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PRELIMINARY STUDY OF THE WRSIS CONCEPT AT THE PADDY-UPLAND CROPS ROTATION AREA IN SOUTHERN CHINA

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ABSTRACT The central demonstration zone of the 16.47 acre Wetland Reservoir Sub-irrigation System (WRSIS) concept field is summarized based on current conditions including irrigation and drainage systems with subsurface drain pipe, constructed wetland, water supply reservoir, monitoring system and other related facilities. The irrigation water is imported from the reservoir to the underground pipeline network by pumping. The drainage waters are routed to the constructed wetland system under gravity through the drainage pipe network. The constructed wetland system consists of three components for drainage water treatment; a ditch wetland, a subsurface vertical flow component, and a surface flow component. Treated water is then routed to the reservoir by pumping. The purpose of the study is to study the effect of the WRSIS concept in increasing crop yields and improving water quality, to study how to link the constructed wetland and irrigation/drainage systems, to identify the best type and size of a constructed wetland and identify the optimum local wetland vegetation, and to reduce the agricultural non-point source pollution by using water-saving irrigation technology and controlled drainage technology. These goals are under study as potential modifications of the WRSIS concept as applied to China. A two-year preliminary study showed that the hydraulic structure used to control the outlet water level is appropriate to control water table in paddy field, and helps increase the use of irrigation water and rainfall. The structure has proven useful to drain rice and upland crops and increase the yields. A reduction in total nitrogen (TN), total phosphorus (TP), NH3-N and NO3-N through components of the constructed wetland treatment system is being observed compared to the controls in preliminary studies. The application of the WRSIS concept on the aquatic environment restoration in paddy and upland crops rotation areas in China is being researched further.

Keywords: WRSIS, Paddy-upland crops rotation, Agricultural non-point source pollution, Aquatic environment restoration, Drainage, Water table management, China.

INTRODUCTION A Wetland Reservoir Sub-irrigation System (WRSIS) is an innovative agricultural water management system (fig. 1). WRSIS is comprised of a wetland and a water storage reservoir linked to a network of subsurface pipes used at different times to either drain or irrigate crops through the root zone (Barry Allred et al., 2000). Runoff and subsurface drainage are collected from cropland into a constructed wetland. Natural processes in the wetland treat the water by removing some of the nutrients, pesticides, and sediments. The water is then routed to a storage reservoir and held until being used to sub-irrigate the crops during dry period of the growing season. The storage reservoir also provides a further opportunity for sediment and adsorbed nutrients to settle out of the water.

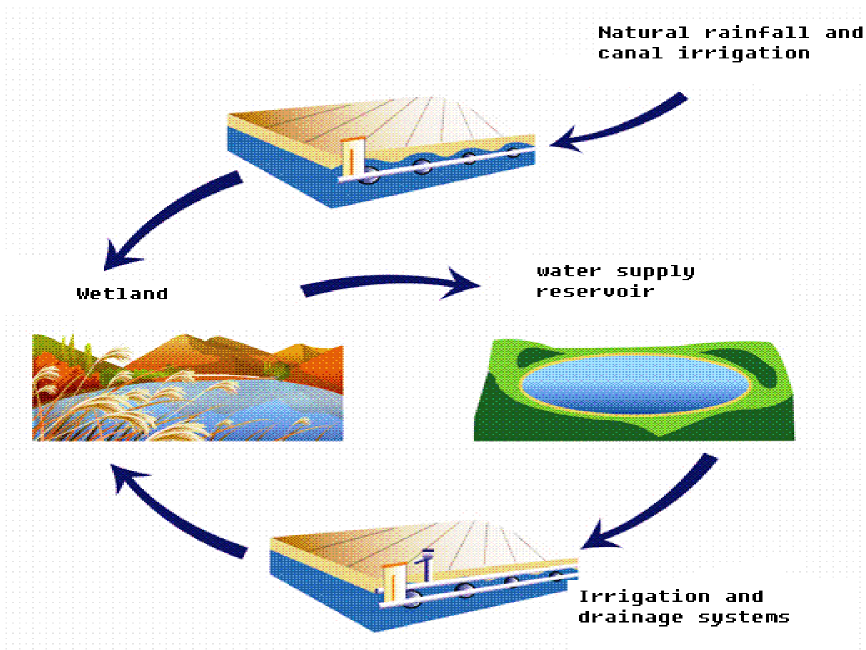

Figure 1. Wetland Reservoir Sub-irrigation System (WRSIS) conception

China is one of the largest chemical fertilizer producers and consumers in the world. The statistics conducted by Bejing Guotai Xinhua Ltd in 2006 indicate that from 1994 to 2005, the fertilizer production in China has increased from 20,390,000 to 39,240,000 tons. In the mean time, the imported fertilizer also increased from 10,140,000 to 12,120,000 tons. In 2004, the fertilizer usage in China has reached to 46,290,000 tons (nitrogen 25,830,000 tons, phosphorus 14,580,000 tons, potassium 5,880,000 tons), occupying more than one third of the total usage in the world. Given 30% to 50% of the average absorption rate of fertilizer to by all crops, there are about 23,140,000 to 32,410,000 tons of fertilizers left in the environment. The excessive application of fertilizer and pesticide and its losses have exerted a great threat on the water environment. With effective abatement of point sources pollution, non-point sources contribution has become a major cause of water quality degradation in China in recent decades (State Environment Protection Administration of China, 2000). Currently, agricultural non-point source pollution caused by fertilizers and pesticides has been leading to the water pollution, abundant nutrition in lakes in countryside. Analysis of polluted water indicates that mud and sands, N, P, toxicant, pathogen, heavy metal and organics are the main components amongst those agricultural non-point source pollution.

In order to find a good way to solve Chinese agricultural production problems and the current status of agricultural non-point source pollution, the Comprehensive Bureau of Water Resource Ministry deputed experts to analyze the mechanism of WRSIS in 2006. The WRSIS sites in the United States were visited and the application of the system in the United States was investigated. The WRSIS system was formally introduced from 2nd half of 2006, and was first implemented in the center of irrigation station in the city of Guilin, Guangxi province. In 2007, Zhanghe irrigation system in Hubei province was selected as the site for the development zone of this system to verify the effect using in China. Combined with relevant technology, the system was upgraded to a newer technology intensive version to suit for characteristics of Chinese agriculture. From 2008 to 2009, the system was verified and upgraded again in WRSIS sample and development zone, in Yaxi Town, Gaochun Country of Nanjing□Jiangsu province. Local contractors completed Yaxi town WRSIS site construction in 2008 at a total capital cost of 500,000 yuan.

MATERIALS AND METHODS

Demonstration Site Descriptions The Demonstration site (31°20′40"N, 119°09′32"E) is located in Yaxi Town, Gaochun Country of Nanjing in China (fig. 2). Yaxi town is of humid subtropical monsoon climate. According to statistics by local government in Yaxi town from 1922 to 1998, annual average solar radiation is 14.85 kcal/cm^2 and average temperature is 59.18 □. The annual average rainfall is 1196.5 mm with a highest value 1878.6mm and lowest figure of 569.5 mm occurred in 1991 and 1978 respectively. Its nature condition is typical and can well represent the southern China situation. Main crops in experiment demonstration zone are paddy rice, winter wheat, rapeseeds, etc. More than 85% of local farmland is being used to grow rice paddy. Soil texture is clay with less organics. Soil physical and chemical properties are given in table 1.

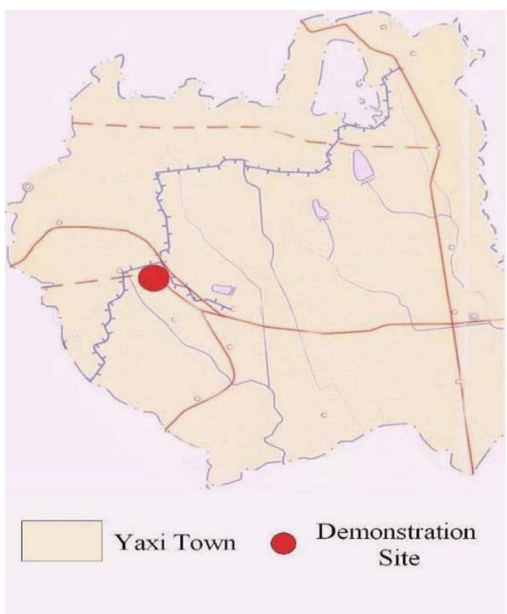

Figure 2. Map showing WRSIS site locations.

Table 1. Physical and chemical properties of soil

Bulk density (g/cm^3)	Porosity (%)	Organic matter (%)	Total nitrogen (TN) (%)	Total phosphorus (TP) (%)	pH
1.35	48.5	1.50~1.85	0.10~0.13	0.13~0.15	6.8

The project is managed by Comprehensive Bureau of Water Resource Ministry. The design work of WRSIS central demonstration zone was performed by Hohai University WRSIS groups. They are also responsible for the testing, observation and research work. The Ohio State University Professor L.C. Brown and Chinese Academy of Engineering Professor Mao Zhi served as the technical advisors and provided technical helps. The relevant sections of the local government have also given strong support to the project.

The Composition of the Demonstration Zone Yaxi town demonstration zone contains 16.47 acre sub-irrigation and sub-drainage fields as WRSIS central demonstration zone and 82.37 acre contrast zone with conventional irrigation and drainage treatments. By the different spacing and depth of drain pipe □the central demonstration zone of WRSIS is divided into four experimental zones. Zone I is same as the WRSIS in America, zone II□ zone III and zone IV are improved WRSIS considering the local conditions and the future extension possibility (fig. 3). Runoff and subsurface drainage are routed into a ditch wetland (3130 m^2) having a storage capacity of 5000 m^3□ the water from ditch wetland □water can be controlled by flood-diversion sluice□flows into a 2760 m^2

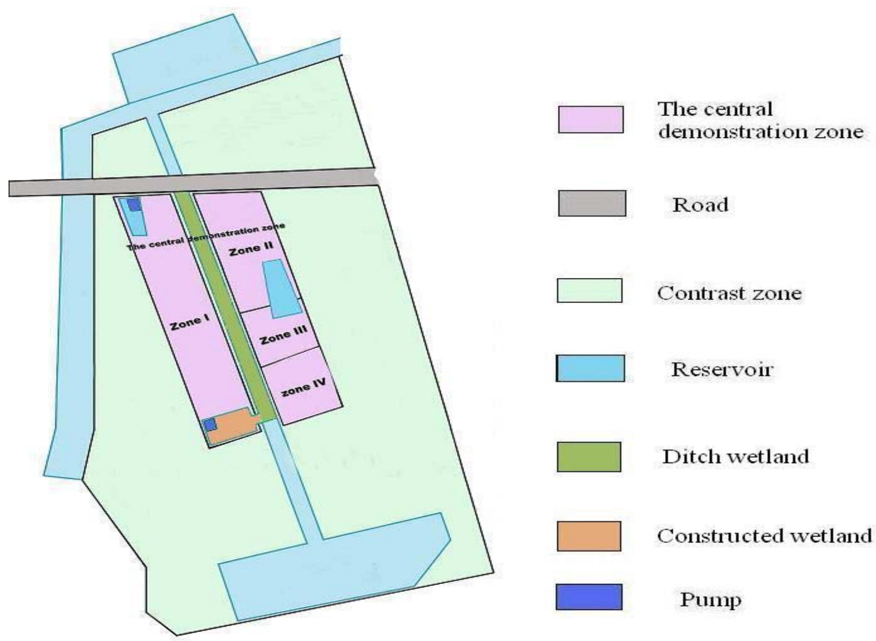

Figure 3. Yaxi town WRSIS demonstration zone

constructed wetland. At the end of constructed wetland□there is a 4kW submersible pump from which water can be elevated to a reservoir (1800 m^2) with storage of 3388 m^3.

Water stayed in the reservoir is used for sub-irrigation of crops by a 0.55 kW submersible pump to the underground pipeline network.

In the experimental demonstration zone, the water table and soil moisture content can be adjusted and controlled by the underground pipe network system. Water from cropland will flow through wetland where to be purified and back to ponds during periods when rainfall alone is insufficient to meet crop demand. Waters from ponds can be used as a source of irrigation water to complement irrigation when necessary. By taking above measures, water resource can be effectively used, thereby improving agricultural environment.

Constructions of the Central Demonstration Zone

Pipeline Network Zone I is used for subsurface irrigation and drainage, and other zones with buried pipes are used for subsurface drainage only. In zone I, main pipes (total length is about 400 m□are used to divert the water to water table control structures by the pump in reservoir for sub- irrigation of cropland. As with all the WRSIS sites, subsurface drain pipes were installed at a nominal depth of 0.8 to 1.0 m beneath the surface and spaced from 8 to 10 m in different zones. Eight water table control structures are installed at each side of ditch wetland along the cropland to manage water table.

Ditch wetland The total length of ditch wetland is 404 m and it consists of three segments, each of which has a flood-diversion sluice to control water level (Fig. 5). The whole channel has an ecology retaining wall: eco-fencing (upper and lower layers) with each layer filled with soil, gravel and vegetation, mainly indigenous ones. In ditch, local submerged vegetation dominates and aquatic vegetation occupies 30% of the water surface of ditch wetland.

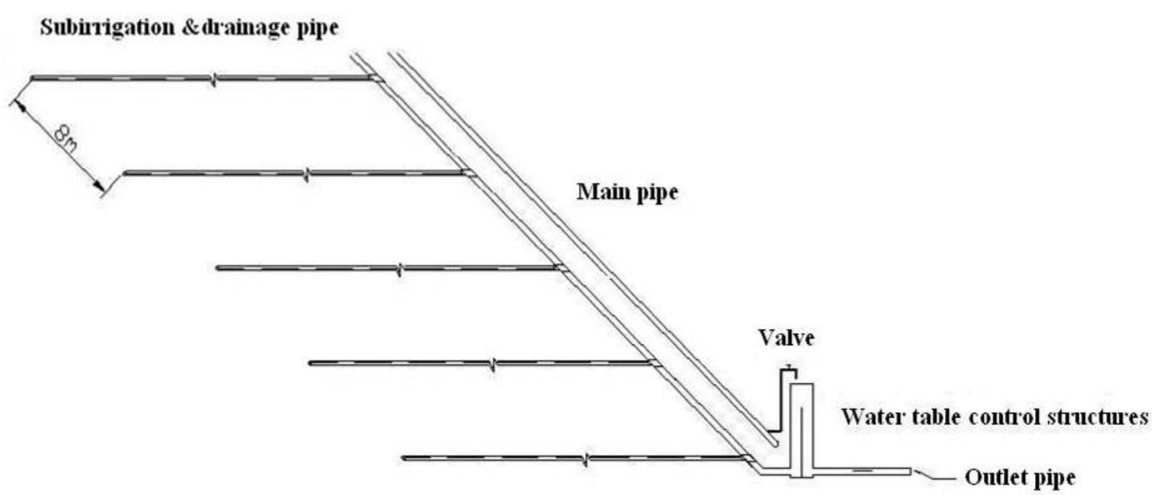

Figure 4. Pipeline network in Zone I

Constructed wetland Wetland has a length of 92 m and width of 30m (2760 m^2). The constructed wetland has two components: subsurface vertical flow wetland and surface flow wetland. The subsurface flow wetland is divided in to three parallel blocks of size

15 x 10 m, made of concrete (Fig. 6). The surface flow wetland has dimensions of length 77 m, width 30 m, depth 2 m. Bottom of wetland is laid with clay to lift up the basement height of the wetland and bed inclines with an angle of 1%. Therefore, it can prevent the water penetrations into underground water system and make water flow out of the subsurface vertical flow wetland into surface flow wetland for the gravity purpose.

Figure 5. Photo of the ditch wetland at Yaxi town WRSIS site

Figure 6. The constructed wetland at Yaxi town WRSIS site

Table 2. Crop yield (kg/ha) of WRSIS and contrast zone

	Corn	Rapeseeds	Wheat	Rice paddy
WRSIS	4500	1950	3750	8025

Contrast zone	3750	1650	3300	7200
Difference (%)	20	18.2	13.6	11.5

Chemistry Analysis Chemical analyses were conducted based on standard methodology (China Standard Press, 1998). Total nitrogen (TN) was determined by alkaline potassium persulfate digestion-UV spectrophotometer method. NH_3-N was analyzed using Nesslers reagent colorimetric method, and NO_3-N was estimated with a spectrophotometer using phenol disulfonic acid. Total phosphorus (TP) was determined by ammonium molybdate spectrophotometer method.

RESULTS AND DISCUSSION

Crop yield increase In 2009, the study indicated that corn, rapeseeds and winter wheat crop yields increased by 13.6 to 20%, while paddy rice yield increased by 11.5% over last year (Table 2). Due to the saving of irrigation water and reuse of disposed water from WRSIS system, farmer can obtain more economic benefits (L.C. Brown et al., 2002). With the promotion of this WRSIS system in larger scale and for long periods, the benefits will increase sharply.

Water Use Efficiency The effectiveness of WRSIS system in terms of water saving and increase in rainfall use rate in case of rice in demonstrated zone is shown in Fig 7. From the Fig 7□it can be seen that the rainfall use rate in WRSIS system is 47.1%, increasing by 17.4% and 9.6% compared with the submerge irrigation and controlled

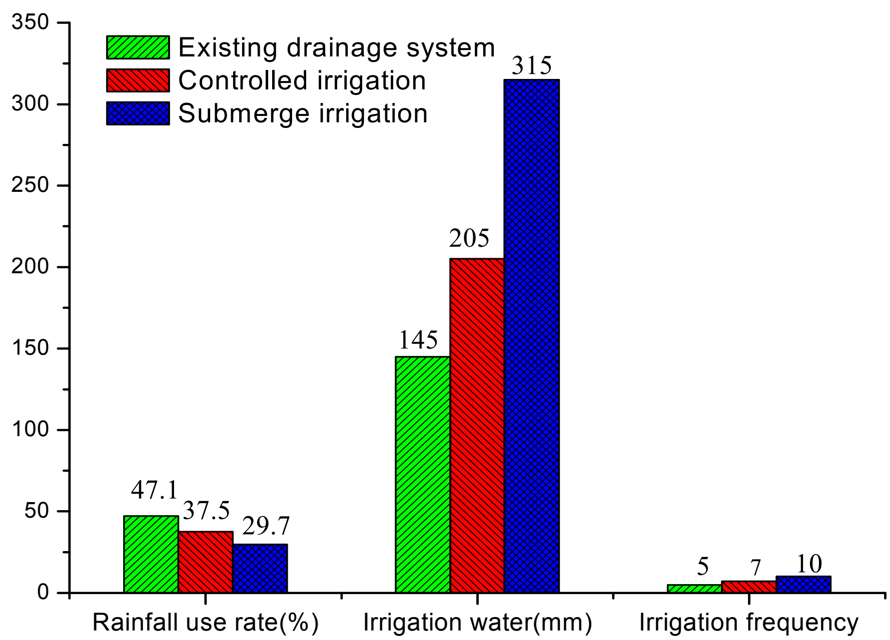

Figure 7.Comparision of water use efficiency among WRSIS and non WRSIS systems

irrigation without WRSIS system respectively. A remarkable improvement of the rainfall usage at WRSIS site further decreases the amount of irrigation water and the duration of irrigation compared with the submerge irrigation and controlled irrigation without WRSIS system. First of all, the hydraulic structure used to control the outlet water level in WRSIS is efficient to control water table in paddy field, and helps increase the use of irrigation water and rainfall, and has proven to be useful to drain which can avoid paddy rice lodging, we maximize the use of rainfall. Secondly, ditch wetlands and constructed wetland in experimented zones have the functions of holding and storing water, as a result, retained water can be used as the irrigation source for the following irrigations. Monitoring in demonstrated field shows that rainfall can be efficiently used to irrigate the corn in dry land with the WRSIS system. Therefore, this WRSIS system can substantially save water usage in irrigation.

Water Quality Improvement Reduction of agricultural non-point source pollution during the stages of paddy rice in 2009 is shown in Table 3. Measurements in experimented zones show that WRSIS can reduce more than 50% of TN□NH_3-N□NO_3-N and 28.8% of TP in paddy rice drainage, which is consistent to the results of experiments conducted in the USA(The U.S. Department of Agriculture, 2002). It indicates that wetlands in WRSIS system can purify waters from the field and degrade contaminants effectively. Preliminary studies suggested a reduction in TN□NH_3-N□NO_3-N□and TP through components of the constructed wetland treatment system was being observed because the wetlands and vegetation can absorb, degrade and settle down those organic and inorganic materials.

Table 3. Average concentration (mg/L) from July 15 to September 15 in 2009

Water quality indicators	TP	TN	NH_3-N	NO_3-N
Inlet of ditch wetland	0.52	10.3	4.21	0.43
Outlet of ditch wetland	0.42	6.90	3.21	0.30
Outlet of constructed wetland	0.37	4.15	2.03	0.17
Ditch wetland removal efficiency (%)	19.2	33.0	23.8	30.2
Constructed wetland removal efficiency (%)	9.6	26.7	28.0	30.2
Total removal efficiency (%)	28.8	59.7	51.8	60.4

CONCLUSIONS Exploration of new agricultural water management system to increase productivity, reduce pollution and improve agricultural soil and water environments is really needed in China. A two-year preliminary study for the WRSIS demonstrate site in Yaxi town suggest that application of WRSIS in Gaochun Country is successful and the hydraulic structure used to control the outlet water level is appropriate to control water table in paddy field, and helps increase the use of irrigation water and rainfall, and has proven useful to drain rice and upland crops which also increases the yields. A reduction in TN□NH_3-N□NO_3-N and TP through components of the constructed wetland treatment system is being observed compared to the control system in preliminary studies. Certainly WRSIS, as an innovative method to rehabilitate soil and water environment, has a long way to go to perfect its application in China. The application of the WRSIS concept on the aquatic environment restoration in paddy and upland crops rotation areas in China is being researched further.

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