_{i,j} x_{i,j} (i = 1, \dots, 11; j = 1, 2, 3)$
Constraints	$\begin{cases} \sum_{i=0}^{11} y_i x_i \le b (i = 0, 1, \dots, 11) \\ x_i = 0 \text{ or } 1 (i = 0, 1, \dots, 11) \end{cases}$	$\begin{cases} \sum_{i=0}^{5} y_i x_i \le a (i = 0, 1, \dots, 5) \\ \sum_{i=0}^{5} s_i x_i < b (i = 0, 1, \dots, 5) \\ x_i = 0 \text{ or } 1 (i = 0, 1, \dots, 5) \end{cases}$	$\begin{cases} \sum_{i=1}^{11} I_{i,j} x_{i,j} \ge b & (i = 1, \dots, 11; \ j = 1, 2, 3) \\ \sum_{i=1}^{11} x_{i,j} = 1 & (i = 1, \dots, 11; \ j = 1, 2, 3) \\ x_{i,j} = 0 \text{ or } 1 & (i = 1, \dots, 11; \ j = 1, 2, 3) \end{cases}$

 Minimize
 evapotranspiration

 under the constraint of yield

 reduction
 (i.e., 5%, 10%,

 15%, 20%, 25%, 30%, 35%,

 40%, 45%, 50%, 55%, 60%,

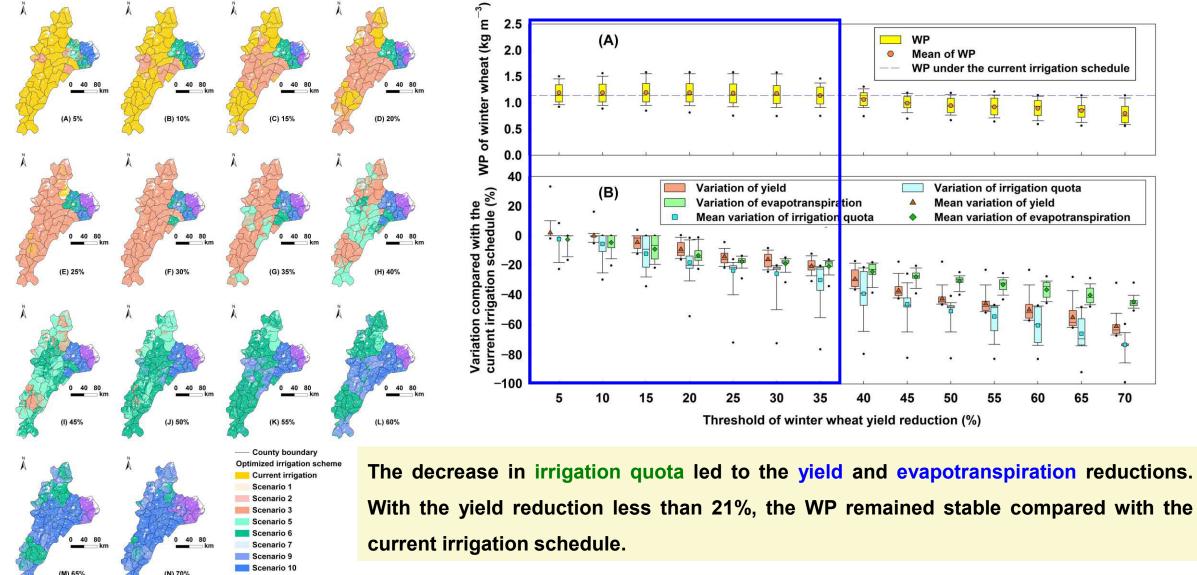
 65% and 70%).

Maximize irrigation water salinity under the constraints of crop yield reduction (i.e., 500 kg hm⁻², 1000 kg hm⁻², 1500 kg hm⁻² and 2000 kg hm⁻²) and soil salt content (3.0 g kg⁻¹).

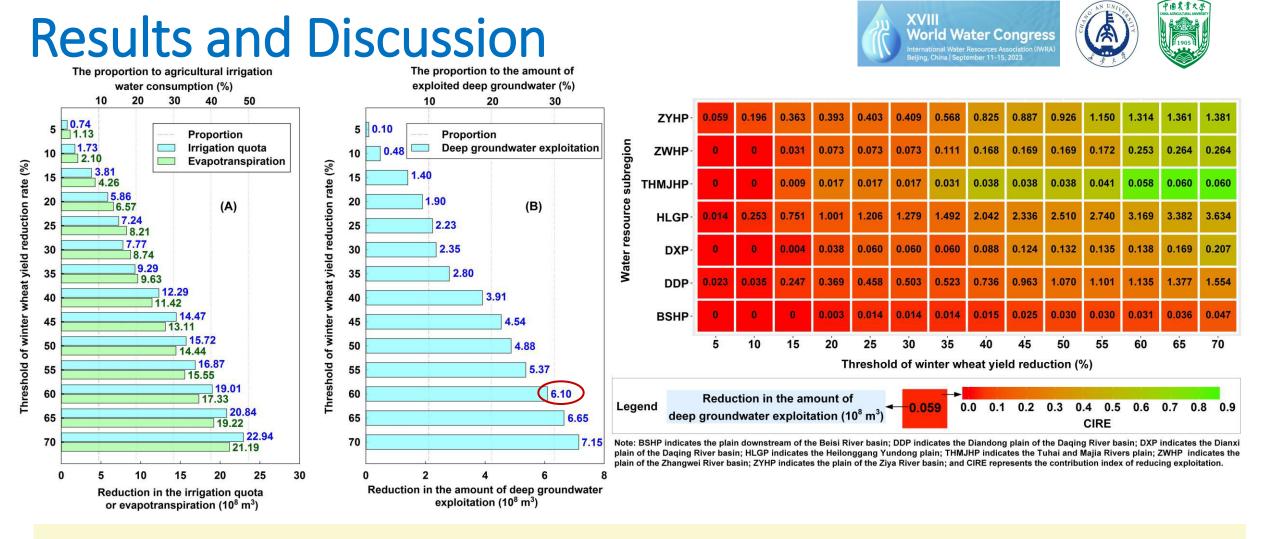
Maximize water productivity (WP) under the constraint of irrigation quota reduction (i.e., 10%, 20%, 30%, 40%, 50% and 60%).

Scenario 11 Noncropland



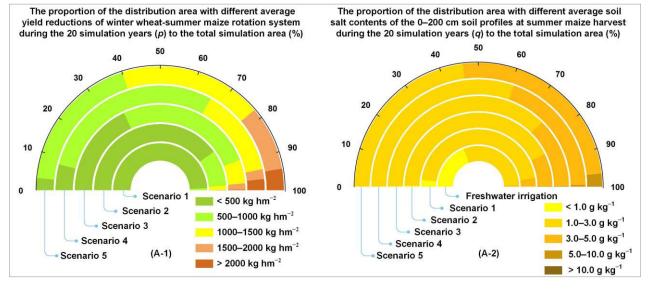


Source: Li and Ren (2019b)



With an increase in yield reduction from 4% to 61%, the reduction in the amount of deep groundwater exploitation under the optimized irrigation scheme increased from approximately 1.40×10^8 m³ to 7.15×10^8 m³. To achieve the target value of 6.05×10^8 m³, the yield decreased by approximately 50%.

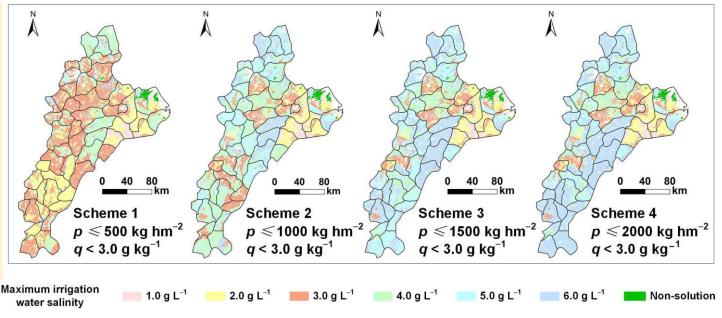
Source: Li and Ren (2019b)



On the premise that the salt content of 2-m soil profile was less than 3 g kg⁻¹, if the average crop yield reduction in the range of ≤ 500 kg hm⁻², ≤ 1000 kg hm⁻², ≤ 1500 kg hm⁻² and ≤ 2000 kg hm⁻² was permitted, the dominant maximum irrigation water salinity in the study area was 3 g L⁻¹, 4 g L⁻¹, 6 g L⁻¹ and 6 g L⁻¹, respectively. XVIII World Water Congress International Water Resources Association (IWRA) Beijing, China | September 11-15, 2023

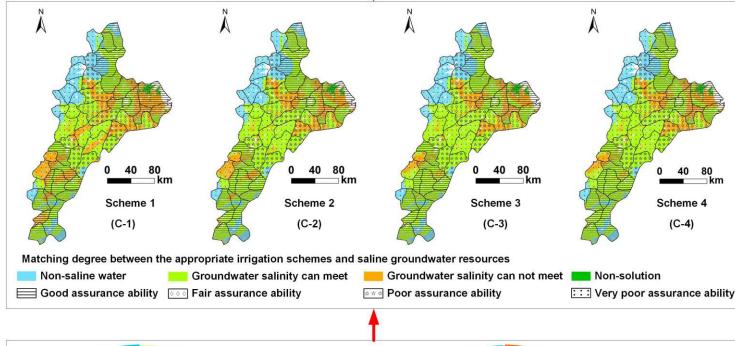
The yield reduction of the rotation system was less than or equal to 2000 kg hm⁻² in more than 94% of the simulation area under the five scenarios.

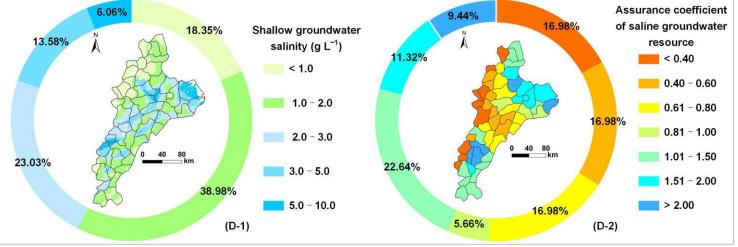
The salt content of the 2-m soil profile at summer maize harvest was less than or equal to 5 g kg⁻¹ in more than 96% of the simulation area under the five



Source: Li and Ren (2021)





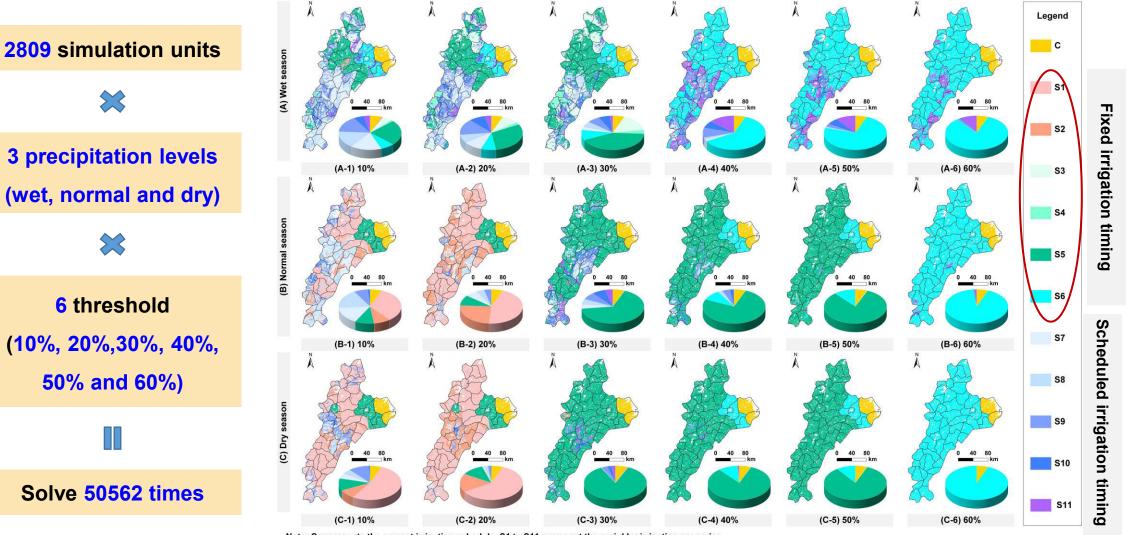


The average saline water amount needed for winter wheat irrigation was approximately 22.78×10^8 m³, which was approximately 9% more than the exploitable amount of saline groundwater.

In the 23 counties of the study area, the exploitable amount of saline groundwater could meet the needs of winter wheat irrigation. In most parts of these counties, the shallow groundwater salinity could also satisfy the appropriate irrigation schemes, showing a high matching degree.

Source: Li and Ren (2021)





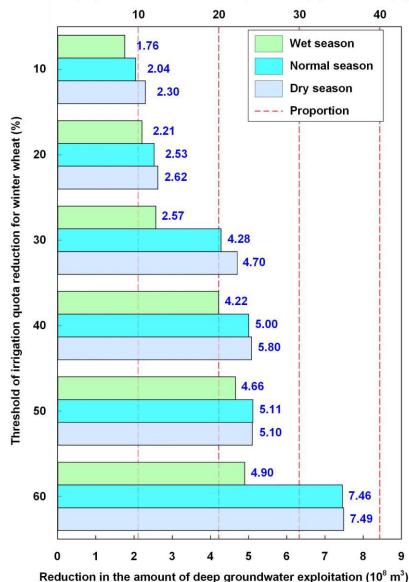
Note: C represents the current irrigation schedule, S1 to S11 represent the sprinkler irrigation scenarios.

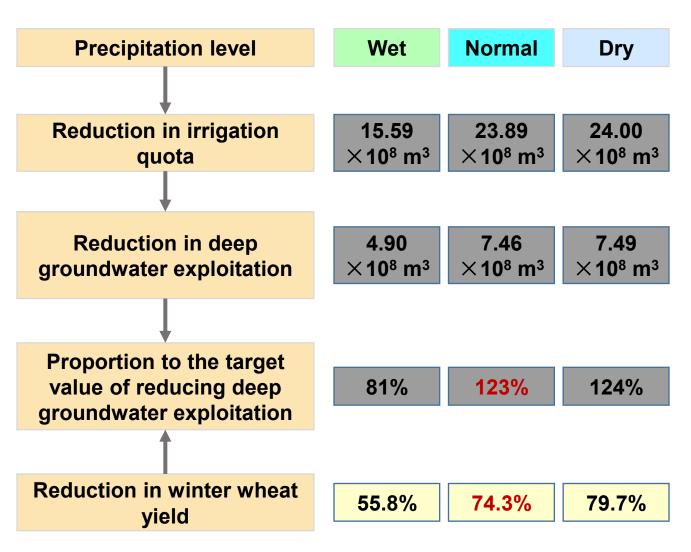
Source: Li and Ren (2022)

The proportion to the amount of exploited deep groundwater (%)









Source: Li and Ren (2022)







- 1. If the irrigation quota was reduced to prevent deep groundwater overexploitation,
 - the applications of sprinkler irrigation and limited surface irrigation led to reductions in yield and WP.
- 2. Under the current planting scale of most farmers, limited surface irrigation rather than sprinkler irrigation is recommended in the most study areas from the perspective of achieving a relatively high yield and a higher WP.







- 3. Saline groundwater is an important alternative water source for irrigation, and
 - reasonable utilization would not cause significant soil salt accumulation and crop yield reduction. Only in half of the study area saline groundwater meets the irrigation requirements from the perspectives of water quantity and water quality.

It is difficult to achieve groundwater sustainability only by changing irrigation methods and schemes, we suggest using other water sources (e.g., external transfer water and unconventional water) and field management measures.

Publications

Journal of Hydrology 574 (2019) 497-









Contents lists available at ScienceD Journal of Hydrolog journal homepage; www.elsevier.com

Research paper

Evaluating the effects of limited irrigation on crop w reducing deep groundwater exploitation in the North agro-hydrological model: I. Parameter sensitivity ana model validation

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 Key Laboratory of Plant-Soil Interactions, MOE, Beijing 100193, PR China

The memory is we handled by C. Corendia, Hintows-Cohie, With the anitance of Weiping Chen, Anaccine Elliter Flywold: Overstpilled (A) Physics of the anital Overstpilled (A) Physics of the anital Regional Intergency Malikaser walking Malikaser walking Malikaser walking Chebi exactivey analysis	The agno-bydrokejcial Sail-Water-Among- trubulerd manare represents an important to different spatiotempool tasks. The reliable generation of the databhed immunities an end of the start start and the start of the design promodivents' areas in the North China (FFAT) was not do conduct global areasi identify the parameters that as significantly in attains in the ready area. On the basis, the observed data from each attains. The norms and all concernations, whitere West led a yield, summer maine LAL nummer maine and corresponding yields and a fair atmutation. WOTOST model was explanated by overlap surveises of the start of the start of the theory of the start of the start of the yield of writer when a and assumer maine with the start when a start assumer maine without of model was explanated in dor the WOTOST model could be used as an effective WOTOST model could be used as an effective immed in trajents necesarios and do revolutat deep groundwater exploitation in this regio			
 Introduction Groundwater is a crucial water sourc substantial role in securing global food Siebert et al., 2010; Wada et al., 2010; groundwater (kalery static characterized by slower than shallow groundwater (kilery et al., 2 	production (Giordano, 2009; 2; Döll et al., 2012). Deep renewal and lower recharge	and Lall, 2 expanding exploited f 2004), the Russo and (Mahmoud tries. The		
*Corresponding author at: No. 2 Yuanmingy E-mail address: renti@cau.edu.cn (L. Ren). https://doi.org/10.1016/j.fhydrol.2019.04.053 Received 24 March 2019; Received in revised Available online 18 April 2019 0022-1694/ & 2019 Elsevier B.V. All rights re-	3 form 15 April 2019; Accepted 16			



Research papers Evaluating the effects of limited irrigation on crop wa

reducing deep groundwater exploitation in the North agro-hydrological model: II. Scenario simulation and Pei Li^{a,b}, Li Ren^{a,b,*}

* College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, PR China * Key Laboratory of Plant-Soil Interactions, MOE, Beijing 100193, PR China

ARTICLE INFO	ABSTRACT			
This examining is we handled by Correlo Correlatio, failures with older with the anisome of Weiping Chan, Annotáne Editor Reported Linnbal dringston scenarios Recommended insignation toning Corporate productivity Corporate productivity Corporate productivity Combutions indice of reducing exploitation Distributed SWAP-WOPCST model	between deep groundwatter exploitation and gro water productivity (WY) and deep groundwatt sustainable agricultural practices. In this study using the distributed Soid Water-Annophere- ipted or WF of winter wheat was acketed; the by 14 winter wheat yield reflection thereholds irrigation scheme on awing water and reduc showed that the recommended intergation tanks and the booting to analysis stage for coin triggat of GPN could achieve the goal of reducing deep video tables and the stage of the stage of the exploration. At the related water resource and relatively and the local excitation the stage information could achieve the goal of reducing deep videotry the countribution of implementing the on- esploration. At the related water resource and relatively higher in the related Tabla and Majii basin (ZWHP) and the related plain of the 22 optimization-caukation, the three results at scheme under the countraint of 14 thresholds			
1. Introduction		irrigation (G et al., 2017;		
The North China Plain (NCP) is a ma China (Liu and Wei, 1969; Liu et al., 20 produces, on average, approximately 53 ticum estivum L.) and 31% of the nation's Bureau of Statistics of the People's Rep Grain production on this plain is primar searcity (Liu and Wei, 1989; Fang and Che	01; Zhang et al., 2013) that % of the nation's wheat (<i>Tri-</i> maize (<i>Zea mays</i> L.) (National ublic of China, 1990-2012). ily bound by water resource	et al., 2017; the NCP, wh aquifer, in th irrigation in a due to the lac saline shallow et al., 2015) maintain sus		



Research papers

Evaluating the saline water irrigation schemes using agro-hydrological model

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. Introduction Irrigation plays a significant role in glo iebert, 2002; World et al., 2012; World Iation grows (Tilman et al., 2011), thus f rater resources. However, irrigation com e global freshwater resources (Scanlor global resources (Scanlor	Bank, 2017). The worldwide om 2005 to 2050 as the pop- urther increasing the need for sumes approximately 90% of	water (e.g., br imposed by for et al., 2014; A for irrigation ii Tunisia (e.g., N and Chen, 200 El Oumlould e saline water to			

and Chen, 90% of saline water t 2010). The supply of good-quality water for irrigation has continued to tion will beco decline in many parts of the world (Do Rom. 2012: ert, 2010; Rodell et al., 2018). Thus, irrigation with "marginal" significance

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problems (e.g.,

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Research papers

Assessing the feasibility of sprinkler irrigation schemes a using a distributed agro-hydrological model

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* Key Laboratory of Subauface Hydrology and Ecological Effects in Arid Region, Miniary of Education, Chang'un Univer ^b School of Water and Briviewanni, Chang'an University, Xi'au, 710054, JPC China ^c College of Resources and Briviewannia Science, China Apricalaru University, Bellyn, 100193, JPC China

ARTICLE INFO ABSTRACT

This manuscript was handled by Huaming Guo Editor-in-Chief Keywords: Water productivity SWAP-WOPOST model Water-food-e Soil texture profile Precipitation levels North China Plain

cording to local conditions to alleviate the severe co duction. In this study, the distributed agro-hydrolog was applied to the eastern central part of the Nort eriously overexploited. The model was used to simul rotation years and to analyze the effects on crop yield net income. Then, the irrigation method and the sprinkler and surface irrigation scenarios to maximiz under three irrigation quotas, three precipitation level scheme was optimized for each precipitation level to threshold of irrigation quota reduction compared wit saving and reducing deep groundwater exploitation average, the reduction in the irrigation quota withi under the 11 scenarios; with respect to the specific in of winter wheat between sprinkler and surface irr respectively. The application of sprinkler irrigation t WP of the following summer maize, and the spatial-t decreased under sprinkler irrigation compared with consumption and greater evaporation were estimated under surface irrigation. The income increase under s a negative change in farmers' net income. (3) To ma gation is recommended for winter wheat in most of th the area with sandy soils in each layer or sandy soils (4) The fixed sprinkler irrigation scenarios dominate threshold was 60%, compared with the current irrig achieved 123% of the target value of reducing deep s season, with a yield reduction of 74.3%.

Drainage De

Quantitatively assessing the feasibility of sprinkler irr food and economy could provide the basis for decis

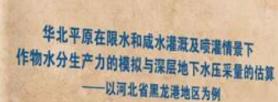
1. Introduction

Biewas, 2015: Li. Sprinkler irrigation, as an advanced irrigation method, has many applied in many o advantages, e.g., saving water and labor, improving land use efficiency, Portugal, Spain, J. and facilitating agricultural mechanization (China Irrig fruit trees, flowers

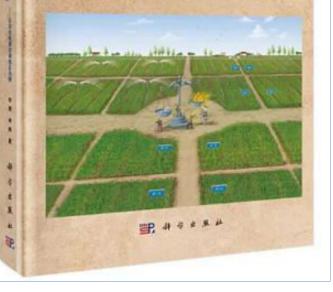
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任理 赤佩莱



Parameter calibration and model validation Journal of Hydrology Li and Ren (2019a)

Limited surface irrigation strategy Journal of Hydrology Li and Ren (2019b)

groundwater depletion because of high-intensity exploitation for

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Saline water irrigation strategy Journal of Hydrology Li and Ren (2021)

Sprinkler irrigation strategy Journal of Hydrology Li and Ren (2022)

Science Press **Ren and Li (2021)**

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