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REVIEW

Implications of agricultural success in the Yellow River Basin and its strategy for green development

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KEYWORDS

Ecological agriculture, drylands agriculture, irrigation, water-saving technology, policy support

HIGHLIGHTS

- Ecological fragility and water shortage are key challenges in the Yellow River Basin.
- Efficient water use technology in drylands greatly increases crop production.
- Water-saving irrigation has been widely adopted and has greatly improved water use.
- Changing water use from unregulated and inefficient to intensive and efficient is key solution.
- Watershed-scale coordination is a key step towards agriculture green development.

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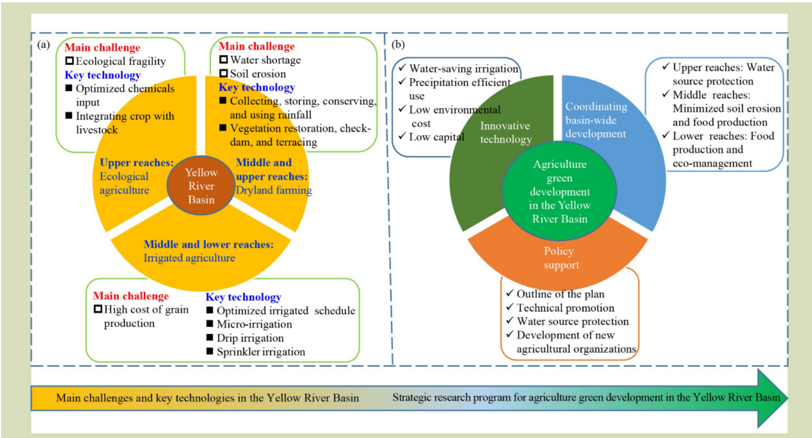
GRAPHICAL ABSTRACT



ABSTRACT

The Yellow River Basin is an important food production area and an ecological challenge for China, where environmental protection and water scarcity are the major constraints. For the upper reaches of the Yellow River Basin, optimizing the adoption of chemicals in agricultural production and integrating crops with livestock are the key strategies for protecting the eco-environment. For dryland agriculture in the middle and upper reaches, this study summarizes four aspects of efficient precipitation techniques in terms of collection, storage, conservation, and use, which have greatly improved crop yields and supported dryland crop production. Irrigated agriculture in the middle and lower reaches is the core area of China's grain production, where the area under water-saving irrigation reached 13.0 Mha in 2018, greatly improving water use. Compared with 1998, cereal production in 2018 increased by 62.2 Mt under similar total water withdrawals (49.7 billion to 51.6 billion m^3), and the annual soil erosion at the Tongguan Hydrological Observatory reduced by 584 million m^3 in 2018, achieving great success in environmental protection and efficient water use. The Chinese government has set a goal for the Yellow River Basin to become the national leader in environmental protection and efficient water use by 2035. Such a high demand requires the combined efforts of the whole community, as well as the adoption of new technologies, coordinated basin-wide development, and adequate policy support.

1 Introduction

The river basins worldwide have always been important habitats for humans, and sustainable agricultural development in river basins has been a key component of the global economy and society[1]. However, a large river basin is often accompanied by large differences in climate, ecological, social and economic development, and its agriculture is therefore difficult to manage[2,3]. Among the many natural factors, environmental protection and the conservation and scarcity of water resources are the main constraints to agricultural development in the river basin, particularly due to the droughts expected in the coming years as a result of climate change, and the increased demand for water as a result of population growth and urbanization[4]. The Yellow River is considered the Mother River of the Chinese nation with the second-largest river basin in China, known as one of the most ecologically fragile and water-stressed in the world[5]. This work looked at the Yellow River Basin as a case study in the global agricultural management of river basins.

The Yellow River Basin is of great importance as a grain production area and ecological challenge for China, where about 160 million people currently live[6]. Between 1998 and 2018, agriculture here developed rapidly and made great achievements[7]. Of these, cereal crop production increased from 171 to 233 Mt, the annual soil erosion in the Tongguan Hydrological Observatory reduced from 650 million to 66 million m^3 (Fig. 1), and the gross value of output from plantation, livestock, forestry and fishery has greatly increased from 737 billion to 3468 billion yuan[8,9]. However, the tremendous development of crop production has also been accompanied by long-term, high inputs of agricultural production materials. For instance, between 1998 and 2018, the

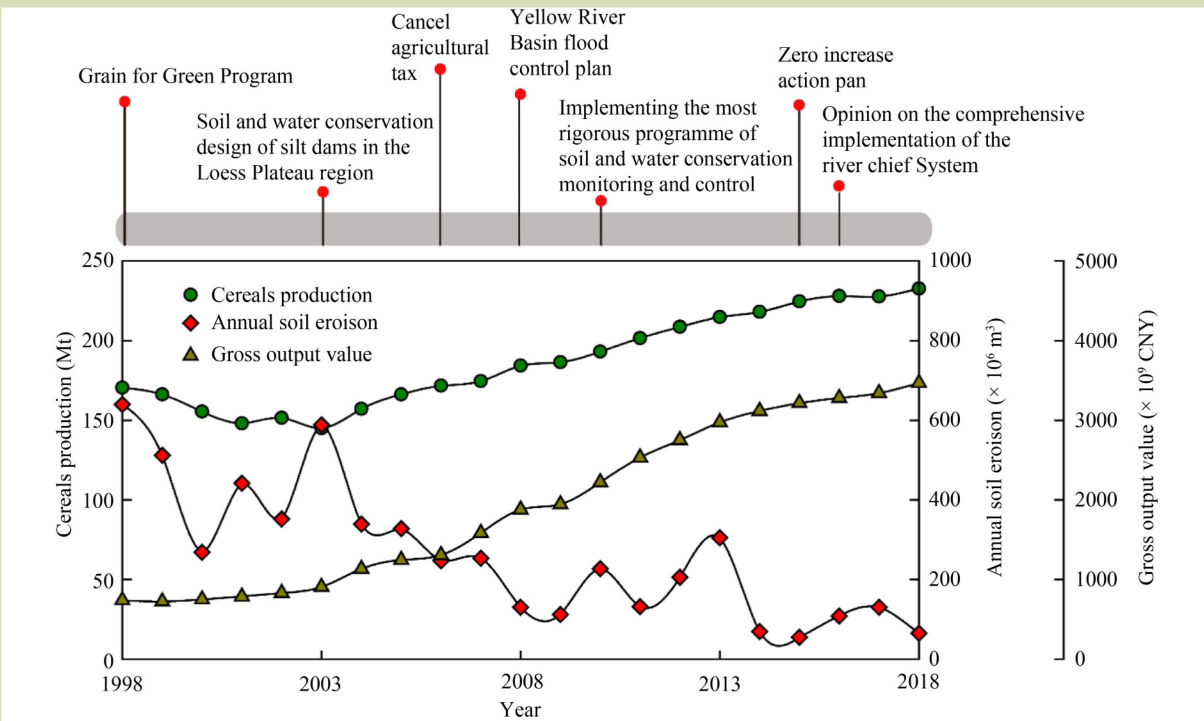


Fig. 1 Agricultural development trend of Yellow River Basin in the cereals production, annual soil erosion in Tongguan hydrological observatory, the gross output value of plantation, forestry, livestock, and fisheries between 1998 and 2018. The top half of the figure shows policies to promote agricultural development in the Yellow River Basin.

mean use of N, P, and K fertilizers reached 7.72, 2.92, and 1.52 Mt, respectively (Fig. 2). Simultaneously, the mean use of pesticides, diesel oil, and agricultural water also reached 0.43 Mt, 5.05 Mt, and 82.9 billion m^3, respectively. The mean annual precipitation in the Yellow River Basin was only 452 mm for the period 1998–2018[10], and most of the area is a typical ecologically fragile region with huge challenges for agricultural production. Given the unprecedented pressures on the environment and the scarcity of critical resources in the future, reconciling the twin pressures of food and environmental security will require prioritizing improved resource use efficiency.

The Yellow River, with a total length of 5464 km, passes through nine Chinese provinces, and the agricultural development of the Yellow River Basin was divided into three reaches in this study. The main challenges that the Yellow River Basin has ecological fragility in the upper reaches, water shortage and soil erosion in the middle reaches, and the high cost of grain production in the lower reaches[11]. The Chinese government has long attached great importance to sustainable agricultural development in the Yellow River Basin, and a great deal of studies have been conducted in response to these major challenges. Despite substantial policy and management efforts, the rapid growth of agricultural production in the Yellow River Basin has come at the cost of excessive use of agrochemicals and substantive environmental damage. If the top-level design of agricultural production could be done better, and if optimized crop and soil management techniques could be adopted as early as possible, more food could be produced at lower environmental costs, and perhaps the ecological and environmental costs in exchange for the achievements of agriculture would be much less. In this paper, we review the process of agricultural development in the three reaches of the Yellow River Basin, analyzing the experiences and lessons, to provide a reference for global river-led agricultural development, and also present three sets of recommendations for achieving sustainable agriculture to promote the transition of the Yellow River Basin toward green agriculture development.

2 Ecological agriculture in the upper Yellow River Basin

The upper Yellow River Basin is a key challenge to China’s ecological security, and the Sanjiangyuan area in Qinghai Province is the most important water source in China. In addition, there are rich in river and lake wetland resources in Yushu and Guoluo Tibetan Autonomous Prefecture in Qinghai Province, and Aba and Ganzi Tibetan Autonomous Prefecture in Sichuan Province, which are the main water supply areas for the Yellow River. Crop production has increased here between 1998 and 2018, for example, the production of apples and grapes increased from 0.3 to 1.1 Mt (Table 1). However, these increases have long been accompanied by high inputs of

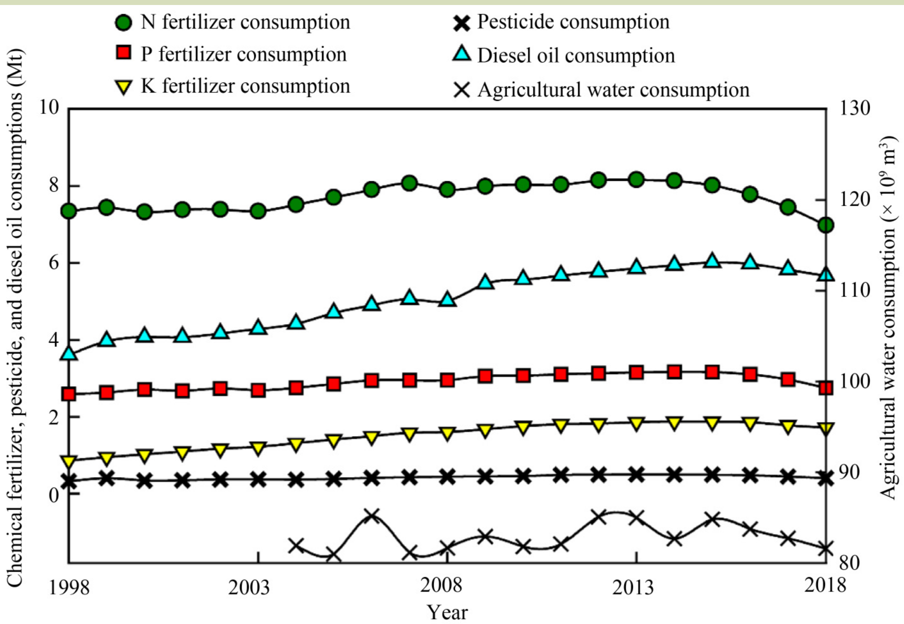


Fig. 2 The trend of agricultural production materials of the Yellow River Basin between 1998 and 2018.

Table 1 Development of plantation, livestock, forestry, and fishery in the Yellow River Basin

Year	Region	Plantation		Livestock			Forestry	Fishery
		Cereals production (Mt)	Production of apple and grape (Mt)	Meat production (Mt)	Egg production (Mt)	Milk production (Mt)	Forest area (Mha)	Freshwater production (kt)
1998	Upper reaches#	36.5	0.3	5.1	0.8	0.2	19.9	424
	Middle reaches	51.3	5.8	3.5	1.1	1.6	38.7	173
	Lower reaches	82.7	8.6	9.6	5.5	0.4	5.9	1110
	Sum	170.5	14.7	18.2	7.5	2.1	64.6	1707
2018	Upper reaches	36.0	1.1	7.0	1.5	1.0	22.6	1552
	Middle reaches	77.0	18.6	6.1	2.5	9.7	44.0	541
	Lower reaches	119.7	15.4	15.2	8.6	4.3	6.7	2237
	Sum	232.7	35.1	28.4	12.6	14.9	73.3	4330

Note: #The upper reaches of the Yellow River Basin included Qinghai and Sichuan; the top reaches of the Yellow River Basin included Gansu, Ningxia, Inner Mongolia, Shaanxi, and Shanxi; the lower reaches of the Yellow River Basin included Henan and Shandong.

agricultural production materials, such as mineral fertilizers, pesticides and diesel oil, with average consumption reaching 1.9 Mt, 60 kt, and 0.45 Mt, respectively[8]. This has increased the risk of environmental pollution and ecological damage.

To reduce pollution from agricultural production and protect the eco-environment, many relevant policies and incentives have been published in the upper Yellow River Basin. Qinghai Province is a case in point. In 2021, it led the way in China by proposing an action plan to establish a green export target for organic agricultural and livestock products. Highland barley and oilseed rape are the special crops here, and overuse of mineral fertilizer in their production was common. Farmer survey results from our group showed that the rate of mineral fertilizer in highland barley and oilseed rape reached 161 and 174 kg·ha^{-1} N, 37 and 56 kg·ha^{-1} P, and 49 and 76 kg·ha^{-1} K, respectively. Further, we conducted a field experiment on the replaced chemical N fertilizer with livestock manure for crop production in Huzhu Tujia Autonomous County in 2020 and 2021. Experimental results showed that the grain yield of highland barley and oilseed rape did not reduce in replaced 20% to 40% chemical N fertilizer (Fig. 3). Also, we conducted a meta-analysis across China showed that replacing 40% of chemical N fertilizer with livestock manure had no significant effect on wheat grain yield[12]. These findings showed that

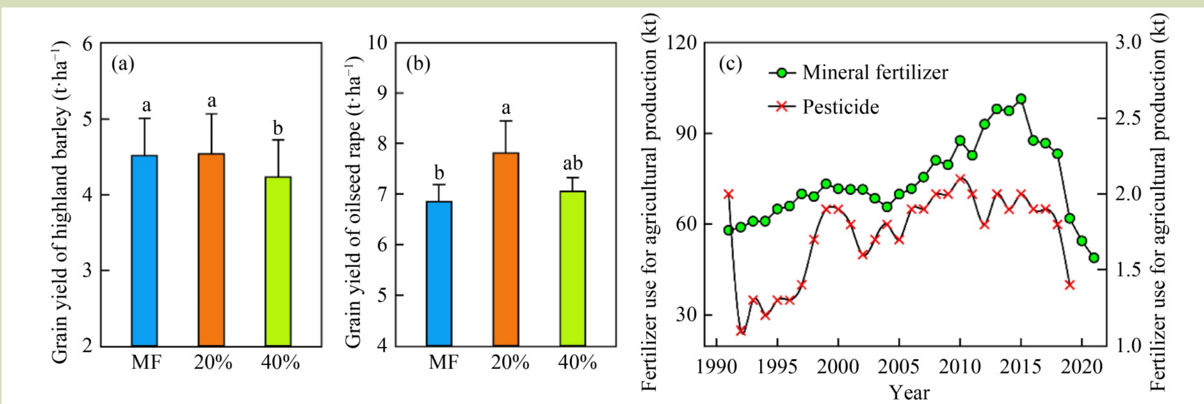


Fig. 3 Effect of replacement of mineral N fertilizers by manure on the yield of barley (a) and oilseed rape (b); the fertilizer and pesticide use for agricultural production during 1991–2021 in Qinghai Province (c). MF: mineral fertilizer; 20%: substituting 20% of mineral N fertilizer by manure; 40%: substituting 40% of mineral N fertilizer by manure. The rates of mineral N fertilizer were 96 and 143 kg·ha^{-1} N for barley and oilseed rape production, respectively.

optimizing mineral fertilizer management is feasible and needed. In 2018, the Qinghai provincial government formulated the action of reducing the amount of mineral fertilizers and increasing efficiency on at a provincial level. The good news is that 4 years into the action plan, total use of mineral fertilizer in the province has decreased by more than 40% (Fig. 3). Similarly, the pesticides has also decreased by 22% in 2018–2019.

In addition, Qinghai province is also a large livestock area, with characteristic livestock such as yaks and Tibetan sheep; meat products here increased from 205 to 365 kt during 1998–2018[8]. In that context, large numbers of livestock have the potential to provide abundant livestock manure resources for agricultural production, but the amount of livestock manure in the farmland is minimal. Recent research has shown that the nutrient content from livestock manure is only 3% of the total nutrient input to cereal crop production[12]. There are two main reasons for this. First, it widely considered that applying livestock manure did not increase economic profits. This was mainly the high cost of livestock manure and the additional cost of application. Second, livestock manure is bulky and labor is required to apply them. However, with the fast-growing economy, increasingly younger farmers are moving to work in the cities, and the rural labor force has been severely depleted[13]. Livestock production has long been a major source of environmental pollution, primarily owing to the failure to resource livestock waste and the low rate of livestock manure application. A crucial approach toward acquiring sustainable food production and environmental protection entails integrating crops with livestock and applying livestock manure to farms. However, further policy and regulatory efforts are required to make manure application possible on farms managed by millions of smallholders.

3 Dryland agriculture in the middle and upper reaches of the Yellow River Basin

The Loess Plateau in the middle and upper reaches of the Yellow River Basin is the core area of the entire basin, covering more than 80% of its area[14]. Groundwater is not available for crop production as it is more than 50 m deep in most areas, and dryland agriculture is a common agricultural production system[15]. Facing the scarcity of water resources, dryland agriculture has achieved great achievements in food production over the last four decades, largely thanks to advances in efficient water use technology. For instance, the results from a series of meta-analyses indicated that the application of clear plastic film mulching increased the average yield of wheat and maize by 18% to 27%[16], and mulching soil surfaces with black plastic film also obtained better yield benefits[17]. Supplementary irrigation increased wheat yield by 16% to 23%[18], and additional application of livestock manure improved wheat yield by 5% to 8%[12]. Global dryland agriculture is based on making full use of precipitation and improving water use efficiency (WUE). Over the last few decades, a large number of precipitation management technologies have been constructed and developed. Here, we have summarized integrated precipitation management in four main pathways: collecting, storage, conservation and use (Fig. 4).

For precipitation collecting, water cellars are the most common form of collecting precipitation and could be used for supplementary irrigation in arid areas. Supplementary irrigation during the critical growth stage is beneficial for optimized the spatial and temporal patterns of water use, enhancing the photosynthetic activity, thereby improving WUE and crop yield[19]. In the semi-humid but drought-prone region of north-west China, supplementary irrigation increased grain yield and WUE of winter wheat by 11.6% to 14.4% and 5.2% to 10.0%, respectively[20]. In Gansu Province, to promote this technology, a specific fund of 6.2×10^6 USD was allocated for cellar construction in 2000. It is gratifying to note that the water cellar measure has been effectively applied to an area of 400 kha, representing 10% of the total cultivated area[21].

For precipitation storage, terracing was a typical engineering measure and straw incorporation was a typical agronomic measure. Of these, terracing can create micro-catchments that absorb rainfall, enhance infiltration and reduce the loss of soil moisture in the lateral ridges, thus enhancing precipitation collection[22]. In China, terracing increased soil moisture by an average of 12.9%, with greater precipitation storage benefits on the northern plains of China[23]. The incorporation of crop straw could improve soil structure, increase water infiltration into the soil, and thus increase precipitation storage[24]. For instance, maize straw incorporation increased soil water storage by 0.2% to 5.1% over the five maize growing seasons in the Loess Plateau of China[25]. In addition, ridge, contour planting and conservation tillage were also used to improve precipitation storage by increasing rainfall infiltration and preventing runoff[26,27].

For precipitation conservation, reducing soil water evaporation through soil surface mulching was the main approach. Mulching soil surfaces with plastic film, crop straw and gravel

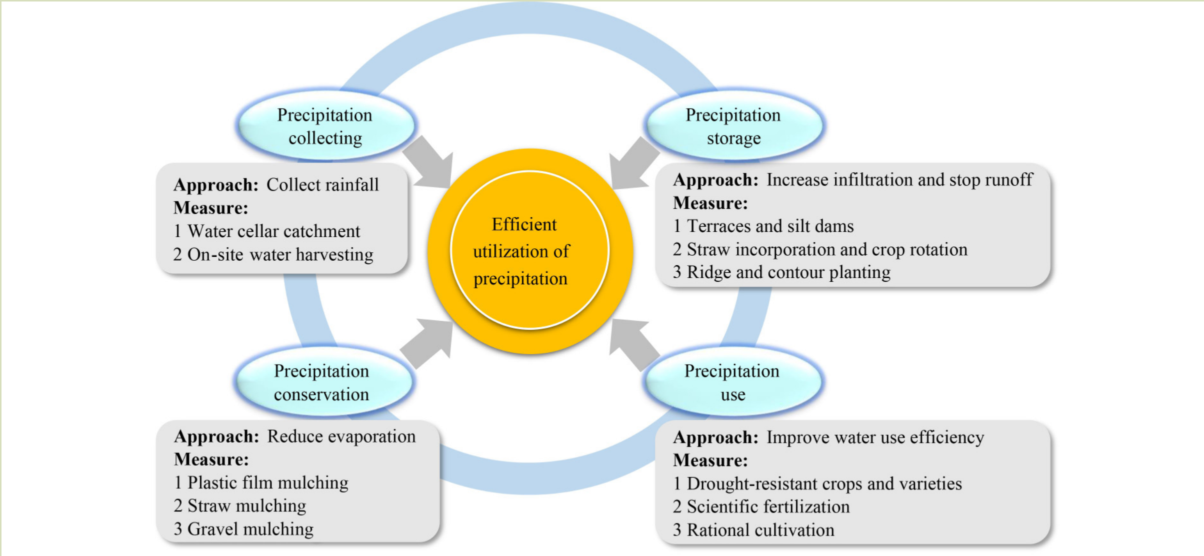


Fig. 4 Technical approaches and main measures for efficient use of precipitation in dryland crop production.

was the most common method[17,28]. Of these, plastic film mulching has been widely used in dryland crop production since it is more effective at overcoming soil water evaporation[29]. Mulching soil surfaces with plastic film resulted in a 30% increase in soil water storage, a 50% reduction in soil water evaporation and more than 15% reduction in water deficit, which meant that more soil water was available for crop transpiration. The field experiment results from the Loess Plateau demonstrated that the application of year-round plastic film mulching technology improved wheat yield by 11%, increased economic income by 12%, reduced soil nitrate residues by 51% and decreased greenhouse gas emissions by 12%[30]. Across China, plastic film mulching is estimated to contribute to about 30 Mt of crop production in 2012, serving as a global example of how yields can be increased with a simple and cost-effective technique[29].

For precipitation use, increasing crop transpiration through rational cultivation, scientific fertilizer, and drought-resistant crops and cultivars was the main approach[31–33]. Intercropping, the practice of growing two or more spatially intermingled crops, was a typical case[34]. Results from the global data set showed that the maize intercropping systems mean increased yield by 0.5 to 2.1 $t \cdot ha^{-1}$ compared with monoculture, while saving 19% to 36% of fertilizer and 16% to 29% of land[35]. Similarly, results from 16 experiments over 12 years on the Loess Plateau also showed that intercropping systems increased annual crop yields by an average of 16% to 50%, reduced carbon emission by 17%, and increased net income by 39%[36]. This is mainly due to promoting belowground interspecies interaction and thus enhancing the efficiencies of water and nutrient use. In conclusion, there are many technologies and approaches to improve water utilization, and adapting these techniques to local conditions is the key to improving water use in agriculture in the Yellow River Basin.

The Loess Plateau, with its thick, fine loess soils, is the area with the most serious soil erosion in the world, producing more than 10% of the global total sediment load[14]. This was mainly due to a large amount of forest cleared for farmland as the population grew rapidly, the limited growth of vegetation cover due to the dried climate, and the ruggedness characterized by thousands of ravines[37,38]. Importantly, sediment loss at Tongguan Station decreased by 95% during 1950–2019[21]. Vegetation restoration, check dams and terracing were the three crucial approaches to reduce soil erosion. Owing to the policy support of the Grain for Green Program, vegetation cover on the Loess Plateau increased from 32% in 1999 to 60% in 2013, realizing the transition from yellow to green[39]. The increase in the ratio of vegetation coverage greatly reduced soil erosion. In addition, the green map of Shaanxi Province has advanced nearly 400 km north[40]. Check dams and terracing were also the main engineering practices to reduce annual sediment discharge[41]. Studies results showed that check dams reduced the sediment and runoff by an average of about 12.0% on the Loess Plateau of China[42]. In that context, the number of check dams increased to nearly 1000 and made an important contribution in reducing soil erosion[43]. In conclusion, after several generations of unremitting efforts, the Loess Plateau, which was only yellow, has become green water and green mountains, and the amount of soil loss has been greatly reduced. This great transformation has attracted worldwide attention.

4 Irrigated agriculture in the middle and lower reaches of the Yellow River Basin

In the Yellow River Basin, irrigated agriculture is one of the important components of agriculture, and there are 84 large-sized irrigation areas and 663 medium-sized irrigation areas, with an irrigated area of 8.22 Mha, accounting for 30% of the total arable land[44]. In that context, the total withdrawal of water (groundwater and surface water) ranged from 42.9 billion to 55.6 billion m^3, with total water use accounting on average for 78% of total withdrawal (Fig. 5(a)). Agricultural production is the largest user of water, using more than 70% of the total water[45], and total agricultural water use in the Yellow River Basin increased from 17.8 billion m^3 in the 1960s to 43.5 billion m^3 in 2020[10]. River water is the main water resource for most areas in the middle reaches, accounting for 74% to 76% of total irrigation water use (Fig. 5(b,c)). Owing to the increase in irrigation water withdrawal, the lower reaches of the Yellow River have been drying up in recent years, creating a critical water shortage known as river depletion[46,47]. In addition, the groundwater continued to be over-exploited, with the number of groundwater leaks increasing to 36 in 2018, posing a serious threat to water security[10]. Therefore, improving water use is essential for sustainable water management, particularly for the middle and lower reaches of the Yellow River Basin.

Flood irrigation is the most common method for irrigation in cereal production, and is accompanied by a serious waste of water and low irrigation WUE. In late 2018, the coefficient of irrigation water use in this area was 0.55, which was significantly lower than the average level of 0.80 in developed countries[48,49]. For intensive agriculture in the middle and lower reaches, the winter wheat-summer maize rotation is the most important cropping pattern. Also, most irrigation water is used for winter wheat, owing to the mismatch between precipitation and water demand of wheat[50]. Importantly, in that context, irrigation water resources relied mainly on groundwater, especially during dry periods. Over the last two decades, the excessive use of groundwater has caused a continuous decline in groundwater levels, undermining the hydrological balance. Unfortunately, the drought will likely worsen over the next 10–30 years[51], and severe water shortages are threatening food security.

Unreasonable irrigation methods overuse irrigation water and lead to inefficient water use; for instance, frequent irrigation resulted in high soil evaporation and excessive drainage from the root zone[52]. The development and adoption of irrigation technology markedly improved irrigation WUE. Our results showed that optimized irrigation volume resulted in a 41% reduction in irrigation water but no reduction in wheat yield, and the optimized irrigation timing brought a 7% increase in

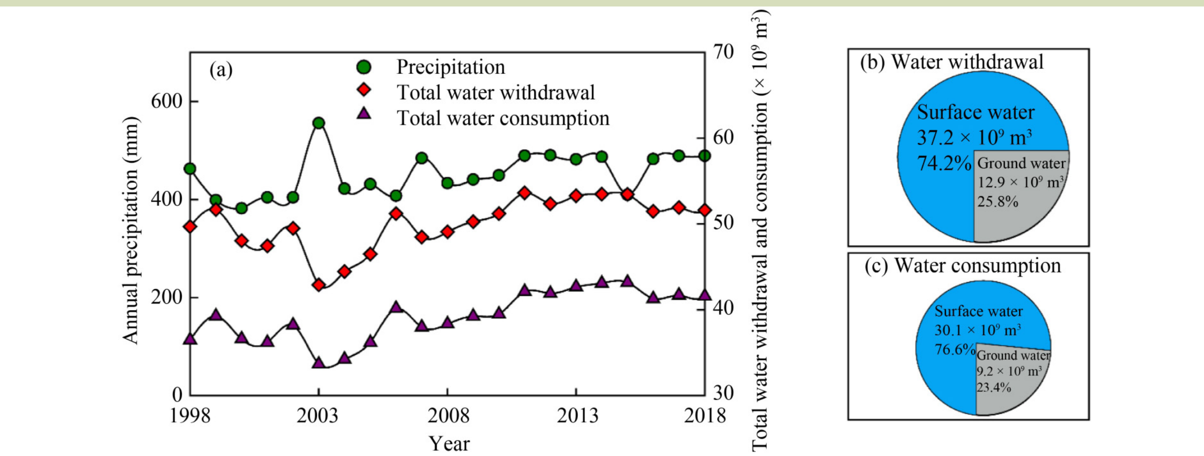


Fig. 5 (a) The annual precipitation, total water withdrawal, and total water use of the Yellow River Basin between 1998 and 2018. (b) The average water withdrawal of surface water and groundwater during 1998–2018 and (c) the average water use of surface water and groundwater during 1998–2018 for the Yellow River Basin.

wheat yield under the same irrigation water volume[18]. Optimized irrigation rates could promote root distribution in deeper soil layers, thereby accelerating water uptake from deeper soil layers and improving soil water utilization, and improved irrigation timing could increase plant transpiration and reduce soil evaporation, thereby improving grain yield[53,54]. The results clearly showed that the adoption of optimized irrigation practices can increase crop yield and irrigation WUE.

In recent years, micro-irrigation technologies have been applied and obtained positive benefits in saving irrigation water[55]. For example, the application of drip irrigation technology reduced irrigation water use by 40% and increased maize yield by 14%, compared with flood irrigation[56]. This was mainly due to improving the photosynthesis/transpiration ratio by optimizing stomatal control and reducing soil evaporation by reducing evaporative surface area with partial root-zone irrigation[57]. Another important reason was that the excess soil moisture caused by flood irrigation prolonged the vegetative period after flowering[58]. In China, due to the support from policy to increase agricultural inputs; currently, micro-irrigation technologies and other water-saving irrigation technologies are becoming more widely used. In 2018, the area under water-saving irrigation in China and the Yellow River Basin had reached 36 and 13 Mha, respectively[59]. The implementation of water-saving irrigation technologies has greatly enhanced irrigation WUE and promoted agriculture green production.

5 Strategies of agricultural green development in the Yellow River Basin

To date, agriculture in the Yellow River Basin has undergone huge development and achieved an incredible agricultural successes. In the future, population growth, increasing per capita demand for food, and the reduction of cropland will exacerbate the pressure on food resources. At present, agricultural production in the Yellow River Basin is at a high level, particularly in its middle and lower reaches. Improving crop productivity in the future will not be as straightforward as it has been in the past, despite the existing growth potential. Most importantly, intensive agriculture in the middle and lower reaches of the Yellow River Basin depends heavily on irrigation water, and achieving sustainable agriculture requires high quality water use.

The major challenges facing agricultural production in the Yellow River Basin are managing water resources, sustaining growth in food production, and shifting to more environmentally friendly production methods. In October 2021, the Central Committee of the Communist Party of China and the State Council released the "Outline of the Plan for Ecological Protection and Quality Development of the Yellow River Basin" (referred to here simply as "the outlined plan"). It outlines a clear pathway for achieving ecological protection and high-quality development of the Yellow River Basin. To tackle these challenges and achieve the goals, it will be necessary to implement new technologies, coordinate basin-wide development and receive adequate policy support. In the following sections, three sets of recommendations are presented.

5.1 Innovative agricultural technologies for producing more food with less water

The scarcity of water resources is the primary concern in the Yellow River Basin. Most of the upper and middle reaches have an arid climate, with a mean annual precipitation of 400 mm, which is only 40% of that in the Yangtze River Basin. However, its water resources are exploited at a rate of 80%, far exceeding the ecological alert of 40%. Over the last two decades, by implementing precipitation-efficient use technologies to increase food production, noteworthy progress has been made. Among these technologies, plastic film mulching is a typical success, with many studies reporting significant yield increases[60–62]. It is widely used in crop production, only for wheat and maize production, its adoption area reached 2.4 kha and 6.2 Mha in 2012, respectively[29]. However, the negative impacts of plastic film mulching are gradually being magnified over time. For instance, it resulted in an 8% reduction in soil water infiltration rate, a 5% reduction in soil available phosphorus and a 5% reduction in plant root weight[63]. In addition, it is estimated that the accumulation of plastic film residue in cropland soils has reached 550 kt (about 10% of the weight of the plastic film) for cotton production, resulting in a 6% to 10% reduction in cotton yield[63].

Further, agricultural irrigation, the largest user of water resources, had to receive more attention. Most studies have reported the benefits of drip irrigation in increasing crop yields and saving irrigation water[64–66], however, it should be clear that some negative impacts were limiting the widespread use of drip irrigation. For drip irrigation, smallholders have to face additional capital costs, which directly increase the economic risk of crop production when faced with natural disasters[67]. In addition, drip irrigation has placed greater demands on the irrigation knowledge and management of agricultural operators. Further, drip irrigation reduced the soil organic carbon content and structural stability of the topsoil[68]. Given the negative impact of adopting drip irrigation, appropriate solutions must be developed. In the future, increased attention should be given to breakthrough technologies that can sustainably improve WUE at a lower environmental and capital cost to promote agricultural green development in the Yellow River Basin.

5.2 Integrating and coordinating the upper, middle and lower reaches of the Yellow River Basin

The primary functions and key challenges faced by different reaches of the Yellow River Basin also differ. As mentioned in the outlined plan, the greatest shortcoming is the uneven quality development of the Yellow River Basin. For the upper reaches, plateau glaciers, grassland meadows, and three river sources are important water-conserving areas and are key ecological barriers in China, but the level of economic development in this area is low. In the middle reaches, it is highly susceptible to degradation due to severe soil erosion and incongruous water-sand relationship, and the recovery is an extremely difficult and slow process. The lower reaches of the Yellow River Basin are the main grain production area in China, but it has environmental pollution from agriculture production.

Governance of the Yellow River Basin should wholly reflect its global and holistic nature ranging from the source to the mouth of the sea. In the upper reaches, there is a need to improve the water retention capability, enhance ecological preservation and environmental protection, and reinforce the foundation of high-quality development within the basin. In the middle reaches, it is essential to enhance comprehensive soil erosion management and minimize sedimentation. At the same time, it will be necessary to develop efficient dryland farming techniques and enhance precipitation use efficiency. The objective in the lower reaches is to consolidate food production, enhance ecological management, and emphasize the features of agriculture green development within the basin.

5.3 Robust political support is an essential guarantee for agriculture green development

Achieving high-quality development through the coordinated development of the upper, middle and lower reaches of the Yellow River Basin is considered a pivotal advancement. Policy support serves as an essential guarantee of this strategy. For instance, to protect the eco-environment and water conservation, the upstream areas, at the expense of crop production and corresponding economic income, should be supported by appropriate ecological compensation policies. In the midstream areas, the vegetation coverage on the Loess Plateau has increased from 32% to 60% between 1999 and 2013[39], and the strong policy support from the Grain for Green Program, is a decisive driver[69].

In addition, policy support is the basis for technical measures to be implemented on a large scale. Water shortage is the biggest resource constraint in the Yellow River Basin, and realizing the water use of the whole basin from unregulated and inefficient to intensive and efficient was the fundamental solution to water shortage. The Chinese government places considerable importance on water-saving agriculture, and the relevant subject has been highlighted multiple times in China’s Central Document No.1. In addition, new agricultural organizations, including large growers, agricultural cooperatives, and family-run farms, started to appear in 2008. These large and intensive agricultural business entities have provided new opportunities for the development of water-saving technology. With policy support and the involvement of positive factors in society, the application areas of water-saving technologies have increased markedly in China, from 23 Mha in 2005 to 37 Mha in 2019[8]. Greater policy support is vital for the efficient transfer of agricultural technology to millions of small farmers. The outlined plan clearly states that the Yellow River Basin is expected to become a national leader in conserving and intensively using water resources by 2035. Meeting such high demand will require the efforts of the whole society; policymakers, researchers, social organizations, industries, and farmers will be the key participants in the transformation of agriculture in the Yellow River Basin toward green development.

6 Conclusions

For a long time, the Yellow River Basin has faced the challenges of protecting the eco-environment, addressing soil erosion, and producing more grain at a lower environmental cost. Owing to the implementation of optimized crop and soil management techniques and substantial policy support, the Yellow River Basin has achieved impressive feats in agriculture over the past 20 years of the new century, setting an example for other regions and countries facing similar challenges. At present, the ecological protection and green development of the Yellow River Basin has become a major national strategy, and the outlined plan clearly sets out the top-level design ideas for the green development of agriculture here. It is anticipated that over the next 15 years, a series of applied measures and policies based on the outlined plan will lead to a more efficient use of water for agricultural production in the Yellow River Basin, as well as better eco-environmental benefits. The research will have a major impact on ensuring the food and eco-environmental security of the Yellow River Basin and similar river basins worldwide.

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Compliance with ethics guidelines

Gang He, Zhaohui Wang, Qichao Zhu, Jianbo Shen, and Fusuo Zhang declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

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