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Assessing the Effects of China's Fallow Pilot Program on Agricultural Irrigation Water Use in Groundwater Depression Cone Regions

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Research Article

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Abstract

To identify the causal effect of the fallow pilot policy on agricultural irrigation water use in groundwater funnel zones, this paper constructs a county-level panel dataset covering 97 counties. The dataset integrates remotely sensed global agricultural irrigation water use data from 2011 to 2018, remote sensing datasets of climate and soil types, and county-level socioeconomic and policy data for Hebei Province. A staggered difference-in-differences (DID) model is used to estimate the policy effects. Event study, placebo test, Goodman–Bacon decomposition, and alternative specifications of the outcome variable are further employed for robustness checks. The results show that the fallow pilot policy significantly reduces irrigation water use and irrigation intensity. On average, irrigation water use and irrigation intensity in pilot counties are 4.96% and 1.21% lower, respectively, than in non-pilot counties. After controlling for the interaction between the 2014 high-water-consumption cropping structure and year fixed effects, the reductions increase to 14.39% and 3.53%, respectively. Mechanism analysis reveals that the policy significantly reduces the share of sown area devoted to high-water-consumption crops, the effective irrigation area ratio, and total factor water use efficiency, with estimated coefficients of − 1.6610, − 0.0516, and − 0.0518, statistically significant at the 10%, 5%, and 5% levels, respectively. Notably, total factor water use efficiency declines temporarily in the early stage of fallow implementation, indicating that water savings mainly arise from cropping-structure adjustment and regulation of total irrigation demand rather than from simultaneous efficiency gains. Heterogeneity analysis suggests that the water-saving effect is more pronounced in deep groundwater overdraft zones, cinnamon soil regions, low-income counties, and counties with a higher share of non-agricultural industry. In deep groundwater overdraft zones, irrigation water use and irrigation intensity decrease by 9.74% and 2.82%, respectively. This study demonstrates that the fallow pilot policy can contribute to achieving the dual-control target by reducing high-water-consumption crops and curbing effective irrigation demand. Nevertheless, attention should be paid to fluctuations in water use efficiency during the initial phase. Differentiated regional subsidies, support for water-saving technologies, and long-term supervision are therefore recommended.

1. Introduction

Hebei Province is one of China's 13 major grain-producing provinces, with more than 6 million hectares of arable land and an annual grain output consistently exceeding 35 million tons [1]. At the same time, it faces severe resource-based water scarcity: available water resources average only about 3,000 m³/ha, only about one-tenth of the national average. Decades of sustained yield growth and high production have led to excessive groundwater abstraction, causing severe environmental and ecological degradation. By 2013, seven long-standing shallow cones of depression and four deep cones of depression had formed in Hebei [2]. In 2014, Hebei launched a pilot program for the comprehensive management of groundwater overexploitation, with seasonal fallowing as one of its key measures. In 2016, the Ministry of Agriculture issued the Pilot Program for Exploring the Implementation of a Crop Rotation and Fallow System, which outlined a pilot scheme for farmland fallowing. In 2025, the State Council released the Plan for Accelerating the Development of an Agricultural Powerhouse (2024–2035), which calls for implementing total control over agricultural water use, advancing comprehensive management of groundwater overexploitation, and improving the crop rotation and fallow system [3]. Fallowing has therefore become a key agri-environmental policy for implementing the "store grain in water and technology" strategy—that is, safeguarding grain security through water conservation and technological progress [4].

Empirical research on the water-saving effects of fallow policies has shown that such policies suffer from adverse selection. Riley et al. (2019) found that farmers tend to enroll land in the program that had not previously been irrigated, implying that fiscal expenditure does not necessarily result in actual reductions in water use. The

difference-in-differences (DID) study by Harris et al. (2017) further documented rebound effects, including switches by farmers to more water-intensive crops. For the groundwater depression cone region of the North China Plain, international studies—such as Wang et al. (2016), Chen et al. (2023), and Yang et al. (2021)—have largely been limited to estimating compensation standards, optimizing the spatial allocation of fallow locations, and conducting field-scale simulations of crop rotation systems. Few studies have evaluated the ecological effects of fallow policies, largely owing to the technical demands, difficulties, and high costs associated with collecting field monitoring data. The vast majority of existing studies assess eco-environmental quality by constructing indicator systems and relying on subjective assessments. For example, Xie Xianxiong selected indicators covering farmland eco-environmental conditions, farmland quality, and cultivation conditions, and obtained indicator values from household questionnaire surveys [8]. Similarly, Yao Liuyang analyzed the welfare implications of farmland conservation policies—such as biodiversity improvement and greenhouse gas emission reductions—using indicator data that were likewise derived from respondents' subjective evaluations [9]. In research on water-saving effects, Hu Zhentong focused on the winter wheat spring irrigation water-saving policy and measured its effect based on whether farmers reduced irrigation frequency [10]. Wu Le [11] and Chen Fei [12] compared irrigation water consumption before and after policy implementation using household interviews and field measurements to assess reductions in groundwater extraction. Taken together, existing studies on the water-saving effects of fallow policies have largely focused on the farm household level or a single cropping system, adopting a relatively narrow perspective and making it difficult to effectively isolate confounding factors and identify the net effect of the policy. Second, the specific water-saving mechanisms and pathways associated with fallow policy still lack rigorous quantitative analysis. In particular, variations in natural conditions and resource endowments across regions, coupled with differences in industrial structure and income levels, may lead to heterogeneity in policy effects. In light of this, the present study treats the fallow pilot embedded in Hebei Province's 2014 groundwater extraction reduction policy as a quasi-natural experiment and employs a staggered difference-in-differences model to identify the causal effect of fallow policy implementation, thereby addressing, to some extent, the data limitations and endogeneity concerns present in the existing literature. Compared with prior studies, the contributions of this paper are threefold. First, in terms of research perspective, it investigates the impact of fallow pilot policy implementation on irrigation water use at the county level, thereby extending the evaluation of the ecological effects of fallowing. Second, in terms of research content, it not only evaluates the effect of the fallow pilot policy on irrigation water use and irrigation intensity, but also examines the underlying mechanisms along three dimensions: aggregate demand (effective irrigation area ratio), demand structure (cropping structure), and water use efficiency (total factor water use efficiency). On this basis, the paper further analyzes the heterogeneous effects of groundwater overdraft type, soil type, income level, and industrial structure on irrigation water use. Third, in terms of data and methodology, drawing on remote sensing data, socioeconomic data, and relevant policy documents, this study uses a sample of 97 counties in Hebei Province and conducts a long-term quantitative analysis, substantially enhancing the objectivity and representativeness of the findings.

2. Mechanisms and Research Hypotheses

2. Mechanisms and Research Hypotheses

Since the 1960s, improved irrigation conditions on the North China Plain have facilitated the expansion of a high-intensity winter wheat–summer maize double-cropping system, and the growing share of water-intensive crops has been a major driver of excessive groundwater extraction [13]. A central component of the fallow policy is therefore to reduce winter wheat acreage and transition to less water-intensive crops such as maize, thereby leveraging the "water consumption gap" between crops to lower total irrigation water use. This paper therefore hypothesizes that

the fallow policy reduces irrigation water use by adjusting the cropping structure and lowering the proportion of water-intensive crops.

In principle, fallowing one season of winter wheat can save approximately 1,500–2,475 m³ of irrigation water per hectare [6], and at the county scale it can reduce groundwater extraction by approximately 19.5 million m³ [1]. However, some scholars argue that the conserved water resources may be redirected to agricultural production; accordingly, this study uses the effective irrigation area ratio to capture changes in aggregate irrigation demand. Following the fallow-induced reduction in winter wheat, the cropping system shifts from double cropping to single cropping, lowering the multiple cropping index and directly reducing fixed irrigation demand. Moreover, because fallowing is often integrated with ecological conservation measures, part of the farmland is permanently withdrawn from cultivation, thereby further reducing effective irrigation demand and leading to a decline in irrigation water use. Hence, this paper hypothesizes that the fallow policy lowers irrigation water use by reducing the effective irrigation area ratio, which in turn diminishes aggregate effective irrigation demand.

The fallow policy is also intended to improve irrigation water use efficiency through technological progress and improved management [7]—for instance, by promoting high-efficiency water-saving equipment and drought-resistant crop varieties. In practice, however, the diffusion of water-saving technologies takes time, and their impacts do not materialize immediately [14]; farmers, wary of yield losses, are reluctant to reduce irrigation, and technologies such as integrated water and fertilizer management face economies-of-scale constraints that limit their adoption. Moreover, during the initial stage of fallowing, the allocation of production factors becomes unbalanced and farming practices cannot be adjusted quickly, causing water use efficiency to decline in the short run. Accordingly, this paper hypothesizes that the fallow policy exerts a temporary downward effect on irrigation water use efficiency.

3. Research Methods

3.1 Identification Strategy

This study employs a staggered difference-in-differences (DID) model to identify the causal effect of the fallow pilot policy, exploiting the 2014 policy rollout as a quasi-natural experiment. The sample covers 116 pilot counties and districts across eight prefecture-level cities, including Shijiazhuang and Baoding, over the period 2011–2018. Treatment and control groups are constructed from this sample. To satisfy the irreversibility assumption of treatment status, 19 counties and districts that withdrew from the pilot program midway (e.g., Daming County, Gaocheng District, and Dongguang County) are excluded, yielding a final estimation sample of 97 counties and districts.

3.2 Baseline Regression Model

This study employs the following staggered difference-in-differences specification:

$$Yi,t = \alpha \ + \beta \ DID\,(i,t) + \gamma\, X\,(i,t) + z^{2014}_i + \mu\,_i + \delta\,_t + \epsilon\,_(i,t)$$

1

In Eq. (1), Y denotes the dependent variable, including irrigation water use and irrigation intensity. The key explanatory variable, DID, is a treatment dummy that equals 1 if county i entered the pilot program in 2014 and for all subsequent years, and 0 otherwise. The coefficient β captures the effect of the pilot policy on irrigation

water use. $X$is a vector of exogenous control variables, including economic development level (per capita GDP), industrial structure (share of agricultural value added), income level (rural per capita disposable income), fiscal support (general budgetary expenditure), and climatic variables (annual average precipitation and annual average temperature) [15]. α is the constant term, $\mu_i$represents county fixed effects, $\delta_t$represents time fixed effects, and $\epsilon_{i,t}$is the idiosyncratic error term.

The mechanism variables include cropping structure (the share of sown area under water-intensive crops, including rice, wheat, cotton, and vegetables), the effective irrigation area ratio (effective irrigated area as a share of total sown area), and water use efficiency. Following Hu [16] and Sun Shuhui [17], water use efficiency is measured by total-factor water use efficiency (AWE), computed as shown in Eq. (2):

$$AWE_n^t = \frac{A_n^t - s_{n,A}^t}{A_n^t}$$

2

where AWE denotes total-factor water use efficiency, W is actual irrigation water use, and s is the irrigation water slack for decision-making unit (DMU) i in period t. In this study, the irrigation water slack is estimated using a slack-based measure data envelopment analysis (SBM-DEA) model. Within the total-factor productivity framework, gross agricultural output serves as the desirable output, and five inputs are specified: agricultural labor (number of workers in the primary sector), land (total sown area of crops), machinery (total power of agricultural machinery), fertilizer (chemical fertilizer in pure nutrient terms), and irrigation water (irrigation water use). The 97 counties constitute the DMUs used to estimate the irrigation water slack.

Given that pilot counties were not randomly selected—selection being based primarily on severe groundwater overdraft and a high share of water-intensive crops—endogeneity concerns may arise. Following Liu et al. (2023) and Li Zhihui (2023), this study addresses such concerns by incorporating into the model the interactions between time fixed effects and predetermined variables that influenced pilot selection (groundwater overdraft type in 2014 and the share of water-intensive crops planted in 2014), thereby controlling for baseline differences between pilot and non-pilot counties. Finally, to assess the robustness of the results, this study conducts an event-study analysis, a placebo test, a Bacon decomposition, and a replacement of the dependent variable, among other checks.

3.3 Data Sources

To objectively capture inter-county variation in natural resource endowments and agricultural development, this study draws on data from three sources.

The first source is remote sensing data, including administrative boundaries, irrigation water use, soil type, and climate variables. Irrigation water use is obtained from the global farmland irrigation water use remote sensing dataset (2011–2018) released by the National Tibetan Plateau Scientific Data Center [18]. Using ArcGIS, this study performs mask extraction and zonal statistics to derive regional irrigation intensity, which is then combined with the effective irrigated area to compute irrigation water consumption. County-level administrative boundaries, climate, and soil type data are obtained from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences and the National Earth System Science Data Center, and are extracted and processed using ArcGIS.

The second source is socioeconomic data, covering control variables and mechanism variables. These data are obtained primarily from the Hebei Rural Statistical Yearbook, with missing observations supplemented from the China County Statistical Yearbook.

The third source is policy-related information, including the list of fallow pilot counties and groundwater overexploitation zoning data. These data are compiled from the Pilot Program for Comprehensive Management of Groundwater Overexploitation in Hebei Province, the Hebei Province Annual Task List for the Pilot Program of the Seasonal Fallow System on Farmland, and the Notice of the People's Government of Hebei Province on Delineating Groundwater Overexploitation Zones, Prohibited Extraction Zones, and Restricted Extraction Zones (2014).

Table 1 presents the descriptive statistics of the variables.

Table 1
Descriptive statistics of variables.

Variable	Unit	Mean	Std. Dev.
Irrigation water use	10,000 m^3	1,381,913	732,858.4
Irrigation intensity	m	0.4359	0.4244
Economic development level	CNY/person	25,252.63	26,851.62
Industrial structure	%	18.7784	17.3964
Income level	CNY	10,061	3,714.691
Fiscal support	10,000 CNY	182,152.5	140,535.9
Annual average temperature	°C	13.4444	1.0713
Annual average precipitation	mm	531.3386	88.8908
Cropping structure	%	41.5268	15.3544
Water use efficiency	—	0.3945	0.2848
Effective irrigation ratio	%	53.7683	12.1664
Source: Authors own work			

4. Results

4.1 Baseline Regression Results

Table 2 presents the baseline estimates of the effects of the fallow pilot policy on irrigation water use.

Table 2
Baseline regression results of the water-saving effect of the fallow policy

	Irrigation water use		Irrigation water use		Irrigation intensity		Irrigation intensity	
	(1)		(2)		(3)		(4)	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Policy interaction term (DID)	-0.0496***	0.0087	-0.1439***	0.0257	-0.0121***	0.0033	-0.0353***	0.0102
Control variables	Controlled		Controlled		Controlled		Controlled	
Year fixed effects	Controlled		Controlled		Controlled		Controlled	
County fixed effects	Controlled		Controlled		Controlled		Controlled	
Pre-treatment characteristics × year fixed effects	Not controlled		Controlled		Not controlled		Controlled	
Observations	776		776		776		776	

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. For the year fixed effects, only the 2014 water-intensive cropping structure is included. Because groundwater overdraft severity is collinear with the core DID term (the treatment × time interaction), this variable is not included in the model.

Source: Authors own work

Model 1 estimates the effect on irrigation water use. After controlling for county fixed effects and year fixed effects, the policy interaction term is negative and significant at the 1% level, indicating that the fallow pilot policy significantly reduced irrigation water use, with irrigation water use in fallow counties averaging 4.96% lower than in non-fallow counties. Model 2 additionally includes the interaction between the 2014 water-intensive cropping structure and the year fixed effects; the absolute value of the estimated policy interaction term increases to 14.39%. From a policy perspective, in areas planted with water-intensive crops, irrigation water use typically exhibits a slower rate of decline than in areas planted with less water-intensive crops; absent the fallow intervention, irrigation water use in the former might have grown more rapidly. By including the interaction between the water-intensive cropping structure and the year fixed effects, the model effectively removes confounding time trends in irrigation water use, thereby identifying the policy's true effect more accurately. Model 3 estimates the effect on irrigation intensity. After controlling for county fixed effects and year fixed effects, the policy interaction term is negative and significant at the 1% level, with irrigation intensity in fallow counties 1.21% lower than in non-fallow counties. Model 4, which adds the interaction between the water-intensive cropping structure and the year fixed effects, also shows a substantial increase in the absolute value of the policy interaction term, to 3.53%. The results of Models 2 and 4 are consistent with the core objective of the fallow policy—reducing irrigation demand through adjustments to the water-intensive cropping structure—and indirectly confirm the appropriateness of the model specification.

4.2 Parallel Trends Test and Dynamic Treatment Effects

A prerequisite for the validity of the difference-in-differences design is that the treatment and control groups exhibit parallel trends in irrigation water use prior to policy implementation. Accordingly, this study applies an event-study approach to estimate year-by-year policy effects and thereby examine the dynamic effects of the policy [19]. Figure 1 presents the dynamic water-saving effects of the fallow pilot policy obtained from the event-study analysis. Before policy implementation, the estimated coefficients cluster around zero and are statistically insignificant, indicating that pilot and non-pilot counties did not exhibit differential trends in irrigation water use and thus supporting the pre-treatment parallel trends assumption. After policy implementation, both irrigation water use and irrigation intensity in fallow counties show a pronounced downward trend, a finding consistent with the baseline estimates in Table 2 and one that corroborates the water-saving effect of the fallow policy.

Source: Authors own work

In practice, Hebei's fallow policy originated from the 2014 groundwater extraction reduction initiative. The program was first implemented in groundwater depression cone areas where conditions were most favorable and water-saving potential was greatest. Owing to precise policy design and active cooperation from farm households and local governments, the water-saving effect peaked in 2015. Between 2015 and 2016, the fallow policy entered a phase of scaled-up promotion, with the number of pilot counties expanding from 63 to 115. As the fallow program underwent rapid expansion, the average water-saving effect gradually diminished. If the "pilot effect" of 2014 reflected concentrated gains in a narrow set of areas with the most severe overdraft, the subsequent decline in the average water-saving rate after 2016 was an inevitable consequence of the policy's transition from localized demonstration to province-wide implementation. In 2017, the fallow program was formally upgraded to a national-level fallow pilot, and the policy objective broadened from a sole focus on water conservation to equally emphasizing water conservation and soil fertility improvement, with greater emphasis on comprehensive ecological benefits. Although the water-saving effect moderated relative to the initial stage, the policy as a whole achieved its intended water-saving targets, marking a shift from emergency groundwater extraction reduction toward long-term ecological restoration.

4.3 Robustness Checks

(1) Placebo Test

The foregoing model results may be confounded by unobservable factors. To address this concern, this study conducts a placebo test on the staggered DID model by randomly reassigning treatment timing and treatment status. The procedure is as follows. First, because 40 counties participated in the first wave of the pilot in 2014, we randomly select 40 sample counties and assign them 40 pseudo policy implementation years, thereby generating a simulated policy shock variable, did^*. Second, we re-estimate the baseline regression for irrigation water use and extract the estimated coefficient on did^*. This process is repeated 500 times to characterize the distribution of the coefficients. Figure 2(a) plots the distribution of the regression results from the 500 random simulations. The estimated coefficients on did^* cluster around zero, are approximately normally distributed, and most of the simulated coefficients have p-values greater than 0.10. Notably, the baseline estimate of did in our model is − 0.14, which lies far in the tail of this distribution. This pattern indicates that the baseline result for irrigation water use is highly unlikely to be driven by unobservable confounding factors, thereby supporting the robustness of the original estimate. The placebo test results for irrigation intensity (Fig. 2(b)) show a consistent pattern, further supporting the reliability of the regression findings.

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Source: Authors own work

(2) Testing for Estimation Bias in the Staggered DID Design

The staggered DID estimator is essentially a weighted average of conventional DID estimates that yields an overall treatment effect. When treatment effects are heterogeneous across groups and over time, the estimates are susceptible to bias from “negative weighting.” This study employs the Bacon decomposition to examine whether comparisons between later-treated and earlier-treated units yield estimates with signs opposite to the average treatment effect. If such comparisons receive substantial weight in the aggregation, they would directly undermine the reliability of the final DID estimate. The results show that the “later-treated vs. earlier-treated” comparison accounts for only 5.4% of the total weight, whereas the “treated vs. never-treated” and “earlier-treated vs. later-treated” comparisons account for 86.8% and 7.8% of the weight, respectively, with both signs consistent with the baseline regression results. This evidence indicates that the “negative weighting” problem causes negligible distortion to the overall estimate and that the baseline results are highly credible and robust. The Bacon decomposition results for irrigation intensity show a pattern consistent with that for irrigation water use.

(3) Replacing the Dependent Variable

To further enhance the robustness of the findings, this study replaces the dependent variable. The original dependent variable is the irrigation water use indicator derived from remote sensing data; it is replaced with surface soil moisture content. By conducting a reverse verification from the perspective of water resource “stock effects,” this study further tests the reliability of the conclusions. The surface soil moisture data are obtained from the China Soil Moisture Dataset (2002–2018) released by the National Tibetan Plateau Scientific Data Center. The results indicate that in the year the fallow policy was implemented, soil moisture content declined by 8.6%, and the estimate is statistically significant at the 1% level. Because irrigation is the principal anthropogenic source of soil moisture replenishment, the post-fallow reduction in both irrigation frequency and volume deprives the soil of regular moisture supplementation, thereby lowering current-period soil moisture content—an effect that is especially pronounced in a semi-arid region such as Hebei. In the long run, however, fallowing is expected to gradually raise soil moisture content, promote water accumulation, augment “soil reservoir” storage, and reduce long-term irrigation demand, a proposition that warrants verification in future research. In sum, the decline in current-period soil moisture content corroborates the robustness of the fallow policy’s effect on irrigation water use.

5. Further Analysis

5.1 Mechanism Analysis

This study conducts a mechanism analysis along three pathways—cropping structure, effective irrigation area ratio, and water use efficiency—and reports the results in Table 3. The main findings are as follows. First, when the dependent variable is cropping structure, the estimated coefficient of the fallow policy is significantly negative, indicating that the fallow pilot policy shifted the cropping structure away from water-intensive crops toward drought-tolerant crops, thereby reducing irrigation water use. Second, when the dependent variable is the effective irrigation area ratio, the fallow policy significantly lowered this ratio. This finding captures the policy’s effect on irrigation water use from an “area coverage” perspective and simultaneously confirms the role of agricultural infrastructure in regulating water resources. Third, when the dependent variable is water use efficiency, the estimated coefficient of the fallow policy is also significantly negative. From the perspective of management

efficiency, this arises mainly because fallowing directly reduces grain output while capital and labor inputs fail to shrink in tandem, leading to an imbalance in factor allocation. From the perspective of technological progress, meanwhile, fallow subsidies are primarily used to compensate for farm household income losses, while investment in water-saving technologies and equipment upgrading remains relatively inadequate, resulting in a short-term decline in water use efficiency. Taken together, the fallow policy operates through three mechanism pathways—optimizing the cropping structure, lowering the effective irrigation area ratio, and (in the short run) reducing water use efficiency—to form a systematic effect of area control, structural optimization, and (long-run) efficiency improvement, jointly driving down irrigation water use.

Table 3
Mechanism analysis results.

	Water use efficiency		**Cropping structure**		**Effective irrigation ratio**	
	Coef.	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Fallow policy	-0.0518**	0.0239	-1.6610*	0.9170	-0.0516**	0.0174
Control variables	Controlled		Controlled		Controlled	
County fixed effects	Controlled		Controlled		Controlled	
Year fixed effects	Controlled		Controlled		Controlled	
Observations	776		776		776	
Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.						
Source: Authors own work						

5.2 Heterogeneity Analysis

Heterogeneity analysis is conducted along four dimensions—groundwater overdraft type, soil type, income level, and industrial structure—as reported in Tables 4 and 5.

(1) Groundwater Overdraft Type

Based on the geological characteristics of groundwater overdraft, the *Notice of the People's Government of Hebei Province on Delineating Groundwater Overexploitation Zones, Prohibited Extraction Zones, and Restricted Extraction Zones* (2014) classifies the sample regions into two categories: shallow overdraft zones (including general and severe shallow groundwater overdraft areas) and deep overdraft zones (including general and severe deep groundwater overdraft areas). This study then examines whether the effect of the pilot policy differs by groundwater overdraft type; the estimation results are reported in Table 4. The policy significantly reduced both irrigation water use and irrigation intensity in deep overdraft zones. This may be because deep overdraft zones face more severe groundwater depletion, where irrigation water is more difficult to obtain and agricultural production costs are higher, making fallowing a direct and effective means of alleviating the water crisis; consequently, both local governments and farm households show a strong willingness to implement the policy. In addition, the fallow policy provides a government subsidy of CNY 7,500 per hectare, which largely compensates farmers for the economic losses from forgoing wheat cultivation; rising off-farm income and the ecological benefits of fallowing—such as soil fertility recovery and higher summer maize yields—further strengthen farmers' incentives to comply. By contrast, in shallow overdraft zones, water competition is relatively less acute and the incremental benefits of fallowing are limited, so the incentive to implement the policy is correspondingly weaker.

Table 4
Heterogeneity analysis by groundwater overdraft type.

	Irrigation water use (deep overdraft)		Irrigation water use (shallow overdraft)		Irrigation intensity (deep overdraft)		Irrigation intensity (shallow overdraft)	
	Coef.	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Policy interaction term (DID)	-0.0974***	0.0283	0.1804	0.5769	-0.0282**	0.0115	0.1453	0.2335
Control variables	Controlled		Controlled		Controlled		Controlled	
Year fixed effects	Controlled		Controlled		Controlled		Controlled	
County fixed effects	Controlled		Controlled		Controlled		Controlled	
Observations	456		320		456		320	
Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.								
Source: Authors own work								

(2) Soil Type

Because arable soil conditions differ markedly across counties, the policy's effects may be regionally heterogeneous. Following the *Report on Monitoring and Evaluation of Farmland Quality in the Seasonal Fallow Pilot Areas of Hebei Province* (2017–2019), this study classifies the dominant soil types in the sample area into two categories: cinnamon soil and fluvo-aquic soil. The full sample is then split at the median share of cinnamon soil in total soil area into cinnamon-soil and non-cinnamon-soil (fluvo-aquic) regions, coded 1 and 0, respectively; these categories are interacted with the pilot policy. As shown in Table 5, the estimated coefficients of the pilot policy on both irrigation water use and irrigation intensity are significantly negative in cinnamon-soil regions. From a natural-attribute perspective, cinnamon soil has a dense clay-illuvial (argillic) layer that impedes deep water percolation, producing a pronounced "soil reservoir" effect (O'Leary and Connor, 1997). From a socioeconomic perspective, cinnamon-soil regions are not major grain-producing areas of Hebei, so their dependence on grain production is lower and the opportunity cost of fallowing is small. Consequently, the pilot policy has more effectively reduced irrigation water use in cinnamon-soil regions.

(3) Income Level

Marked differences in economic income levels exist across counties, and these differences may generate regional heterogeneity in the policy's effects. This study splits the full sample at the median of rural per capita disposable income into high-income and low-income areas, with low-income areas coded as 1 and high-income areas coded as 0; this binary indicator is then interacted with the fallow pilot policy variable. As shown in Table 5, the estimated coefficient of the pilot policy is significantly negative in low-income counties. The core concern in low-income counties is economic livelihood. A stable fallow subsidy is more attractive than the uncertainty of engaging in low-productivity agriculture—indeed, it represents a guaranteed income irrespective of external conditions. Moreover, fallowing releases a larger share of labor from the land for off-farm employment, substantially increasing

household earnings and thereby providing strong short-term economic incentives. In high-income areas, by contrast, the marginal benefit of the subsidy is relatively low, and compliance with the fallow policy, viewed through the lens of livelihood income, is correspondingly weaker [5]. Consequently, the fallow pilot has more effectively reduced irrigation water use in low-income regions.

(4) Industrial Structure

Disparities in industrial structure across counties may induce regional heterogeneity in the policy's effects. Accordingly, this study splits the full sample at the median share of agricultural value added into agricultural counties and non-agricultural counties, with non-agricultural counties coded as 1 and agricultural counties coded as 0; this binary indicator is then interacted with the fallow pilot policy variable. As shown in Table 5, the estimated coefficient of the fallow policy is significantly negative in non-agricultural counties. Non-agricultural counties—where agriculture accounts for a relatively low share of GDP—exhibit limited dependence on farming, such that the fallow subsidy represents a "net gain" for farmers rather than mere "compensation," leading to stronger policy implementation outcomes. By contrast, agricultural counties depend almost entirely on cropping income, and fallowing entails a direct loss of part or all of that income. The subsidy cannot compensate for the psychological loss of security; moreover, in counties where a high agricultural share has persisted over the long term, path dependence in cropping patterns is difficult to break, and mature industrial chains (e.g., wheat procurement, processing, and distribution networks) have already taken shape. Once fallowing is introduced, farmers must not only alter their cultivation practices but also bear the technical and market risks of planting new crops, while facing the potential collapse of established sales channels. As a result, the fallow pilot in non-agricultural counties has more effectively reduced irrigation water use.

Table 5
Heterogeneity analysis results.

	Irrigation water use (cinnamon soil)	Irrigation intensity (cinnamon soil)	Irrigation water use (low income)	Irrigation intensity (low income)	Irrigation water use (non-agricultural)	Irrigation intensity (non-agricultural)
	Coef. / Std. Err.	Coef. / Std. Err.	Coef. / Std. Err.	Coef. / Std. Err.	Coef. / Std. Err.	Coef. / Std. Err.
Policy interaction term (DID)	-0.0520**	-0.0230***	-0.0372***	-0.0092**	-0.0286**	-0.0076*
	0.0160	0.0063	0.0104	0.0041	0.0103	0.0041
Control variables	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Year fixed effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
County fixed effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Pre-treatment characteristics × year fixed effects	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Observations	776	776	776	776	776	776
Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.						
Source: Authors own work						

6. Conclusions and Policy Recommendations

6.1 Conclusions

This study employs a staggered difference-in-differences (DID) approach to examine the effects of the fallow pilot policy on irrigation water use. The empirical results show that the policy achieved significant effects: it effectively reduced both irrigation water use and irrigation intensity, thereby attaining the “dual control” objective. Specifically, the pilot policy optimized the cropping structure by steering production away from water-intensive crops toward drought-tolerant crops, directly lowering irrigation demand. The policy also reduced the effective irrigation area ratio, curbing irrigation demand from an area-coverage perspective. With respect to water use efficiency (AWE), a short-term decline was observed because capital and labor inputs failed to adjust in tandem; however, this represents a temporary phenomenon at the initial stage of the policy. Finally, areas with deep groundwater overdraft showed a strong willingness to implement the policy; in cinnamon soil regions, the actual water-saving effect was more pronounced; fallow subsidies proved particularly attractive to low-income farm households, leading to higher compliance rates; and in agricultural counties, an undiversified industrial structure created path dependence in cropping decisions and thus considerable resistance to policy implementation.

6.2 Policy Recommendations

(1) Strengthen policy targeting to focus on water-intensive regions and crops.

The fallow policy should be prioritized in counties and cities with severe groundwater overdraft. Fiscal subsidies could be raised—for example, by 10%–15% above the standard rate in ordinary areas—to strengthen local governments' incentives to implement the policy. The area sown to water-intensive crops should be strictly controlled, and farm households should be guided to transition toward drought-tolerant crops such as legumes, with technical support for improving drought-tolerant varieties.

(2) Establish a "fallow–cropping structure adjustment" linkage mechanism.

Fallow pilot programs should be aligned with agricultural industry planning, and additional rewards should be provided to farm households that voluntarily reduce the area sown to water-intensive crops. The effective irrigation area ratio should be dynamically adjusted to progressively lower irrigation coverage. Through high-standard farmland development, priority should be given to meeting the irrigation needs of staple grain crops, while a "rain-fed agriculture plus water-saving irrigation" model should be promoted on farmland used for non-staple crops.

(3) Mitigate efficiency fluctuations during the initial policy phase and promote optimal factor reallocation.

To address the mismatch between capital and labor inputs in the early stage of fallowing, a dedicated fund for water-saving technology retrofitting should be established, offering farm households a 30%–50% purchase subsidy for drip and sprinkler irrigation equipment. Family farms and cooperatives should be encouraged to take over fallowed land so that water-saving technologies and labor can be integrated efficiently through scaled-up operations, thereby raising total-factor water use efficiency (AWE).

(4) Design regionally differentiated policies to overcome implementation resistance.

In pilot areas with low economic income, fallow subsidies should be linked to household income—for example, by setting subsidy tiers based on per capita household income and raising the subsidy rate by 20% for low-income farm households—to enhance the policy's attractiveness. For agricultural counties with an undiversified industrial structure, transformation support should be provided by pairing fallowing with an "industrial upgrading" package (e.g., developing agricultural product processing and leisure agriculture), thereby reducing path dependence on traditional cropping through industrial diversification.

(5) Strengthen long-term supervision and dynamic evaluation mechanisms.

A regular, third-party evaluation mechanism should be institutionalized to periodically assess the ecological effects of policy implementation and to adjust and optimize subsidy standards and complementary measures in a timely manner—for example, by adding a special subsidy for soil fertility improvement.

Empirical evidence shows that the fallow pilot policy can effectively reduce irrigation water use; however, the transition from short-term administrative control to sustainable agricultural transformation requires sustained efforts in precision targeting, complementary safeguards, and long-term planning. Advancing the coordinated enhancement of ecological, social, and economic benefits will chart a sustainable pathway for the green transformation of agriculture.

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Ethics statement

Declarations

Competing interests

The authors declare that they have no competing interests.

Author Contribution

Song Haifeng (First and Corresponding Author): Made substantial contributions to the conception and design of the work, data collection and collation, manuscript drafting, and final approval of the version to be published; agrees to be accountable for all aspects of the work, ensuring that any questions related to the accuracy or integrity of any part of the work are appropriately addressed. Liu Yingzong: Critically reviewed the key intellectual content and provided revisions to the research framework. All authors read and approved the manuscript.

Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

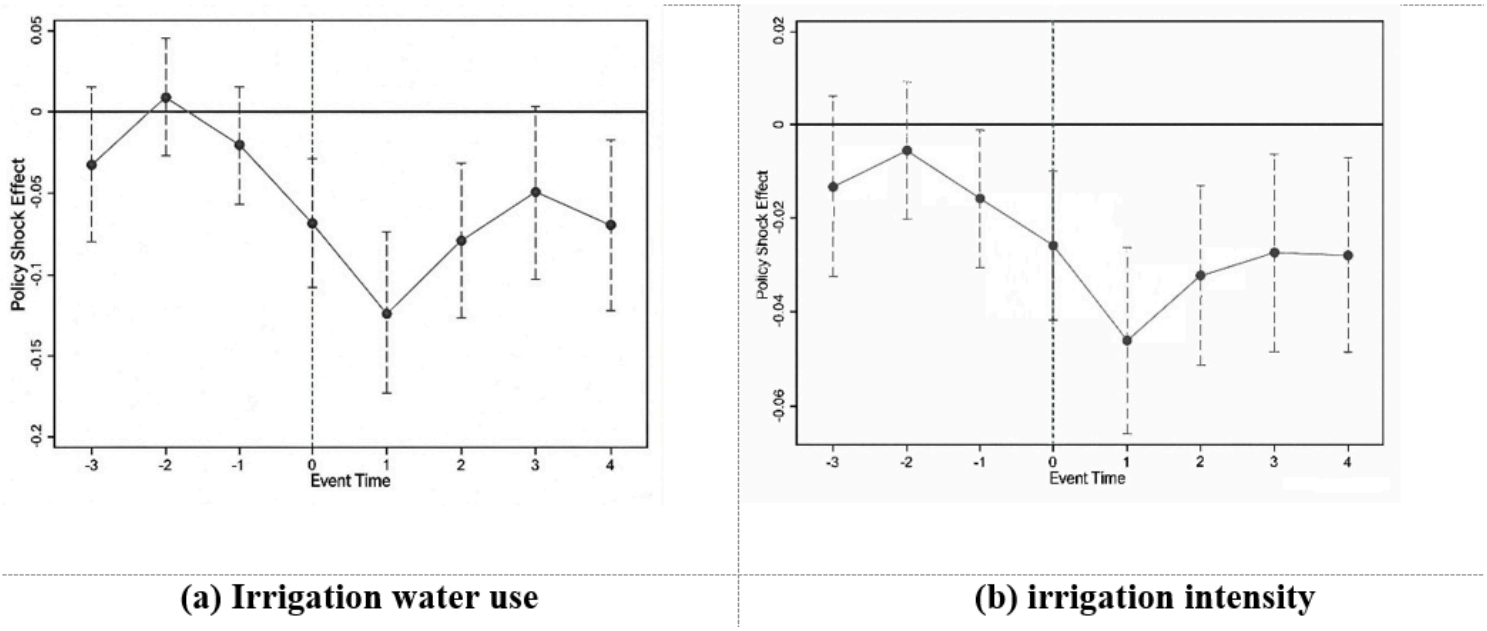
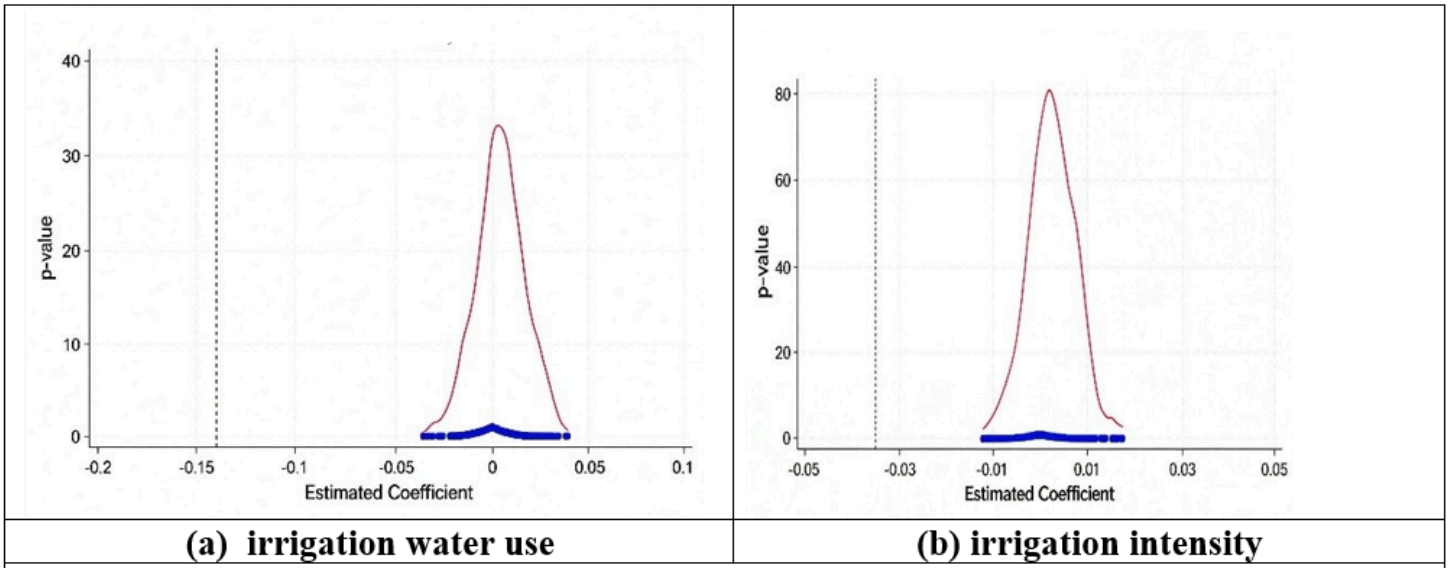


Figure 1

Event-study estimates of the dynamic effects of the fallow pilot policy

Source: Authors own work



(a) irrigation water use (b) irrigation intensity

Figure 2

Placebo test results

Source: Authors own work