BCAS Vol.26 No.1 2012

# Advances in Water-saving Agriculture and its Future Strategies in North China Plain

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## 1. Water limitation and agricultural water use

China has almost one-quarter of the world's population, but only 6% of its fresh water. China's water resource distribution is extremely uneven. To the north of the Yangtze River, including the Hai River Basin, the Huai River Basin, the Yellow River Basin, Northeast and Northwest of China, Shandong Peninsular, there is only 19% of China's total water resources, *i.e* 0.546 trillion $m^3$. Quick depletion of groundwater level and dramatic shrinking of river water flow in the downstream river systems of the arid, semi-arid and semi-humid regions of North China suggest that present water use is difficult to sustain.

Agriculture is the biggest user of water resources and a major factor influencing the regional water balance and economic sustainability. In 2008, agricultural water use was 366.4 billion $m^3$, accounting for 62.0% of China's total water use. In comparison, 68.8% of the total water consumption in China in 2000, or 378.4 billion $m^3$, were used by agriculture. Considering the facts that China's water use efficiency varies from 0.5 to 1.1 kg grain/ton water and that the future increase in agricultural water use will be very limited with more and more serious water shortage (Li, 2003), to expand China's food production from 540 to 630 billion kg in the coming 20 years will be a huge challenge.

Similar to most parts in North China, North China Plain (NCP), one of the most important agricultural regions in China with nearly 30% of China's food production, is facing an increasing challenge of water shortage. Especially

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in the northern part of the NCP, where some big cities such as Beijing, Tianjin, and Shijiazhuang are located, water/cap.a is only about 293 $m^3$ (Liu and He, 1996), which is far lower than 1,000$m^3$/cap.a per annum, a benchmark of water scarcity recognized by world organization (*e.g.*, IPCC). Over 4.06–7.57 billion $m^3$ of groundwater were overtaken each year in the region during the years from 2003 to 2006. (Moiwo *et al.*, 2009). Rapid groundwater-table decline caused by over pumping of groundwater for irrigation is taking place in more than 40,000 $km^2$ of the plain (Chen, 1999). A dramatic improvement in water use efficiency is expected (Liu & He, 2000).

## 2. Recent advances in high efficient use of agricultural water resources

No irrigation can supply water for crop growth without some waste or losses because the cost to prevent all losses is prohibitive. Irrigation water waste mainly takes place in the following ways: canal seepage, leakage from defective pipe connections, evaporation in canal or leakage in an irrigation distribution system, soil evaporation, less efficient use of crop transpiration, and percolation below the root zone. At the national level, China's attention has been paid to two directions: increasing water supply through new water projects, for instance the South-to-North Water Transfer projects, and decreasing water loss during water transfer processes especially in canals. Both countermeasures need huge financial input. For instance, according to the 2011 Central Document No. 1, which was jointly issued by the central committee of the Communist Party of China and the State Council, 400 billion yuan will be input to improve water supply and to decrease water leakage during water transfer processes, while low efficient water use especially in field level is less considered.

The study by the Key laboratory of Agricultural Water Resources of the Chinese Academy of Sciences focus more on development of fundamental science and applicable technologies to save water in a much broad aspect in the agricultural field and to remain China's food production under water limitations. Scientific researches were carried out at three levels:

● On a crop individual scale, physiological responses of different crops and cultivars to water limitations and the genetic controlling mechanism for high efficient use of water at physiological and gene level are studied. Cultivars, especially of wheat, with high water use efficiency are produced based on both traditional and newly developed biotechnology.

● On a field scale, by improving the understanding of the mechanism of water, heat, and gas fluxes in the Soil-Plant-Atmosphere-groundwater-Continuum (SPAC), especially water transfer and loss through the interfaces of soil-atmosphere, plant-atmosphere, and shallow soil layers to deep soil layers, and by studying the responses of crop water use to deficit irrigation, irrigation scheduling change, and crop pattern change, different water-saving technologies together with necessary irrigation equipments, especially dripping irrigation, and accessories agricultural machines are developed to save water at field level.

● On a regional scale, scientific assessment methods for temporal and spatial changes of agricultural water use are developed to provide the scientific base of agricultural water management. The influencing magnitude of driving factors such as climatic change, human generated land use and spatial crop plantation patterns on water cycle are analyzed aiming to provide strategies to decision-makers for more efficient water use on a regional scale.

### 2.1 Decreasing water loss in SPAC system in agricultural field

At the present level, water requirement for 1 ha irrigation of winter wheat is 3,264 ton according to the study by Liu *et al*. (2002) and 3,370 ton by Yang *et al*. (2006 a). Water loss in agricultural field mainly occurs in soil evaporation, luxury transpiration during less-water-requiring growth stages, and water leakage. Water leaking is not considered as water loss, since most water lost from irrigation can recharge groundwater. However, recent studies show less water supplies in agriculture can significantly decrease nitrogen leaching to groundwater, a risk factor for human (especially farmer's) health. And studies in the piedmont region of the Taihang and Yanshan mountains show that nearly 40% of the groundwater wells are facing the threat of over richness of nitrogen (Li *et al*., 2007). Thus, accurate irrigation to delay nitrogen leaching process and to increase nitrogen uptake efficiency is becoming more and more necessary.

Studies on water transfer processes in SPAC system for winter wheat and summer maize rotation system clarified the water and energy transfer between soil-atmosphere boundary layer, crop-atmosphere layer, and soil-groundwater layers, which set up the theoretical basis for scientific design of water-saving agriculture. For instance, our long-term experiment shows that nearly 30% of the evapotranspiration (ET) is sourced from soil evaporation, which does nothing useful for plant growth and grain formation. Based on such estimation, different technologies were developed to cut soil evaporation. It is approved that straw cover can decrease soil evaporation by 90mm annually, when annual soil evaporation is around 270 mm and annual ET varies from 850–940mm. Scientific irrigation scheduling can also increase water use efficiency and decrease soil evaporation and crop transpiration. For instance, through crop modeling analysis, Yang *et al*. (2006 a) shows that moderate water deficits in March can save water in wheat growing season and moderately low growth in leaf area index (LAI) of wheat does not result in low yield. A good irrigation scheduling can save up to 75mm of water, equals to 18% of total ET. Through the long-term field experiment, Zhang *et al*. (2008) clarified the stages when deficit irrigation has less impact on wheat and corn yield. Suitable technological and agricultural machinery has been developed in order to manipulate deficit irrigation and partial irrigation to increase water savings by allowing crops to withstand mild water stress with no or only marginal decreases of yield and quality.

Those technologies, in combination with applications of other practical irrigation technologies for instance dripping and micro-spraying irrigations developed by the Laboratory, low-pressure irrigation systems and intelligent card for irrigation control, are tested in a large demonstration area in Hebei Province and the nearby provinces. Water use efficiency can be as high as 1.95 kg/m$^3$ water in contrast to 0.8–1.0 kg/m$^3$ averagely in NCP. Owing to its dramatic evidence in saving water and scientific and technological improvements, the laboratory won a second-class prize from the National Scientific and Technological Improvement Award. In Hebei, the laboratory was given a top-class prize in science and technology, the Award for Outstanding Contribution for Scientific Improvement in Hebei.

### 2.2 Improving water use efficiency through new crop breeding

Wheat (*Triticum aestivum* L.) is one of the most important crops in North China. It also has the highest water consuming. Understanding its genetic control of water use efficiency is very important to provide strategies for development of higher water efficient cultivars.

Intensive research was carried out at molecular and single plant level from physiological and genetic aspects to see difference in traits of water use efficiency of different wheat cultivars. By testing cultivars of winter wheat and corn generated in different decades from the 1960s to the 2000s under different irrigation conditions, experiments show that, while annual ET increased slightly along with improvement in crop varieties, crops can produce much higher yields (Zhang *et al*., 2005). Meanwhile water use efficiency of 26 wheat cultivars was clarified. Results showed that WUE increased substantially from 1.0–1.2kg m$^{-3}$ for cultivars from the early 1970s to 1.4–1.5kg m$^{-3}$ for recently released cultivars. Using molecular linkage genetic maps and quantitative trait loci (QTLs) mapping technology, the locations of a series of QTLs controlling water use efficiency of wheat was identified (Cao *et al*., 2009). Up to now, those QTLs relevant to high water use efficiency have been used in breeding of new wheat cultivars. Several high water efficient wheat cultivars and drought-resistant wheat cultivars have been successful bred.

### 2.3 Effect of agricultural water use on water system changes

● Effect of agricultural activities on depletion of surface water.

In the north part of the North China Plain, most subcatchments are experiencing a quick decline of runoff since the 1970s. It is generally understood that runoff decrease are caused by human activities and climate change. But it is so far not sure which factor has the most dominating influence on the runoff decline. Our recent study (Yang and Tian, 2009) shows that runoff decrease mainly started in the 1978 –1984 period, the starting period of China's agricultural reform, and that the higher the percentage of agricultural cover is, the stronger the runoff decline can be. Further study by Fan *et al*. (2010), through the application of SWAT (Soil and Water Assessment Tool) model, testified that the dramatic decline of runoff in the upstream mountains is heavily caused human activities rather than climate change or precipitation decline during the 1978 –1984 period. Taking Hutuo River as an example, precipitation decline only resulted in 24% of runoff decrease, while human forces resulted in 76% of the runoff decrease. Thirdly, by selecting Dazhai as the research focus, Tian *et al*. (2009) show that agriculture effect on runoff is dominate, since runoff decrease started in 1968 in Dazhai area where there were the strongest agricultural activities in China. All those evidances suggested that agriculture is the major factor of runoff decrease or the decrease of regional water resources.

This result indicates that future changes in agricultural activities in mountains can further cause decline of the regional water resources.

● Effect of agricultural activities on depletion of groundwater

Agriculture uses over 60% of water resources. However, the present method in estimating agricultural water use by farmer level survey is less reliable. In order to increase the accuracy of water use estimation, DSSAT (wheat and maize crops) (Yang *et al*., 2006a, 2006b) and COTTON2K (Yang *et al*., 2008) models were calibrated by using data from field experiment to construct the capability of estimating agricultural water use.

Yang *et al*. (2010) estimated agricultural water use in spatial level through the application of three crop models. The results from crop models are considered to be more reflective to the field conditions (*e.g*. precipitation, cropping pattern, irrigated land area, *etc*.) than the statistical obtained data. Based on our simulation results, water supply under the support of SNWT project will likely be sustained, while in the coast region nearby the Bohai Sea, water shortage could remain.

The assessment of above models also increased our estimation on how much water has been purely used for crop growth and how much water will be recharged back to groundwater through infiltration. Using above estimation results, the influence of water use by wheat and corn, two staple crops in the North China Plain, on groundwater is studied. Yang *et al*. (2006b) testified that the effect of seasonal crop water use on groundwater is very strong. Similarly, Hu *et al*. (2010) used spatially and temporally estimated crop water use data from crop models in combination with MODFLOW model to simulate the effect of irrigation water pumping on groundwater. The method is successfully tested for the 4,763 $km^2$ Shijiazhuang Irrigation District in the piedmont region of the Mount Taihang. Results show that at the present, nearly 135.7mm of irrigation water has been overtaken from our groundwater system. Such amount of water need either be saved or supplied through the South-to-North Water Transfer Project in order to stop further depletion of groundwater.

The recent development of energy-based ET estimation model such as SEBAL and its derivatives has made it much favorable to calculate spatial and temporal ET. Using intensive field data, in collaboration with the Institute of Applied Remote Sensing, spatial and temporal irrigation use in the NCP was estimated (Ma *et al*., 2011). Analysis on such irrigation results showed that spatial and temporal variation of irrigation water use can be influenced naturally by precipitation, and artificially by crop pattern change (for instance cotton has much lower irrigation water requirement), especially wheat cultivation and vegetable plantation, and application of water-saving technologies. And it is possible to use such data to improve agricultural water management spatially and temporally in the future, although dramatic adjustment on irrigation water use could influence future's food production or food types.

## 3. Challenges in sustaining a healthy water system in NCP

Advances in science and technology for high efficient use of water in the agricultural sector have showed huge potential of water-saving from a single crop, to a field or regional level. Such efforts made the NCP still retaining its significant potential as a prime food producing region. This won't last long if no step is taken to minimize the overdraft of water, particularly groundwater, the very significant groundwater quality problem, and soil salinisation. Some areas across the NCP now have significantly drawn down cones and apart from experiencing deteriorating water quality. There is also an increasingly expensive pumping cost to continue to access the water that remains.

While development of science and technology is very necessary for solving the serious water shortage problem, there is an apparent lack of a coherent whole of system framework to address water management on the NCP. For example, the massive South-to-North Water Transfer project will deliver a lot of water to urban, industrial and ecological users. It was not clear however how this process is expected to redress the acknowledged problem of groundwater over-exploitation by the agricultural sector on the NCP. It seemed that neither the policy settings to encourage surface water substitution for groundwater nor the need to increase recharge and decrease extraction at the same time are part of the science setting.

Experience from the NCP also shows that farmers are not yet ready to be involved in water-saving if applications of water-saving technologies do nothing to help them to increase income or decrease labor input. Experience from Western countries suggests that there is a need of transdisciplinary approaches that integrate science, policy, planning, and management together to tackle difficult and complex water management problems.

While water shortage or the gap between water use and water supply remain in the long-term, regulating forces to adjust the contradiction between water supply and water demand in all sectors should receive more attentions. Those regulating factors, including water price, water audit and water right or water entitlement, water policy, and so on, have been testified as important, effective and more directive forces for a balanced water management for food production and water use in all regions and sectors, a healthy river system, and an environmental friendly community.

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