Contributions and Achievements to Water-savings in Agriculture by Prof. Kang Shaozhong

Prof. Kang Shaozhong's research is mainly on the principle and practice of water-saving agriculture and water management during the past 25 years. He has developed theories and practices to improve crop water use efficiency and regulated deficit irrigation by studying the water transport in soil-plant-atmosphere continuum (SPAC) and its regulation mechanisms for improving water use efficiency, presented the controlled indicators in Northwest China for high efficient irrigation by studying calculation method of crop water requirement and evapotranspiration model, and established the optimal regional water management model by studying the impacts of water-saving irrigation and regional irrigation development on hydrological processes and eco-environment. The high efficient irrigation model and new water-saving method developed by him have been extended broadly in Northwest China. His main contributions and achievements for water-saving agriculture and irrigation management have the following aspects:

(1) He developed the calculation method of crop evapotranspiration in arid and semiarid areas, and presented the high efficient irrigation models in Northwest China. He presented a rice evapotranspiration calculation method and irrigation regime in Hanzhong basin of Shaanxi Province in 1980's. Application of the results in water management in 80,000 hectares led to irrigation reduction by 10% and yield increase by 15% in rice production.

He presented a crop evapotranspiration model suitable to arid and semiarid areas of Northwest China, and found that crop evapotranspiration is apparently influenced by soil water content only when the relative soil available water content is lower than 0.5 in the Loess Plateau. The result supplied a basis for deficit irrigation in Loess region. And the method of calculating the ratio of soil evaporation and crop transpiration developed by him, which was applied by some scientists in China, is apparently better than the model raised by Richie and Burnet, and by Childs.

Moreover, he presented a new method to calculate the soil water-modified coefficient in crop evapotranspiration model under deficit irrigation, analyzed the effects of soil surface wetting patterns (partial rootzone wetting), cultivate patterns (plastic film mulching), groundwater table, and irrigation methods (drip irrigation under plastic film mulching) on crop coefficient, presented a relationship of crop coefficient and groundwater table, and crop coefficients in drip irrigation under plastic film mulching and in different wetting patterns. The results modified and supplemented the data recommended by Irrigation and Drainage Book 56 of FAO in 1998, supplied a scientific basis for water-saving irrigation in China.

He studied and presented water requirement indicators of wheat, maize, cotton, rice, oil bearing crops, millet, potato, sorghum, peanut, Chinese cabbage, tomato and tobacco based on the lysimeter experiment data, and made the isoline maps of water requirement for 6 main crops and irrigation water requirement in different hydrological years, studied and presented the high efficient irrigation models for wheat, maize, cotton, rice, oil bearing crops, millet, potato, sorghum, peanut, Chinese cabbage, tomato and tobacco and different regions in Shaanxi Province. The results have been extended and applied in accumulated 15,233,333 hectares in Shaanxi Province in recent 10 years, 7.125×10^{8} m^{3} of water was saved in irrigation, and the cost of ￥71,250,000 was saved in crop production.

(2) He developed and extended the technique of controlled alternate partial root-zone

irrigation in China. He and Prof. Zhang Jianhua (Hong Kong Baptist University) developed a new irrigation method systematically, so called controlled alternate partial root-zone irrigation (CAPRI), in 1996 to improve crop water use efficiency by exploiting the plant physiological responses to partial soil drying in their rootzone. It is a new irrigation technique that can improve crop water use efficiency without significant yield reduction and exposes approximately half of the root system to soil drying while the remaining root system is irrigated as in full irrigation. The wetted and dried sides of the root system are alternated on a time cycle according to crop water requirements and soil drying rate. The method was developed on the basis of four theoretical backgrounds. Firstly, fully irrigated plants usually have widely opened stomata. A small narrowing of the stomatal opening may reduce water loss substantially with little effect on the photosynthesis. Secondly, part of the root system in drying soil can respond to the drying by sending a root-sourced signal to the shoots where stomata may be inhibited so that water loss is reduced. Thirdly, controlled partial root-zone wetting and drying alternately can stimulate the root uptake ability for soil water and nutrients. Fourthly, partial root-zone watering can enhance soil water movement from the wetted part to the dried part, and reduce the depth of water infiltration. Therefore the ineffective percolation can be reduced.

CAPRI is a technique system, and includes different patterns in the field practices, such as the controlled alternate drip (or subsurface drip) irrigation on partial root-zone, controlled alternate partial root-zone irrigation in soil vertical profile, controlled alternate border irrigation, controlled alternate furrow irrigation, and controlled alternate surface irrigation and subsurface irrigation and so on. He also designed an alternate valve for the field application of CAPRI. He and his colleagues investigated photosynthesis rate, transpiration rate, yield production, water use efficiency (WUE), soil water distribution, irrigation water advance and uniformity with CAPRI for irrigated maize in an arid area with seasonal rainfall of 77.5-88.0 mm for four years (1997 to 2000) in Northwest China. The most surprising result was that CAPRI maintained high grain yield with up to 50% reduction of irrigation amount, while conventional irrigation technique showed a substantial decrease of yield with such reduced irrigation. The technique was extended to 4133.3 hectares in this region, crop water use efficiency was 2.93kg/m^3 on average, maize yield was 12,750-13,500 kg/ha. The results of hot pepper in greenhouse showed that water use efficiency in CAPRI was increased by 15.82% and water use was reduced by 40.91% compared with conventional drip irrigation. Water use efficiency for pear trees was increased by 27.55% and irrigation water use was decreased by about 40% in CAPRI compared with conventional border irrigation. The technique is being extended in large regions in Shaanxi and Gansu Provinces. He and his colleagues wrote a book with pictures and the guideline of CAPRI for irrigation managers and farmers. The papers published by him were well cited by scientists in American, Canada, UK, Germany, France, Portugal, Spain, the Netherlands, Switzerland, Hungary, Yugoslavia, Denmark, Turkey, Australia, New Zealand, Morocco, Japan, Indonesia, Malaysia, Argentina, Venezuela, Bangladesh, India, Pakistan, Egypt, Iran, Palestine, and others.

(3) He studied and demonstrated systematically regulated deficit irrigation technology for field crops in Northwest China. He with his colleagues studied systematically and extended regulated deficit irrigation technique for maize, wheat, cotton and other crops in Shanxi, Gansu, Shaanxi and Xinjiang of Northwest China from 1995-2002. In the experiments, controlled soil water deficit, either mild (50%-60% of field capacity) or severe (40%-50% of field capacity), was applied at both the seedling and the stem-elongation stages. A soil drying at the seedling stage plus a further mild soil drying at the stem-elongation stage is the optimum regulated deficit irrigation method for the maize production in this semi-arid area. The results on maize in Shanxi and Shaanxi, cotton in Xinjiang and Gansu, wheat in Shaanxi and Gansu also suggested that RDI should be applied at the early growth stage.

The degree of water deficit can reach 45%-50% of field capacity, which has no bad effect on crop yield and can increase crop water use efficiency obviously. From the research, it concluded that the feasible regulation deficit indicator of winter wheat as follows: the soil moisture content should not be below 60% of field capacity in 0-50 cm soil layer before living through winter, not be below 55% of field capacity in 0-50 cm soil layer from returning green to rising stages, be higher than 65% of field capacity in 0-50 cm soil layer in jointing stage, not be below 65% of field capacity in 0-80 cm soil layer in pregnant spike stage, be higher than 60% of field capacity in 0-100 cm soil layer in tassel to milking prophase, can be below 50%-55% of field capacity in 0-100 cm soil layer in milking evening without obvious reduction of yield. For maize, moderate or light water deficit is feasible, with the soil moisture above 50% of field capacity in seedling season, light water deficit is compatible, with the soil moisture above 60% of field capacity in jointing season, and sufficient irrigation for other periods. For cotton, bad effect of soil moisture as low as 48% of field capacity on cotton alimentation growth can be recovered by irrigation in budding season, and under condition of high soil moisture in the prophase, the soil moisture as low as 45% of field capacity has no bad effect on yield in flower and belling evening seasons.

Based on the experiments, he presented the optimal technique system of regulated deficit irrigation, the results were applied 6,667 hectares in Hongdong of Shanxi Province, irrigation water use was reduced 34.1% and crop yield was increased 19.3% on average than that of the conventional irrigation method , and the benefit of ￥10,566,800 was got by extending the technique in this county. The technique was also extended in Minqin and Wuwei of Gansu Province for 1,787 hectares ，2,140,000 m^3 of irrigation water was saved ，and the electric energy of 385,200 Kw·h for pumping groundwater was also saved ，the benefit of ￥667,100 was got in the region.

Furthermore, He and Prof. Chen Yaxin wrote a book of 《Principle and Practice of Deficit Irrigation》 which was published by China Water Resources and Hydro-power Press in 1995 and cited more than 200 times by scientists, engineers, irrigation managers and postgraduates, it has been playing an important role for expanding deficit irrigation technology in China. And the research result in this area was published in 《Agricultural Water Management》(Vol.55, No.3, p.203-216, 2002) in title of “Effects of limited irrigation on yield and water use efficiency of winter wheat in the Loess Plateau of China"was one of the most downloaded 25 papers of the journal in 2002.

(4) He developed the optimal irrigation technique parameters to improve water and fertilizer use efficiency for drip irrigation, sub-surface drip irrigation, and surface irrigation methods, studied the suitable flow measurement facilities and standardization for U-shape canals, and presented the flow measurement equipment for irrigation water with high sediment content in Northwest China. He studied systematically the water and fertilizer movement in soil profile and soil-root system, water and fertilizer use efficiency in root-zone under different irrigation scheduling, irrigation technique parameters, different fertilizer use patterns, different depths of irrigation pipe for drip irrigation, sub-surface drip irrigation, and surface irrigation methods. He presented the optimal irrigation technique parameters for the lower cost sub-surface drip irrigation system suitable to apple orchards in north part of Shaanxi in order to improve water and fertilizer use efficiency, the results supplied the rational technique parameters for designing and managing irrigation systems, and were applied in large area in apple orchard irrigation of Shaanxi Province.

Evaluation has been made of the existing flow measurement techniques by him and his colleagues, selective and adoptive models which apply to the flow measurement techniques of different U-shaped channels have been given in Northwest China, he with his colleagues presented the design and standardization of flat parabolic non-floated segment of U-shaped channel flow measurement flume, and 28 standard flumes were proposed by using the form coefficient of the parabolic (P) as the index. The examinations and observations both in the lab and on the spot had shown that the measured values were identical with the theory value, which indicated that the flume can meet the demand of flow measurement. More than 2650 standard flow measurement flumes were expanded in Guanzhong canal irrigation districts of Shaanxi province and in Huangyang and Yingda irrigation districts, which controlled irrigation areas of about 6666.7 hectares.

(5) He studied systematically the groundwater management model in Fen-Wei Plain with a shallow groundwater table for water-saving and controlling soil salinity. He presented the coefficients of groundwater use in winter wheat and maize growing seasons under different water tables were obtained based on the measured data by lysimeters in Yangling of Shaanxi province, and Qixian of Shanxi province. He found that yield and water use efficiency of winter wheat was decreased with groundwater table lifted when the depth of water table was shallower than 1.5 m, and the water table should be controlled deeper than 1.5 to 2.0 m in order to improve yield and water use efficiency in winter wheat growing season, deeper than 1.0 to 1.5 m for maize in Fen-Wei Plain of Shanxi and Shaanxi province. He established soil water and salt adjustment and control model, and simulation model of groundwater table for infiltration and evaporation processes, presented irrigation models under different groundwater tables. The irrigation model responded to the impact of groundwater table could reduce one time irrigation in generally compared to the conventional irrigation model in the region. The research results have been extended 3,333 hectares in Fenhe irrigation district during 1998-2001, and 840 m^3 irrigation water could be saved for per hectare and each year, totally 11,200,000 m^3 of irrigation water was saved in the region during 1998-2001.

(6) He studied systematically the reasonable allocation of water resources and water-saving in agriculture and ecology in Shiyanghe river basin of Gansu province in Northwest China, presented and extended six strategic measures for sustainable use of water

resources and six kinds of water-saving models in agriculture and ecology which have been played an important role in this region. The Shiyanghe river basin is a typical interior river basin with an area about 4.16×10^4 km^2. The area faces water shortage and environmental deterioration in the arid northwest of China. Due to its arid climate, limited water resources and some inappropriate water-related human activities, the area has developed serious loss of vegetation, and gradual soil salinization and desertification, which have greatly impeded the sustainable development of agriculture and economy in this region. The proportion of water use in the upper and middle reaches compared to the lower reach was increased from 1:0.57 in the 1960s, to 1:0.27 in the 1970s and 1:0.09 in the 1990s. A reduction of about 74% in the river inflow to the lower reaches and a 15-m drop in the groundwater table has occurred during the last four decades.

The integration studies for reasonable allocation of water resources and water-saving in agriculture and ecology in Shiyanghe river basin have been carried out by him and his colleagues from 1995 up to now, which has been playing an important role to promote science research and subject progress, and sustainable utilization of water resources in the inland river basin of Northwest China. The research included applied basic theory, applied technology development and demonstration zone establishment. The applied basic theory study includes water resources transformation and ecology change mechanism, regional crop and plant evapotranspiration distribution and variation with time, water transport in soil-plant-atmosphere continuum and crop water-saving mechanism, water-saving potential evaluation model and reasonable allocation model of water resources in Shiyanghe river basin. The applied technology development includes no-full irrigation and regulated deficit irrigation technology for wheat, maize, cotton, grape, water melon and others, controlled alternate partial root-zone irrigation technology for grape, maize and cotton, drip irrigation technology for mulching cultivated cotton with plastic film and artificial planting ecological vegetation, irrigation and water resources management decision support system. And demonstration zone establishment includes water-saving in agriculture and in artificial ecological vegetation.

Based on the research works, strategies for improving the water–soil environment of the basin, such as the protection of the water resources of the Qilian Mountains which is the source of water in this basin, sustainable use of water resources, maintenance of the balance between land and water resources, development of water-saving agriculture, diverting of water from other rivers and control of soil desertification, were proposed. And the guidelines were also presented for reconstruction of the sustainable water management and development of agriculture in this region. He expanded a rainfall high efficient use model which includes rainfall harvesting technology, limited irrigation technology, and agronomic methods to improve crop water use efficiency in the upper reach of Shiyanghe river basin, irrigation water high efficient use model which includes canal flow monitoring and controlling technology, improving surface irrigation method by using small border irrigation, leveling land, using water-saving irrigation scheduling and so on in the middle reach, water-saving model by well water pumping in the lower reach. The technologies and models of water-saving were used about 333333.3 hectares, and about $5.60 \times 10^8 m^3$ of water use was saved in agriculture in Shiyanghe river basin from 1996-2003.

(7) He established academic organization and research laboratory of water-saving in agriculture, organized international and national conferences on water-saving in agriculture, and popularized and extended water-saving technologies in agriculture. He sponsored and established Agricultural Soil and Water Branch of Chinese Agricultural Engineering Society, and was selected as the Chairman of the branch, and organized academic conferences in Shaanxi, Inner Mongolia, Beijing and Shenyang for water-saving agriculture and sustainable use of water resources, also organized an international conference of water-saving in agriculture and sustainable use of water resources in Yangling in 2003. More than 300 participants attended the conference and came from USA, UK, Australia, Germany, France, Italy, Portugal, The Netherlands, Switzerland, Denmark, Yugoslavia, Japan, India, Thailand, Indonesia, Iran, Syrian, and China.

He established the Key Lab of Water-saving in Agriculture by Ministry of Agriculture, and the Key Lab of Agricultural Soil and Water Engineering in Arid and Semiarid Areas by Ministry of Education, and established the Research Center of Water-saving in Agriculture and Water Resources in Northwest Sci-Tech University of Agriculture and Forestry, and also established the Center for Agricultural Water Research in China, China Agricultural University.

He supervised 36 Ph.D students and 46 M.Sc. students for water-saving and irrigation management studies.

He presented some suggestions to Chinese government about establishing national nets of water-saving irrigation experiment and monitoring, and importing the advanced water-saving technologies from developed counties according to Chinese conditions. He took part in the management of state key science and technology project of “Research on Water-saving Techniques in Agriculture and Development of New Products and Equipments for Water-saving in Agriculture”. He organized and took part in the research on “State Development Strategy of Science and Technology in Water-saving Agriculture of China in the Future 20 Years”, and the research on “State Development Strategy of Water-saving Agriculture in China during ‘the Eleventh Five Year Plan’ ”.

He wrote or organized several popular books about water-saving technology and irrigation water management in arid and semiarid areas for farmers and irrigation managers. He organized or lectured more than 20 classes of training irrigation managers and farmers in Shaanxi, Shanxi, Hubei, Henan, Beijing and Gansu Provinces. His works extended and popularized water-saving technology in agriculture. He made great contributions and achievements in water-saving theory development and technology application.