SESSION 3. IRRIGATION PRACTICE AND WATER MANAGEMENT

NO:3–001

Increasing agricultural water productivity to manage water scarcity in China

Yuanhua Li*

National Centre for Irrigation and Drainage Development, Ministry of Water Resources, Beijing, 100053, China

Based on an analysis of supply and demand for fresh water, the key activities for water savings from irrigated agriculture in China are discussed, and strategies for increasing water and land productivity are suggested. Less water will be available for irrigation, which currently consumes the largest amount of fresh water. This arises because of the rapidly increased demands for fresh water by industry and urban domestic users. Water pricing, along with adoption of on-farm WSI (water saving irrigation) practices on a widespread basis, provides the opportunity for efficient water use on a large scale because it impels every water user to value water, capture return flow, better harvest rainfall and control percolation losses. There are many success stories about 'real' water savings in China, resulting from institutional support at the national level, for dissemination of good practice.

Key words: water pricing, water-saving irrigation, institutional support, water productivity, benchmarking.

*E-mail: yuanhli@yahoo.com

NO:3–002

Water-saving small-holder irrigation experiences from Africa

Nico van Leeuwen*

Water Resources, Development and Management Service, Land and Water Development Division, Agricultural Department, FAO, Rome

Necessary conditions are discussed for successful use of drip irrigation by small-holder farmers. Information is based on experience of testing equipment at the Interstate School for High Level Technicians in Hydraulics and Rural Engineering near Ouagadougou, in Burkina Faso. Drip systems should be affordable, in order to be adopted by small-holder farmers in rural areas. They should be low-cost relative to farm income, easy to install and operate by farmers without particular technical training, cost effective with investment recouped in one season, and have low operation and maintenance costs. Companies are proposing systems covering 500–2000 m^2 that meet these needs, except that water supply arrangements may be oversimplified. Inclusion of treadle and kerosene pumps has been important in this respect. Markets for vegetable crops should be well established and within a reasonable distance of cultivated areas. Farmers should receive additional agronomic assistance for long periods. Clusters of small-holder farmers practising irrigation will lead to savings on the part of the infrastructure and in particular on the cost of pumping. Such clusters could employ a 'water man' who takes care of the water provision. To make the technology available to poor farmers, subsidies should be provided and a small-scale credit system should be put into place.

Key words: necessary conditions, drip irrigation, small-holder farmers, clusters, cost of pumping.

*E-mail: nico.vanleeuwen@fao.org

NO:3–003

Application and replication of efficiency and agricultural water-saving measures in Hebei Province

Xintai Jia[1,*], Jinping Wang[1] and Jianming Liu[2]

[1]Department of Water Resources of Hebei Province, Shijiazhuang, 050011 and [2]The Shijin Irrigation District Administrative Bureau of Hebei Province, Shijiazhuang, 050021, China

Progress with the popularization of efficiency and agricultural water-saving measures is reviewed. Such measures include conversion to overhead irrigation, canal linings, provision of low pressure pipeline supplies, and mixing of fresh and saline waters. Engineering management methods have also improved. Through establishing water-saving replication networks, fulfilling the related policies and good project management, we have accelerated productivity transfers using the achievements of water-saving techniques and made notable economic, social and ecological–environmental benefits.

Key words: agricultural water-saving and efficiency-increasing techniques, replication, water resources, Hebei Province.

*E-mail: jmliu@inhe.net; Tel: 0311-6218958

NO:3–004

Subsurface clay pipe irrigation to increase water-use efficiency

Gh. Zarei[1,*], A. Keshavarz[2], I. Majidei[3] and S. M. Hejazei[4]

[1]Iranian Agricultural Engineering Research Institute (IAERI), PO Box 31585-845, Karaj-Iran, [2]Iranian Seed and Plant Improvement Research Institute (ISPIRI), PO Box 31585-845, Karaj-Iran, [3]Iranian Agricultural Biotechnology Research Institute (IABRI), PO Box 31585-845, Karaj-Iran and [4]Modifier of Clay Pipe Irrigation System

Details of reduced water consumption, increasing yield and increasing water-use efficiency are described for very simple and efficient subsurface clay pipe systems used for irrigation over a period of 4 years. Clay pipes to provide an appropriate discharge are combined with a polyethylene injector network to deliver water. The method uses local materials and operates at low pressure. So, it is useful for irrigation of orchards, vegetables and greenhouses. This system had been used from many centuries in dry areas of Iran, such as Yazd and Ardakan, for production of vegetables and other crops. Mechanization and standardization of this irrigation system is an important step in the improvement of water productivity in Iran.

Key words: subsurface irrigation, clay pipes, pot irrigation, water-use efficiency.

*E-mail: Ghzarei45@Yahoo.com

NO:3–005

Subsurface drip irrigation of a vertisol under cotton: increased WUE and reduced off-farm environmental impacts

Allen D. McHugh* and Gavin B. Lotz

Natural Resources and Mines, PO Box 19 Emerald, Queensland 4720, Australia

A trial was conducted to compare furrow irrigation and subsurface drip irrigation (SDI) since the latter is assumed to increase infiltration as well as reducing run-off, sediment and chemical movement from rainstorm events. Twelve 0.4 ha plots, with laterals spaced at either 1 or 2 m, contained four replicated irrigation treatments with 50%, 75%, 90% and 120% of daily evapotranspiration. There was a furrow-irrigated bay for comparison. There were no yield reductions when reducing crop water requirements by up to 25%, based on ETcrop. SDI yields were similar to non-optimized furrow-irrigated cotton but 50% less water was used. Non-optimized furrow-irrigated systems and poorly managed SDI systems could have significant adverse environmental impacts arising from tail water and rainstorm events.

Key words: subsurface drip, run-off, furrow irrigation, water-use efficiency, cotton.

*E-mail: jack.mchugh@nrm.qld.gov.au

NO:3–006

Estimation of nitrate distribution under drip irrigation using artificial neural networks

Jiusheng Li[1,*] and Ronald E. Yoder[2]

[1]National Centre of Efficient Irrigation Engineering and Technology Research, Beijing, 100044, China and [2]Biosystems Engineering and Environmental Science, University of Tennessee, Knoxville, TN, USA

A combination of artificial neural networks (ANN) and laboratory experiments is proposed as a means of describing nitrate dynamics under drip irrigation. Seventeen experiments were conducted, with apparent discharge rates varying from 0.6 l h^{-1} to 7.8 l h^{-1}. Applied volumes ranged from 6 l to 15 l, and input concentrations from 100 mg l^{-1} to 700 mg l^{-1}, to provide a database for the ANN. Model input parameters were initial soil water content, initial soil nitrate concentration, discharge rate, input concentration of fertilizer (NH_4NO_3), applied volume and final soil water content. A total of 298 vectors was used to train the ANN model, with 212 independent vectors to test the model. The results of the test show a good correspondence between the model-estimated nitrate concentration in the soil and laboratory-measured nitrate concentration in the soil. The coefficient of determination (r^2) was 0.83 and much higher compared to the results obtained by HYDRUS-2D ($r^2 < 0.01$) in a previous study. These results show that the optimized ANN model is reasonably accurate. This approach can provide an easy and efficient means of estimating nitrate distribution in the soil under fertigation through drip irrigation systems.

Key words: drip irrigation, nitrate distribution, artificial neural networks.

*E-mail: jli5@utk.edu

NO:3–007

Oriental kabocha squash yield and Brix level as affected by subsurface drip irrigation and plastic mulch

Mahbub Alam[1,*] and Rick Zimmerman[2]

[1]Department of Biological and Agricultural Engineering, Kansas State University, SWREC, Garden City, KS 67846 and [2]Agricultural Experiment Stations, Colorado State University, Rogers Mesa Research Center, Hotchkiss, CO 81419, USA

Oriental squash, kabocha, *Cucurbita moschata*, has become an important cash crop for western Colorado in the USA. A combination of different coloured plastic mulches with subsurface drip irrigation (SDI) was compared to non-mulched furrow-irrigated kabocha squash. An average of 457 mm of water was applied through SDI, which was one-fourth the amount applied by furrow irrigation. Subsurface drip in combination with plastic mulch produced consistently higher total yield averaging 3017 Mg ha^{-1} for transplanted kabocha squash as compared to furrow-irrigated squash without mulch, which produced 1122 Mg ha^{-1}. Transplanted squash produced higher yields compared to direct seeded plots. Direct seeded plots produced an average of 2366 Mg ha^{-1}. Average marketable yield from 2 years of data was 2213 Mg ha^{-1} for SDI with mulch treatments for transplanted squash. Furrow-irrigated transplanted squash with no mulch averaged at 902 Mg ha^{-1} of marketable squash. Soluble solids (measured as Brix level) ranged from 11.3 to 15.2 and were consistently higher for subsurface drip-irrigated squash compared to furrow-irrigated squash. SDI with mulch was significant in improving kabocha yield and the Brix level. The colour of the mulch had no significance in this study.

Key words: *Cucurbita moschata,* subsurface drip, furrow irrigation, yield, Brix level, plastic mulch.

*E-mail: malam@oznet.ksu.edu

NO:3–008

Sediment deposition associated with muddy surge flow along an irrigated border strip

Liangjun Fei*, Wenyan Wang and Hui Jia

Xi'an University of Technology, Xi'an, 710048, China

Field data were collected for surge flow and continuous border strip irrigation with muddy water. Measurements included sediment distribution along the border strip, the particle grading components, thickness of sediment deposition, soil bulk density values and their effects upon infiltration after irrigation. The results provide a foundation for further study of the design and water-saving aspects of surge flow using muddy water.

Key words: surge flow, border strip irrigation, muddy water, silt sediments, distribution uniformity.

*E-mail: Feiliangjun@sohu.com

NO:3–009

Scheduling drip irrigation of young mango crop by tensiometer

Pramod Kumar Singh*, Kamla Kant Singh and Kamal Narayan Shukla

Department of Irrigation and Drainage Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar-263145 Uttranchal, India

A field experiment was conducted to evaluate the response of a 5-year-old mango crop (*Mangifera indica* Linn) to irrigation scheduling at different soil tensions, when using drip irrigation and black polyethylene mulch. Resulting water requirements and fruit yield were determined when the crop was grown under the typical tarai condition of Uttranchal (India). Tensiometers were used to automatically schedule irrigation whenever the soil tension reached 20 kPa, 30 kPa or 60 kPa. A significant increase in final fruit retention and marketable fruit yield was observed in drip irrigation and drip irrigation with black polyethylene mulched treatments. The highest fruit retention of 453 fruits per tree and fruit yields of 76.3 kg per tree were obtained from the treatments irrigated at 20 kPa tension, under drip irrigation with mulch. However, water-use efficiency was maximum for the treatment irrigated at 60 kPa tension. Water was applied after flower bud development until maturity during the months of February, March, April and May. The applications varied from 180 to 1544 l, from 135 to 1180 l and from 90 to 800 l per plant in the treatments irrigated at 20 kPa, 30 kPa and 60 kPa soil tension, respectively. In contrast, water applied in surface irrigation treatments was 600 l, 1150 l and 1810 l per plant, respectively, in the months of March, April and May.

Key words: drip irrigation, tensiometer, mango.

*E-mail: pramad_singh_upa@rediffmail.com

NO:3–010
Projection pursuit evaluation model based on accelerating genetic algorithm to optimize irrigation schedules

Qiang Fu[1,*], Yonggang Xie[1] and Shiying Liu[2]

[1]College of Water Conservancy and Civil Engineering, Northeast Agricultural University, Harbin, 150030 and [2]College of Economy of Heilongjiang University, Harbin, 150080, China

A projection pursuit evaluation model (PPE) is suggested based on a real coding accelerating genetic algorithm (RAGA). The test projection value of each irrigation schedule is derived by means of optimizing the best projection direction. Thus, the irrigation schedule can be classified and evaluated. At the same time, the weighting coefficients need not be inferred from views of different experts. Irrigating with small amounts of water seems to be the best strategy. This appears to be what farmers do.

Key words: real coding based accelerating genetic algorithm (RAGA), projection pursuit evaluating model (PPE), paddy, irrigation system, optimization.

*E-mail: fuqiang100@371.net

NO:3–011
Evapotranspiration estimation

Richard G. Allen*

University of Idaho, 3793 N. 3600 E., Kimberly, ID 83341 USA

Quantifying evapotranspiration (ET) from irrigated projects is important for water rights management, water resources planning and water regulation. Knowledge of ET is also important for quantifying impacts of water scarcity and for prediction of yield relationships. Traditionally, ET from agricultural fields has been estimated by multiplying a weather-based reference ET by a crop coefficient (K_c) determined according to the crop type and the crop growth stage. Various international publications and tables of K_c values exist, including the recent FAO-56 publication. Other approaches to predict ET from plant systems include single-layer and multi-layer 'resistance' models such as the Penman–Monteith equation and Shuttleworth type models. These models typically require large effort for calibration to specific crops and agronomic cultures, and require direct weather measurements over the crop in question, and therefore are not widely used.

There is typically some question regarding whether 'real' crops grown in field environments compare with the conditions represented by K_c values in the literature. This is especially true in water-short areas and for developing countries. Recent developments in satellite remote sensing ET models have enabled us to accurately estimate ET and K_c for large populations of fields and water users, and to quantify net ground-water pumpage in areas where water extraction from underground is not measured. One of these remote sensing models, SEBAL (Surface Energy Balance Algorithm for Land), will be summarized in this paper. SEBAL is an image-processing model that calculates ET as a residual of the surface energy balance. SEBAL was developed in The Netherlands by Bastiaanssen and has been modified by Allen in Idaho for application to mountainous terrain. SEBAL has been applied in many countries, including China. The ET images generated by SEBAL show a progression of ET during the year as well as distribution in space. The images show 'actual' ET as compared to 'potential' ET as computed by K_c ET_o.

ET from satellite images may ultimately replace current procedures used by state planning and regulating agencies and ministries that rely on ground-based ET equations and generalized crop coefficients. Applications of SEBAL in Idaho indicate substantial promise as an efficient, accurate and inexpensive procedure to predict the actual evaporation fluxes from irrigated lands throughout a growing season.

Key words: evapotranspiration, crop coefficients, remote sensing, Penman–Monteith.

*E-mail: RALLEN@kimberly.uidaho.edu

NO:3–012
Effects of irrigation interval and nitrogen application on soil moisture, salt distribution and cotton growth under plastic mulch drip irrigation

Guangyong Li[1,*], Fujun Cai[2], Qiong Zhang[1], Alam Mahbub[3] and Tingwu Lei[1]

[1]China Agricultural University, Beijing, 100083, [2]Water and Soil Research Institute of Xinjiang Academy of Agricultural Sciences, Urumqi, China and [3]Department of Biological and Agricultural Engineering, Kansas State University, USA

Field experiments were arranged to investigate effects of irrigation interval and fertilization application on soil water, salt movement and cotton growth under plastic-mulched drip irrigation. Treatments included moderate (0.28 dS m^{-1}) and high (2.76 dS m^{-1}) salinity soils, 2 and 7 days irrigation intervals in the blossom period, and 270 kg N ha^{-1}, 210 kg N ha^{-1} and 150 kg N ha^{-1} application rates. Experiments were conducted with lysimeters. Measurements included soil moisture, soil salinity as electrical conductivity, total soil nitrogen, cotton growth and yields. Results indicated that cotton yields under the 2 day irrigation interval were increased by 45.2% as compared with those under the 7 day irrigation interval for highly saline soil. But yields under the 7 day irrigation interval were increased by 8.1% as compared with those under the 7 day irrigation

interval for moderately saline soil. The cotton yields under middle and high fertilization treatments were increased by 12.0% and 25.1%, respectively, as compared with those under low fertilizer treatment.

Key words: saline soil, plastic mulched drip irrigation, cotton growth.

*E-mail: lgyl@163.net

NO:3–013
Irrigation scheduling effects on cotton growth and yield for drip irrigation under plastic mulch

Huanjie Cai*, Guangcheng Shao and Shaozhong Kang

Key Lab of Agricultural Soil and Water Engineering in Arid and Semiarid Areas, Ministry of Education, Northwest Sci-Tech University of Agriculture and Forestry, Yangling, Shaanxi, 712100, China

Effects of different irrigation schedules were investigated for drip irrigation of cotton under mulch, to determine optimal crop yield, quality and water-use efficiency. The field experiments were conducted at Shihezi Experimental Station for Soil Amelioration, Xinjiang, from April to October 2000, using experimental plots each 88.3 m long and 1.7 m wide. Drip laterals were placed under plastic mulch in alternate mid-rows. Three irrigation levels were designated for each growing stage, making 11 treatments in total, with three replicates. Regression analysis showed that a quadratic relationship best described lint and seed cotton yields in relation to irrigation amount. The irrigation amount corresponding to maximum lint yield was 385 mm, which included three irrigations with 55.5 mm to ensure crop emergence. Excessive irrigation or severe water deficit could reduce cotton quality. Peak seed cotton yield was 6380 kg hm^{-2}. The cotton was irrigated 9–11 times, with 25–30 mm each time. Peak water-use efficiency was of the order 0.55 kg m^{-3}.

Key words: cotton, drip irrigation under plastic mulch, irrigation schedule.

*E-mail: huanjie@163.net

NO:3–014
Progress in demonstration of efficient agriculture in China

Xiuqiao Huang*, Feng Wu, Yingneng Li and Songmei Zai

Farmland Irrigation Research Institute, Ministry of Water Resources, Xinxiang, Henan, 453003, China

Developing water-saving agriculture and building up a water-saving society is becoming an essential strategic measure for the future. Over the last 20 years, considerable progress has been made in completing construction work for improved water use in irrigation, especially during the Ninth Five-year Plan. Specific technologies for water-saving have been adapted to local conditions, helping to guarantee stable increases in agricultural production and to benefit rural economies. Such measures have also deepened the reform of rural water conservancy provisions. As a result of many practical measures, the environment has been improving and the measures to cover situations in which there is high water demand can be relaxed. The levels of technology and equipment provisions for water-saving irrigation have been increasing at the same time.

Key words: efficient agriculture, water-saving irrigation, benefit.

*E-mail: hhxxqq@public.xxptt.ha.cn

NO:3–015
New method for design of in-line dripper

Quanli Han*

Xi'an Jiaotong University, Xi'an, Shaanxi, 710049, China

A design theory is presented for the development of a new in-line drip irrigation emitter, which should benefit water-saving measures. Steps in the design method are established from fractal theory. The line in fractal space is a 'metamorphic' one that has characteristics of a piecewise continuum but is highly fragmented. The boundary of a fractal fluid-line is made up of beeline joints, which are created from an infinite number of well-connected line intersections. The fractal centre-line of a fluid-line is first created, which has an offset of $\pm W/2$, where W represents the width of a flow-line. To have an integrated plane configuration, the depth of the centre-line is similar to that of widely used labyrinth emitters. The exponent of the head/flow relationship for the emitter was found to be 0.33, which is considered promising from the point of view of product development.

Key words: emitter, fractal theory; energy efficiency.

*E-mail: Qlhan7211@sohu.com

NO:3–016
Soil moisture measurement in agricultural water management

Shouyu Chen[1,*] and Honglan Ji[2]

[1]Civil Engineering and Water Conservancy Institute, Dalian University of Science and Engineering, Dalian, 116024 and [2]Water Conservancy and Civil Engineering Institute, Inner Mongolia Agricultural University, Huhehot, 010018, China

Watermark sensors, tensiometers, neutron probes, TDR and FDR instruments are introduced. They may be used to schedule irrigation, thereby reducing water losses and water pumping costs.

Key words: soil water content, measurement, application.

*E-mail: waterrr@dlut.edu.cn

NO:3–017
Improving irrigation efficiency: a water pricing perspective

Hector Malano[1,*] and Yongping Wei[2]

[1]Department of Civil and Environmental Engineering, The University of Melbourne, Victoria 3010, Australia and [2]Shanxi Provincial Institute of Hydraulic Research, Taiyuan, 030002, China

China faces many water resource and environmental problems caused by low irrigation efficiency. This paper attempts to analyse the problem from the point of view of the agricultural water pricing policy. The existing problems in the Chinese agricultural water pricing system are analysed together with an outline of the objectives pursued by agricultural water pricing reform policy. These comprise economic, financial, social, political, and resource and environmental aspects. Two constraints to pricing policy reform are also discussed: the current Chinese water resources management system and low farmers' income. Finally, the Australian experience in water management reform, market-based instrument for water pricing and water trading are presented, and lessons from the water reform process are discussed for their relevance to Chinese water resource policy.

Key words: irrigation, water pricing, China, Australia.

*E-mail: h.malano@civenv.unimelb.edu.au

NO:3–018
Engineering innovations to improve irrigation water-use efficiency

Takeyama Kouichi[1,*], Ide Mitsuo[2], Nazmun Nahar Karim[1], Kita Ichiro[1] and Abe Yukuo[3]

[1]Shimane University, [2]Tamano Consultants Co. Ltd, Nagoya and [3]University of Tsukuba, Japan

Two examples are given of engineering innovations to improve water-use efficiency in irrigation. First, water savings are possible for light soils by converting from surface to overhead irrigation practice, but the related energy supply needs to be affordable and sustainable. Use of combined wind and solar cell units to power sprinkler systems was examined with two types of pump powered by direct current (DC). A wetted diameter of 1.5–2.5 m was possible with the 50 W submersible pump. A 120 W diaphragm pump was capable of producing a 10 l min^{-1} flow with a pressure of 10 m water head. Both arrangements seemed compatible with energy storage using a conventional car battery. Secondly, successful hydraulic regulation of irrigation control gates has considerable benefits. A new means of achieving this uses a regulation plate that is rigidly connected to a float, which is actuated by water levels upstream of a weir in the supply channel. Movement of the regulation plate promotes a steady offtake flow despite large variation in upstream water levels. Corresponding improvements to water distribution efficiency are described for Japanese irrigation networks.

Key words: irrigation, water-use efficiency, sprinkler system, hydraulic regulation.

*E-mail: takeyama@life.shimane-u.ac.jp

NO:3–019
Modelling irrigations for best management practices

Renduo Zhang*

University of Wyoming, Laramie, WY 82071-3354, USA

Modelling irrigation was developed fast in the world, and it can help managers to compare the effects of different types of irrigation scheduling and select the best one. Many results showed that it is a valuable tool for best management practices, and irrigation water-use efficiency can be improved by modelling irrigations. In this paper, some methods of irrigation modelling are introduced, and the advantages and disadvantages are pointed out.

Key words: irrigation modelling, water management, water-use efficiency.

*E-mail: Renduo@uwyo.edu

NO: 3–020
Model of optimal irrigation quantity for spring wheat

Hudan Tumarbay*, Dianhan Ma, Xiwan Guo and Yingjie Ma

School of Water Conservancy and Civil Engineering, Xinjiang Agricultural University, Urumqi, 830052, China

The water requirements of spring wheat were determined using the Penman–Monteith formula, in the context of surface irrigation systems. Then a dynamic soil water model was applied to the simulation of changing water contents for the spring wheat root zone. There was good agreement between the calculated values and observations. Thus, upper and lower limits of the soil water content were established, together with more reasonable irrigation water quotas. This study provides a scientific foundation for field water management and agricultural water-saving. Determinations of optimal irrigation water quantities required for spring wheat are in accordance with reality.

Key words: optimized irrigation water quantity, mathematical model, calculation method, soil water movement.

*E-mail: hudant@hotmail.com

NO:3–021
Estimating surface soil moisture using NOAA/AVHRR and ground station meteorological data

Tiesong Hu*

Department of Drainage and Irrigation, School of Water Resources, Wuhan University, 430072, China

A neural network model is proposed to improve the accuracy of predicting surface soil moisture using NOAA/AHVRR and ground station meteorological data. This is called a goal programming neural network (GPNN). Field measurements from three watersheds in the northern part of Hubei Province were used to calibrate and test the accuracy of predicting surface soil moisture as a function of microwave brightness temperature, NDVI, wind speed and antecedent rainfall. The results demonstrate that the GPNN consistently outperformed the generally used back-propagation neural network.

Key words: surface soil moisture, NOAA/AHVRR, NDVI, neural network.

*E-mail: tshu@wuhee.edu.cn

NO:3–022
Decision support system for saving irrigation water

Jianxin Xu*, Junjie Li, Zhaoying Shi and Hongjun Wu

North China Institute of Water Conservancy and Hydroelectric Power, Zhengzhou, China

The essential software parts have been developed to create a decision support system, related to saving irrigation water, which is capable of reasoning. The objective is to optimize the technological, economic, resource and environmental benefits, and it is based on the half-structure and multi-goal fuzzy theory. This work will establish an index system to evaluate strategies for irrigation water saving, by using Borland Delphi and the Paradox 7.0 database, applying fuzzy reasoning and an expert grading approach, confirming membership degree originally with mood operator and adopting the way of multi-pole optimization. The software has been applied in a typical region and has provided satisfactory predictions. It is easy to operate, has good intercommunication and is based on advanced theory. Furthermore, the software is important in confirming divisional models of irrigation water saving.

Key words: multi-pole optimization, fuzzy theory, decision-making, expert-grading approach.

*E-mail: Xujianxin1954@163.com

NO:3–023
Sewage-irrigation effects on growth and development of winter wheat

Shaoyuan Feng*, Zhiming Qi, Guanhua Huang and Guifeng Zha

China Agricultural University, Beijing, 100083, China

The effects of irrigating winter wheat with sewage were determined by comparing fresh water and sewage, at high, middle and low levels

of water supply, and either fertilized or unfertilized. The nine treatments were replicated. Results indicated that irrigation using sewage could promote the growth and development of stems and leaves of winter wheat, with a yield increase of about 17.6–31.1%. While sewage could provide some crop nutrition, this should be supplemented by a top dressing to meet the full nitrogen requirement of winter wheat.

Key words: sewage irrigation, winter wheat, field experiment.

*E-mail: fshyu@263.net

NO:3–024
Spring wheat under salt stress—a controlled environment study

Nasir M. Khan*, S. Shiozawa and Y. Sato

Graduate School of Agricultural and Life Sciences, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan

A control chamber experiment was conducted to examine the impact of shallow groundwater salinity (GWS) on spring wheat, keeping typical climatic parameters constant. Two levels of salinity treatment were maintained for 0.55 m water table depth. These were ECw = 3 dS m^{-1} (C-2) and ECw = 6 dS m^{-1} (C-3), compared with a controlled value of ECw = 0.2 dS m^{-1} (C-1). There were three replications with four transplanted plants per replication. Growth and productivity parameters were analysed statistically by ANOVA and LSD tests at $P(0.05)$, after crop harvest. In terms of grain yield and dry biomass, the results showed that effects of GWS were not significant for C-2, but were highly significant for C-3 when compared to C-1. No significant differences were found for plant height, but there was a significant difference in the number of spikelets for C-3. Maximum water consumption was observed for C-1 with gradually decreasing amounts for C-2 and C-3. A higher salt concentration in the root zone soil profile was observed in C-3, approaching a tolerance level, corresponding to the wilting point threshold at 15 bar, causing a serious decline in productivity. It was concluded that a moderately tolerant crop like wheat could survive shallow GWS with ECe < 4 dS m^{-1} without serious harm, provided extra surface water is periodically used for leaching.

Key words: groundwater salinity, saline agriculture, stress, crop response, spring wheat.

*E-mail: anasir@mail.ecc.u-tokyo.ac.jp

NO:3–025
Surface water flow characteristics of film hole irrigation

Junhu Wu*, Liangjun Fei and Huaien Li

Institute of Water Resources Research, Xi'an University of Technology, Xi'an, 710048, China

The characteristics of surface water flow were analysed for irrigation practice, based on infiltration through holes in a plastic film, covering each border strip. Field experimental data were used, where the holed ratio represents the ratio of the total film hole area to the field border area. The effects of discharge per unit width and holed ratio on water advance and recession were also examined. Film hole irrigation has the advantage of saving water, having a more rapid advance flow relative to a bare field. A power function and a quadratic function, respectively, describe the advance and recession curves of this irrigation practice. The advance flow velocity of film hole irrigation increases as the discharge per unit width increases, and reduces as the holed ratio increases. The maximum recession time of film hole irrigation reduces as discharge per unit width increases, and increases as the holed ratio increases. This new technique of water-saving surface irrigation is likely to spread and be applied extensively.

Key words: film hole irrigation, holed ratio, irrigation uniformity.

*E-mail: wjh@xaut.edu.cn

NO:3–026
Border strip irrigation using infiltration via slit films

Huifang Fan* and Biyu Luo

Water Conservancy Department, Yangling Vocational Technology College, Yangling, 712100, Shaanxi Province, China

Generalized rules for irrigation practice with slit films are described, along with the associated infiltration characteristics. Field measurements were used to construct and validate a mathematical model to describe the film slit-width and wetted volume associated with border strip irrigation using slit films. The study provided a theoretical foundation for further study.

Key words: film slit infiltration, film slit-width, mathematical model

*E-mail: fhfangcn@yahoo.com.cn

NO:3–027
Modeling water uptake in soils under alternate furrow irrigation

Xinmei Hao* and Renduo Zhang

University of Wyoming, Laramie, WY 82071-3354, USA

Soil water uptake was simulated for different alternate furrow irrigation practices, as well as for conventional furrow irrigation (EFI). In one form of alternate furrow irrigation practice, irrigation is fixed for one furrow (FFI) and further irrigations alternated on either side. Otherwise, irrigation is alternated between two neighbouring furrows during consecutive irrigations (AFI). Simulations were conducted for two soil types: clay loam and loamy sand. Several levels of irrigation water application and either 0.4 m or 1 m root depth were used. With the same irrigation time, water applied was reduced nearly by half for AFI and FFI, compared with EFI. Water uptake was reduced by 30.6% for AFI and by 33.9% for FFI, relative to EFI, for a clay loam with 0.4 m rooting depth. About 20% water uptake reduction might be expected for AFI and EFI with 1 m rooting depth. For loamy sand, the largest water uptake reductions of AFI and FFI were about 60% and 70%, when rooting depths were 0.4 m and 1 m, respectively. There were no significant differences in water-use efficiency predicted for the three irrigation methods used with clay loam, based on similar amounts of water being applied. For loamy sand, EFI appeared to achieve the highest water-use efficiency. Predictions for the two alternating irrigation methods suggested higher leaching losses than for EFI for both soils, with the leaching losses tending to be similar at the higher irrigation levels.

Key words: alternate furrow irrigation, simulation, water uptake, water-use efficiency.

*E-mail: xinmei@uwyo.edu

NO:3–028
Alternate furrow irrigation of maize

Yinghua Pan[1,*], Shaozhong Kang[2], Taisheng Du[2] and Zongsuo Liang[1]

[1]Institute of Soil and Water Conservation, CAS & MWR, Yangling, Shaanxi, 712100 and [2]Key Lab of Agricultural Soil and Water Engineering in Arid and Semi-arid Areas, Northwest Sci-Tech University of Agriculture and Forestry, Yangling, Shaanxi, 712100, China

Spatial and temporal variability of soil water and water-use efficiency were determined during a comparison of conventional (CFI) and alternate furrow irrigation (AFI) of maize. Results showed that there was considerable lateral movement between irrigated furrows and non-irrigated furrows. Whilst water-use efficiency of AFI was lower than that of CFI, there was no obvious difference between them in irrigation uniformity (IU). Photosynthetic rates did not decrease, but evapotranspiration rates did, in the AFI treatment. With AFI, water supply could be cut by one-third to achieve the same yield.

Key words: alternate furrow irrigation, soil water, water-use efficiency.

*E-mail: 7011302@263.net

NO:3–029
Effect of under-mulch-drip irrigation on apparent canopy photosynthesis, canopy structure and yield formation of high-yield cotton in Xinjiang

Wangfeng Zhang[1,2,*], Zhenlin Wang[2], Songlie Yu[2], Shaokun Li[1,3], Lianpu Cao[1] and Litong Ren[1]

[1]Research Center of Xinjiang Crop High-Yield, Shihezi University, Shihezi, 832003, [2]College of Agronomy, Shandong Agricultural University, Taian, 271018 and [3]Institute of Crop Breeding and Cultivation, CAAS, Beijing, 100081, China

The influence of different drip irrigation amounts on apparent canopy photosynthesis, canopy structure and yield formation was studied under high-yield conditions in Xinjiang. The aim was to explore the physiological mechanisms associated with water-saving and high yield, for drip irrigation of cotton under mulch. Results indicted that drip irrigation with 25 mm, rather than the usual 37.5 mm applications employed in Xinjiang's cotton cultivation, caused water deficiency and reduced apparent canopy photosynthesis and dry matter. But the proportion of dry matter associated with seeds increased rapidly. Canopy respiration declined significantly in the full boll stage, while the respiration/photosynthesis ratio was higher in the full flowering stage. Limited drip irrigation also reduced the leaf area index and canopy light interception. It increased the mean inclination angle of foliage, canopy transmission coefficients for radiation penetration and canopy transmission coefficients for diffuse penetration. There were great differences in the response to drip irrigation among varieties, with Xinluzao6 being insensitive to limited irrigation while Xinluzao8 was sensitive. This is the importance of breeding drought-resistant varieties of cotton in Xinjiang.

Key words: cotton (*Gossypium hirsutum* L.), under-mulch-drip, irrigation, photosynthesis, canopy structure.

*E-mail: wfzhang@ns.ibcas.ac.cn or zwfgl-sh@mail.xj.cninfo.net

NO:3–030
Root zone irrigation technology

Qingan Ma[1,*] and Qingli Ma[2]

[1]Xinjiang Shihezi University, Xinjiang, 831100 and [2]Xinjiang Changji Agricultural Bureau, Xinjiang, China

Root zone irrigation technology is an advanced subsurface irrigation technique, which has overcome a lot of the technological problems that still hinder other subsurface irrigation techniques. Blockage of outlets is one such problem. Innovative design theory is at the heart of this new concept, which has been carried through to production of new equipment. The expected applications include use in desert conditions, in protective woodlands and for energy biomass production.

Key words: new technology, subsurface irrigation.

*E-mail: mountainma@mail.china.com

NO:3–031
Studies on the drip irrigation experiment with mulching technology and the water-saving irrigation system in the apple orchard

Huaiyou Li* and Bin Wang

Xifeng Supervisory Bureau of Soil and Water Conservation of the Huanghe River, 745000, Gansu, China

On the basis of the water balance principle and the combination of pit tests and field experiments, through four pit tests, some soil management methods, such as mulching technology, sodden mulching and clean tillage, were adopted in the apple orchard during the fruit-bearing phase to ascertain the water consumption, the critical period of water demand and the time of maximum water demand under the conditions of drip irrigation in each phenological phase. Meanwhile, according to the precipitation information, the field experiment was also conducted to determine some relevant parameters concerning the irrigating water quota, irrigating position, critical irrigating water period, times for irrigation, planned depth of the damp layer, soil moisture ratio, capillary-laying method, the irrigation method, etc., and to establish the water-saving irrigation system of drip irrigation in the apple orchard. In addition, the moisture-producing rate and efficiency of the apple tree were determined on the basis of the water consumption, the output and production value of the fruit tree in each pit for many years. Therefore, the irrigating water quota, irrigation method, irrigation time and the irrigation position are not only fixed by these above experiments but are also demonstrated and popularized.

Key words: mulching method, apple orchard, drip irrigation, water consumption law, water-saving irrigation system, moisture-producing rate.

*E-mail: qyxflhy@sohu.com

NO:3–032
Evapotranspiration of drip-irrigated cherry tomatoes in solar greenhouses with high groundwater

Shuhan Zhang[1,*], Yueyuan Ding[1] and Tingwu Lei[2]

[1]Beijing Hydraulic Research Institute, Beijing, 100044 and [2]College of Hydraulic and Civil Engineering, China Agricultural University, Beijing, 100083, China

Low, medium and high quantities of water were provided by drip irrigation during the three growth stages of cherry tomatoes, so that

evapotranspiration rates could be determined. The autumn/winter cherry tomatoes were grown in solar greenhouses with high local groundwater conditions, located in Beijing's Chaoyang District. Daily averaged evapotranspiration rates varied from 1.65 mm day^{-1} to 2.16 mm day^{-1} during establishment, blossom and fruit setting, and fruiting stages. A hyperbolic function best described the relationship between evapotranspiration and irrigation amount. The work indicated that there are minimum and maximum evapotranspiration rates for such greenhouses. Yields were correlated to some extent with the total seasonal evapotranspiration and that for different growth stages. Appropriate irrigation amounts are suggested for drip-irrigated cherry tomatoes.

Key words: evapotranspiration, cherry tomato, solar greenhouse, groundwater presence.

*E-mail: Zhangshuhan2002@sohu.com

NO:3–033
Computerized precision irrigation system based on estimation of crop water stress with xylem acoustic emission technique

Shifeng Yang[1,*], Xiaojing Huo[2], Dongping Qian[2], Limi Okushima[3] and Yuqiu Guo[3]

[1]Department of Automation, Tianjin University of Science and Technology, Tianjin, 300222, [2]College of Electric and Mechanical Engineering, Agricultural University of Hebei, Baoding, 071001, China and [3]Laboratory of Environmental Control in Agricultural Buildings, National Research Institute of Agricultural Engineering, Japan

A computerized and automatic system for precision irrigation was developed in a modern greenhouse, based on estimation of crop water stress using the acoustic emission (AE) technique. The system can automatically acquire real-time AE signals and transpiration data from a tomato crop using an AE sensor and electronic balance, respectively. Then the system automatically carried out precision irrigation, according to an optimum control algorithm. Results have shown that AE events increase gradually with the increase in transpiration rate of crops to some extent. The system has the potential to implement optimum and automatic irrigation based on the information acquired from AE data of crops, but the system is easily affected by noise within the environment.

Key words: acoustic emission technique, water stress, transpiration, virtual instruments.

*E-mail: yshifeng@eyou.com

NO:3–034
Using fertigation for feed corn in a semi-arid region

A.R. Vaezi and M. Homaee*

Department of Soil Science, University of Tarbiat Modarres, Tehran 14155-4838, Iran

The influence of fertigation on corn productivity in a semi-arid region of Iran was investigated. Consequently, a split-plot experiment was carried out on feed corn with a complete randomized block design having 10 treatments and three replicates. The fertilizers were applied using either fertigation or surface application. Fertilizer applications consisted of 400 kg of $CO(NH_2)_2$, 400 kg of KCl, 50 kg of $FeSO_4$, 30 kg of $ZnSO_4$, 65 kg of $MnSO_4$, 20 kg of $CuSO_4$ and 15 kg of H_3BO_3 per ha. The five levels of recommended fertilizer (0%, 25%, 50%, 75% and 100%) were applied to all treatments using both methods. Plots were irrigated by sprinkler. The results indicated that yield and fertilizer-use efficiency (FUE) were affected by fertilizer practice. For both methods, increasing the amount of fertilizer increased yield, but with the fertigation method, the yield of the 75% treatment was higher than that of the 100% treatment. The yield with fertigation was significantly ($p = 5\%$) increased on the 50%, 75% and 100% treatments. The yield of the 50% treatment by fertigation was the same as that of the 100% treatment by surface application. FUE of fertigation applications were higher as compared to the same treatments by surface application. In both methods, maximum FUE was obtained for the minimum amount of applied fertilizers (25% treatments). These results suggest the use of fertigation in semi-arid regions to save a considerable amount of water and fertilizers for sustainable agriculture.

Key words: fertigation, corn, semi-arid.

*E-mail: Mhomaee@hotmail.com

NO:3–035
Root architecture and water uptake for cotton under furrow and mulched drip irrigation

Mingsi Li*

College of Water Conservancy and Architectural Engineering, Shihezi University, Shihezi, Xinjiang, 832002, China

The drip irrigation system is commonly designed based upon crop root architecture and water uptake. Owing to the improvement of soil moisture and soil heat states, the mulch trickle irrigation (MTI) technique will result in changes in crop root architecture and water uptake. Characteristics of cotton root structure and water uptake were determined for furrow irrigation (FI) and mulched drip irrigation (MTI). Cotton absorbed water primarily through shallow roots for both irrigation methods, although a higher specific weight of shallow roots was found for the MTI treatment. In addition, during key growth periods, the specific water consumption of MTI cotton roots was larger than that of the FI cotton roots, despite the MTI's cotton root system being shallower.

Key words: drip irrigation, plastic film cultivation, cotton, roots architecture, water uptake by roots.

*E-mail: leemince-709@163.com

NO:3–036
Use of pumps for irrigation with variable speed drive, producing constant pressure supply

Wuquan He*, Zhinong Wang and Yubao Wang

Northwest Sci-Tech University of Agriculture and Forestry, Yangling, Shaanxi, 712100, China

Electrically driven pumps for sprinkler and micro-irrigation usually operate at constant speed under fixed power supply frequency. So centrifugal pump performance cannot remain efficient for the commonly varying operating conditions within related pipe networks. A variable frequency supply unit to produce constant pressure incorporates feed-back sensors to adjust the rotational speed of a motor and pump set, thereby satisfying different discharge requirements within pipeline networks. A specific mode of use is proposed for irrigation-water saving conditions. Examination of system performance and analysis of economic benefits suggest that this control system has application to water-saving irrigation with significant benefits in saving water and energy.

Key words: variable frequency, constant pressure, water-saving irrigation, applied mode.

*E-mail: hewuquan1967@sina.com

NO:3–037
Water-saving irrigation in China

Yuanhua Li*

National Center for Irrigation and Drainage Development, Ministry of Water Resources, Beijing, 100053, China

Per capita freshwater availability in China is among the lowest in the world and it is increasingly in short supply. Less water will be available for irrigation, which consumes the largest amount of fresh water, because of the rapidly increased demands for fresh water for industrialization and domestic urban consumption. But both population and income growth have been influencing the demand–supply balances of staple grain and fresh water, and will remain a major force in future. To feed her 1.6 billion population in 2030 under the conditions of maintaining sound ecosystems and environment, there is a more urgent need for China to produce more food with less water than for many other countries in the world.

In recent decades, China has pioneered some water-saving policies and water-saving irrigation (WSI) techniques, aiming at increasing water and land productivity. The adoption of on-farm WSI practices on a widespread basis and water pricing provide an opportunity for efficient water use on a large scale because it impels every water user to value water, capture the return flow, harvest the rainfall water and control the percolation losses. Policies for WSI from high level support the conducive institutional development, leading to maximization of the effects of agricultural infrastructure, and of successful research on, and dissemination of, new technologies. There are many success stories about 'real' water savings in China.

This paper introduces the development of the WSI techniques and the impacts of WSI on society, the economy and the environment, and presents the experiences and lessons on WSI from China. Based on the analysis of the supply–demand of fresh water, the objectives and tasks for water savings from irrigated agriculture in China are discussed, and the strategies for sustainable water use and agricultural development and the main measures leading to increasing water and land productivity are suggested.

Key words: water-saving irrigation, efficient water use.

*E-mail: yuanhli@yahoo.com

NO:3–038
Dynamic model of water production function of rice in northern China

Daocai Chi*, Xuan Wang and Guimin Xia

Water Resources College, Shenyang Agricultural University, Shenyang, 110161, China

With the methods of planting rice in lysimeters and ceramic pots, based on the analysis of the rice dry matter growth law, a mathematical model was put forward that expressed the relationship of dry matter accumulative quantity and seed production, and a mathematical model of dry matter accumulation with time. Based on the Morgan model, to construct water deficit influence functions, which are subsection linear function, multiplication of exponent function and the third power function, and the parameters of these function were fit. The rice dynamic production mathematics model was advanced, and the parameters of the rice dynamic production model in Shenyang were solved. The rice dynamic production model was tested with the data measured in 1999, and the sensitivity of the model was analysed. The results show that the model has good adaptability of time region.

Key words: rice, dynamic model, dry matter, water deficit, influence function.

*E-mail: daocaichi@vip.sina.com

NO:3–039
Pipe network optimization for greenhouse drip irrigation

Xuan Wang[1,*], Daocai Chi[1] and Zhanbin Li[2]

[1]Shenyang Agricultural University, Shenyang, 110161 and [2]Xi'an University of Technology, Xi'an, 710048, China

Optimal drip-irrigation pipe networks were identified for a typical 667 m^2 greenhouse, based on four kinds of sub-lateral arrangement, so that a least-cost design could be selected. Sub-lateral designs included built-in drip-lines produced by the Luyuan Company, drip-lines made in Israel, pressure-compensated double-wall drip-lines produced by the Rain Bird Company and orifice drippers produced by the Shenyang Seventh Plastic Company. Optimal hydraulic design was programmed in FORTRAN, to select pipe diameters for a range of lateral discharge rates, with their corresponding sub-laterals, and to identify equivalent annual costs. Results showed that cost of the composite built-in drip-line design is lowest for lateral diameters of 40–32 mm. Relative to the nearest competitor, this represents an investment saving of about 9.7%.

Key words: design optimization, pipe network, greenhouse.

*E-mail: xuanw@vip.sina.com

NO:3–040
Water-yield function of winter wheat and its application

Zengjin Liu[1] and Yuanhua Li[2,*]

[1]Department of Irrigation and Drainage, Wuhan University, Wuhan, 430072 and [2]National Centre of Irrigation and Drainage Development, Ministry of Water Resources, Beijing, 100053, China

In North China Plain (the Yellow-Huai-Hai Plain), per capita fresh water is less than 500 m^3 per year, and about 7.7% of the total available water is irrigating 39% of the total farmlands and bringing up about 35% of the total population in China. Moreover, the ecosystems of this region have sacrificed significantly because the pumping of underground water in the areas is exceeding the recharge rate of aquifers. Many studies claimed that the development of a sustainable water supply for this region is an essential factor for China's food security and national economy.

Agriculture in the North China Plain is very intensive, and winter wheat is a dominant crop which greatly depends on irrigation. Great attention has been paid to improving irrigation water management for winter wheat production in this area, aiming to increasing water and land productivity. Based on the field experiments at Chahezui Irrigation Experiment Station in Heilonggang, this paper presents the evapotranspiration (ET) of winter wheat and its changing pattern with different water supply, analyses the components of water consumption at the on-farm level and discusses the major influencing factors on ET of winter wheat. To avoid evident reduction of crop yields or other negative impacts resulting from the change of irrigation practices, the models of water production function (WPF)

for winter wheat were carried out, and then the optimum irrigation regimes for winter wheat in different hydrological years suggested. These irrigation regimes concern the physiological and ecological water requirements of winter wheat, soil moisture and rainfall, and both irrigation depth and irrigation events may be reduced with surface irrigation. The case study shows that the recommended irrigation practices are feasible and simple for farmers to use.

Key words: winter wheat, evapotranspiration, water-yield function, optimal irrigation programme.

*E-mail: yuanhli@yahoo.com

NO:3–041
Rapid prototyping of water-saving emitter design

Ruihuan Wang*, Wanhua Zhao, Yiping Tang and Bingheng Lu

Institute of Advanced Manufacturing Technology, Xi'an Jiaotong University, Xi'an, 710049, China

Prototype emitters with a labyrinth structure can be built in a few hours, using a rapid prototyping technique based on a CAD model of emitters. The prototypes were used to carry out flow experiments and to finalize designs. Flow data were obtained at different pressures under test bed conditions. Pressure versus flow relationships were obtained using MATLAB software. Six formulae and regression plots were derived for emitter pressure versus flow. The data suggest that the greater the number of labyrinth cells, the less the emitter discharge depends on operating pressure.

Key words: drip irrigation, emitter, rapid prototyping, pressure versus flow, regression analysis.

*E-mail: wangnancy102@sohu.com

NO:3–042
Drip emitter design by parameterized method

Qi Wang*, Wuanhua Zhao, Zhengying Wei and Ruihuan Wang

Xi'an Jiaotong University, Xi'an, 710049, China

The necessity for, and method of, parameterized design of drip emitters is presented. From an abstract classification of emitters, a modular design for the basic body and channel units is evolved. The algorithmic language and API function of CAD software are used to extract module parameters to facilitate parameterized design. So a software platform is created for the rapid development of drip emitters.

Key words: drip emitters, CAD technology, parameterized design, base channel unit.

*E-mail: wqi2000@163.com

NO:3–043
Mobile irrigation system for arid areas of Northeast China

Saixing Zeng*, Youqi Guo and Hualiu Qing

School of Hydraulic and Building Engineering, Northeast Agricultural University, Harbin, 150030, China

The serious effects on agricultural production that result from the arid conditions in Heilongjiang Province are described. Some unsuitable cultivation practices and certain human activities are contributing to erosion, desertification and alkalization, which threaten the sustainable development of agriculture. A mobile sprinkler irrigation system has been developed that contributes to reversing this trend. Benefits include combating drought and improving water efficiency. However, there are some problems over operation and maintenance aspects of the system, under the current 'land-contract' system in the Chinese countryside. Problems include restrictions on farmer involvement in water management, including the use of wells, and high irrigation costs. Organizations for co-operative irrigation management are discussed which are fundamental to water-saving agriculture.

Key words: mobile sprinkler, O & M constraints, land contract system, co-operative irrigation management.

*E-mail: zengsaixing@163.com

NO:3–044
Feature-based ANN model for estimation of reference evapotranspiration

Pramod Kumar Singh[1,*], Kamla Kant Singh[1], Sanjay Mathur[2] and Paras[2]

[1]Department of Irrigation and Drainage Engineering and [2]Department of Electronics and Communication Engineering, G.B. Pant University of Agriculture and Technology, Pantnagar-263145, Uttaranchal, India

A feature-based artificial neural network (ANN) model was developed for the estimation of reference crop evapotranspiration (ETo). This ANN model required six weather parameters. These weather parameters were maximum and minimum temperatures (T_{max} and T_{min}), relative humidity values (Rh and Rh_2), wind speed (u_2) and sunshine hours (n). Using the pattern-matching capability of ANNs, the network was trained to recognize the pattern of daily meteorological data of an India Meteorological Department weather station and its corresponding ETo, which was estimated using the FAO Penman–Monteith method. Results of the feature-based ANN model trained by the back-propagation technique were found to be in good agreement with those of the FAO Penman–Monteith model and observed field data.

Key words: artificial neural network, reference evapotranspiration.

*E-mail: pramod_singh_upa@rediffmail.com

NO:3–045
Self-exciting threshold auto-regressive model (SETAR) to forecast well-irrigated rice water requirements

Qiang Fu[1,*], Fulin Wang[2] and Yankun Sun[3]

[1]College of Water Conservancy and Civil Engineering, [2]College of Agricultural Engineering and [3]College of Resources and Environment, Northeast Agricultural University, Harbin, 150030, China

The self-exciting threshold auto-regressive (SETAR) model has much merit in dealing with complicated data sets. Through observing the variation of rice evapotranspiration over time, we found that the variation contains some periodicity. Through auto-correlation analysis, we found that the rice evapotranspiration values for different growth phases depended on each other. Weather and other factors cause the rice evapotranspiration to change periodically. So the SETAR model was prepared for analysis of groundwater use to irrigate rice in the Sanjiang Plain. Nine parameters were used

to describe the periodicity of weather factors. By comparison with practical values, the precision is high. So, the model can be used to lay out and manage an irrigation area. At the same time, it can be applied to optimizing an irrigation system.

Key words: SETAR model, well irrigation rice, water requirements.

*E-mail: fuqiang100@371.net

NO:3–046
Using partial least-squares regression to develop a model of rice evapotranspiration

Qiang Fu*, Likun Wang, Ling Song and Zhenxiang Xing

College of Water Conservancy and Civil Engineering, Northeast Agricultural University, Harbin, 150030, China

Calculating evapotranspiration with weather data, it was found that some independent variables had interactions with each other. This phenomenon can distort and destabilize the multivariate regression model of the traditional least-squares method. A partial least-squares regression model was used to model rice evapotranspiration. A model of rice evapotranspiration was suggested to resolve problems associated with the correlation. The model was found to give satisfactory predictions.

Key words: partial least-squares regression, evapotranspiration, rice, modelling.

*E-mail: fuqiang100@371.net

NO:3–047
Evaporation from bare soils with shallow groundwater table

Gh. Zarei[1,*], A. M. Liaghat[2] and M. Homaee[3]

[1]Iranian Agricultural Engineering Research Institute, PO Box 31585-845, Karaj, [2]Department of Irrigation and Reclamation Engineering, University of Tehran, Karaj and [3]Department of Soil Science, University of Tarbiat Modarres, Tehran 14155-4838, Iran

An analytical solution of the Richards' equation, with minimum input parameters, was developed and verified for one-dimensional unsteady upward flow from a shallow falling groundwater table. This was based on specified initial and boundary conditions governing the evaporation process. The Campbell equation to represent soil water retention data was used to obtain solutions. The evaporation amount from the soil surface and the duration of evaporation could be estimated as functions of water-table drawdown, impermeable layer elevation and the retention curve parameters. Experiments to verify the derived analytical solution were performed on nine cylindrical soil columns, which were packed with sandy loam, silty clay loam and silty clay soils. Results indicated reasonable agreement between measured data and theoretical solutions. However, the models underestimated evaporation amount and overestimated evaporation time during the evaporation process. The small discrepancies can be attributed to evaporation from gaps between the soil columns and cylinders due to soil shrinkage, a small vapoor phase flow contribution and the collapse of macropores resulting from soil packing. The model proved to be applicable to different soil types, requiring-only-a few-accessible-input-parameters.

Key words: bare soil, evaporation, non-steady evaporation, water table draw-down, soil drying, upward flow, Richards equation.

*E-mail: Ghzarei45@Yahoo.com

NO:3–048
Calculating evaporation from groundwater for the Tarim River Basin, Xinjiang

Shunjun Hu[1,2,*], Shaozhong Kang[2] and Yudong Song[1]

[1]Xingjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, 830011 and [2]Key Lab of Agricultural Soil and Water Engineering in Arid and Semi-arid Areas, Ministry of Education, Yangling, Shaanxi, 712100, China

Data for 1984–1987 have been used to develop an empirical formula to calculate evaporation associated with shallow groundwater. Results show that the main factors are groundwater depth (H; m) and atmospheric evaporation capacity or demand (E_{20}; mm day^{-1}) applied to sandy loam soils of the Tarim River Basin. The smaller the groundwater depth, the greater is the influence of atmospheric demand. When the groundwater depth is larger than a critical value, evaporation becomes close to zero. For a given groundwater depth, when atmospheric demand is small, then evaporation increases with demand up to a critical value, the limited groundwater evaporation E_{max}. When atmospheric demand is small, a power type formula is suitable to estimate evaporation for regional sandy loam soils. For large atmospheric demand, a new empirical formula was established.

Key words: Tarim River Basin, bare soil, atmospheric evaporation capacity, calculation method.

*E-mail: xjhushunjun@yahoo.com.cn

NO:3–049
Benefits of storage irrigation in Hetao Irrigation District

Jingwei Wu*, Jiesheng Huang and Jinzhong Yang

Irrigation and Drainage Department, Wuhan University, Wuhan, 430072, China

An experimental field located in the middle of Hetao Irrigation District was chosen and two irrigation experiments were carried out to examine the importance of storage irrigation to spring sowing. Measurements of soil water content, water table depth and soil salt content were collected at 14 points. The data indicated that storage irrigation has a dual function. Water is stored and surface soil is leached to ensure good germination and growth of spring wheat. Values of leaching efficiency and field application efficiency were not high, due to the freezing and thawing process and strong evaporation. Additional work appears to be warranted to further improve the efficiency.

Key words: Hetao Irrigation District, storage irrigation, salt, water content, leaching.

*E-mail: wjwwh@public.wh.hb.cn

NO:3–050
Real-time irrigation forecast and its application in Dou Shan Irrigation District

Jigang Ma*, Xueliang Cai and Yuanlai Cui

Department of Irrigation and Drainage Engineering, Wuhan University, Wuhan, 430072, China

The real-time irrigation forecast is one of the essential parts of the work for compiling a dynamic plan of irrigation water use. It plays an important role in saving water, increasing water productivity and crop yields in an irrigation area. The real-time forecast of the water requirements of a crop is the essential and difficult part in real-time irrigation. The conventional methods for forecasting crop water

requirement are based on the application of the historic data from typical hydrologic years. This could not be used for the real-time irrigation forecast. In this paper, based on the application of the real-time forecasted results of weather types (clear, cloudy, overcast and rain) and real-time measured data of leaf screen percentage and soil moisture, a new method for the real-time forecast of crop water requirements is presented and recommended. Based on the results of the real-time forecasted crop water requirement and precipitation, the real-time measured data of soil moisture (for dry food crop fields) or depth of the water layer (for paddy fields), and the maximum and minimum limits of soil moisture content or water depth for obtaining high yields and saving water, and applying the principle of field water balance, a method of real-time irrigation forecast including the real-time forecast of the date and quota of irrigation for both dry food crops and rice is presented. The method was applied and validated in a large pilot irrigation district: Dou Shan Irrigation District in Junan County, Shandong Province. With the results of the case study, the precision of the forecast and the effects on increasing yield and saving water of applying the real-time forecast are also introduced and discussed.

Key words: real-time forecast, irrigation, water requirement, Shandong.

*E-mail: Mjg99@sohu.com

NO:3–051
Farm soil moisture forecasting and irrigation information system

Zhenlong Wang*, Jialiang Zhao, Bing Wang and Xinhong Shang

Anhui and Huai River Water Resources Research Institute, Bengbu, 233000, China

A practical model for soil moisture forecasting is based on a moisture index and a waning coefficient. Parameters are easy to obtain and use is simple. The method is combined with geographical information systems in such a way that moisture and drought indices are readily presented.

Key words: soil moisture, forecasting, information system.

*E-mail: Skywzl@sina.com

NO:3–052
Automated monitoring and prediction of soil moisture in irrigated farmlands

Xilu Li [1], Xin Wang[1,*], Zhengdong Du[1], Zhenghe Xu[1] and Fangshu Jiao[2]

[1]Shandong Institute of Water Conservancy Research, Jinan, 250013 and [2]Irrigation Experimental Station of Xueye Reservoir Irrigation Area, Laiwu, 271114, Shandong, China

Sensors for soil water potential were buried at 0.3 m, 0.5 m, 1 m, 1.5 m and 2 m depths in irrigated farmland. In fields under wheat, changes in potential were very evident at the 0.3–0.5 m depths, with almost no change at the 1.5–2 m depths. Regression analysis suggested that the average potential values for the 0.3–0.4 m or 0.4–0.6 m depths were very similar to weighted means of the entire 1 m soil profile. So sensors for soil moisture potential should be buried at 0.3–0.5 m depth. Soil characteristic curves were determined on undisturbed samples. These relationships were represented by $\theta_v = a(-\varphi_m)^b$, where θ, φ, a and b are empirical coefficients. Software to forecast irrigation is based on parameters obtained in the irrigation area. The automation of soil moisture sensing on farms, data collection by computer and irrigation forecasting has been realized. Testing in the irrigation areas suggests only relative errors of –6.8% to 4.9%.

Key words: soil moisture, depth, monitor, predict.

*E-mail: wxjya@jn-public.sd.cninfo.net

NO:3–053
Distribution and movement of farmland soil moisture in Southern China

Hongwei Chen and Mingyao Zhou*

College of Hydraulic and Civil Engineering, Yangzhou University, Yangzhou, 225009, China

Crops use moisture mainly by root systems that absorb soil water. The distribution of water within the root zone and movement of water into or out of it can have an important bearing on crop uptake. Contributions to the root zone water balance by groundwater have been examined. An analysis has been made of the relationship between groundwater depth and root zone soil water contents, or associated soil tension values. From this, a field soil water index is proposed for water-saving irrigation in South China.

Key words: soil moisture, water balance, water uptake.

*E-mail: biangeya@sina.com

NO:3–054
Hydrodynamic model for forecasting soil moisture content

Mingyao Zhou*

College of Hydraulic and Civil Engineering, Yangzhou University, Yangzhou, 225009, China

More efficient use of soil water can be achieved through formulation of crop water-saving irrigation systems. Unsaturated water transmission rate and moisture diffusion coefficient were used to predict suction pressure in field soil water. Transformation processes had been established using soil hygronomic parameters. Crop water-saving irrigation systems had a great effect on efficient use of soil water.

Key words: soil moisture content, model, forecast.

*E-mail: biangeya@sina.com

NO:3–055
Irrigation by low-pressure pipeline using combined flows from wells and canals

Wuquan He[1,*], Yingpu Zhang[1], Jizhe Li[2], Xinming Chen[1] and Mingke Cai[1]

[1]Northwest Sci-Tech University of Agriculture and Forestry, Yangling, Shaanxi, 712100 and [2]Qindu Water Resources Bureau of Xianyang City, Shaanxi, 712000, China

Irrigation by low-pressure pipeline is currently one of the most popular technologies for water-saving in China. It is now being tested in Baojixia Irrigation District (ID) using water supplied by both wells and canals. Considerations for successful use include water control and distribution, coping with trash, means of adjusting pressure and water pricing. Combining flows has the advantage of mutual compensation by well and canal water. Measures of assured flow and the conservation of groundwater are improved, while water

prices can be reduced. Water-saving and yield improvement benefits can be expected for an irrigation district using combined flows.

Key words: low-pressure pipeline, irrigation, combined flows, wells, canals.

*E-mail: hewuquan1967@sina.com

NO:3–056
Hierarchical flow network for water allocation in large-scale irrigation districts

Qiang Luo*, Jiesheng Huang and Shingling Lei

School of Water Resources and Hydropower, Wuhan University, Wuhan, Hubei, 430072, China

A model was developed to represent a two-level hierarchical network for water resource allocation in large-scale irrigation districts. The proposed model is based on the 'decomposition and harmonization theory of large-scale systems' and on 'nonlinear network flow programming', with the potential benefits of faster computing times and smaller memory allocation for computing flow in water networks. An algorithm based on 'stepwise linearization and an out-of-kilter (OKA) representation' is used to describe upper and lower level subsystems. The model has been applied to Dongfengqu Irrigation District in Hubei province and compared with a 'self-optimization simulation model'. Good agreement was found between the two models.

Key words: large-scale irrigation district, network flow programming, hierarchical structure.

*E-mail: qluo@wuhee.edu.cn

NO:3–057
Consequences of upstream–downstream inequity in Bojili Irrigation District

Jingwei Wu[1,*], Sami Bouarfa[2], Jinzhong Yang[1] and Bernard Vincent[2]

[1]Irrigation and Drainage Department, Wuhan University, Wuhan, 430072, China and [2]Drainage and Barriers Engineering Research Unit, Cemagref Parc de Tourvoie, BP 44, 92163 Antony Cedex, France

Upstream users inevitably have priority in water resource distribution. Downstream soil water storage and conjunctive use of groundwater and surface water are typical responses of many regions facing water scarcity. Groundwater and irrigation water information for the Bojili Irrigation District was collected for a 6 year period and then used to examine inequity and the role of groundwater. Great heterogeneity was evident across the activities of upstream and downstream users, and in the extent of using groundwater to regulate the variability of water availability in spring. Upstream, the groundwater is used to regulate the variability of water availability during the spring period. Downstream, water stored as groundwater during the monsoon season is used to overcome water scarcity in spring. Another way farmers have to cope with water scarcity is through cropping intensity. Ways to improve the equity between downstream and upstream users must be found in the context of increasing water scarcity and to improve water-use efficiency.

Key words: conjunctive use, groundwater, surface water, Bojili Irrigation District.

*E-mail: wjwwh@public.wh.hb.cn

NO:3–058
Monitoring and evaluation method for management system reform of irrigation district

Hujun Shang*, Zhinong Wang, Mixia Wang and Yejuan Wang

Institute of Agricultural Soil and Water Engineering, Northwest Sci-Tech University of Agriculture and Forestry, Yangling, Shaanxi, 712100, China

The monitoring and evaluation (M&E) networks of Guanzhong Irrigation Districts (GID) are briefly introduced and then the monitoring indices and evaluation system data presented. Through quantifying some qualitative indices and using the analytical hierarchy process (AHP), a simple, effective and comprehensive evaluation method is developed. The factors taken into account include policy evaluation, evaluation of irrigation effect, evaluation of irrigation project performance and social evaluation. The goal is to offer a simple method so that others may come up with valuable opinions to evaluate the reform and promote more development of the irrigation management system reform.

Key words: irrigation district (ID), management system reform, monitoring and evaluation (M&E), analytical hierarchy process (AHP).

*E-mail: shajugn@163.net

NO:3–059
Modelling the water supply system in the irrigated area of Ninth Extractive Industry division of Xinjiang Corps

Xiaoyun Lei[1,*], Chunmei He[1], Dachun Chen[1], Yongfeng He[2], Lixin Zhang[2] and Liqiang Zhang[2]

[1]College of Water Conservancy and Civil Engineering, Xinjiang Agricultural University, Urumqi, 83005 and [2]Conservancy Bureau of the Ninth Extractive Industry Division of Xinjiang Corps, E Min County, Ta Cheng Region, Xinjiang, China

A dynamic water supply model is needed to make full use of the local water supply potential of existing reservoirs and raise the extent of guaranteed water supply within a whole system. A computer simulation model has been prepared for goal programming of real-time operation of a multi-reservoir system. It generates a set of acceptable solutions for subsystems, which meet the goal of the system. In this instance, the objective is satisfying given water supply requirements of an irrigation district. The goal programming simulation model is used to study irrigation water supply planning and distribution procedures. The new model has been successfully applied to multi-reservoir operation in the irrigated area of the Ninth Extractive Industry division of Xingjiang Corps, China. This is a unique management model of an intensive irrigation district, receiving 280 mm of rainfall per year, and possessing a strong evaporative demand of about 1800 mm per year.

Key words: Ninth Extractive Industry division, water supply system, goal programming, simulation model, reservoir operation chart.

*E-mail: binhuang123@21cn.com

NO:3–060
Decision support system for real-time allocation of irrigation water

Jigang Ma[1,2,*], Xueliang Cai[1], Yuanlai Cui[1], Hongyuan Yuan[1], Luoxi Wang[1] and Wu Lei[1]

[1]College of Water Resources and Hydropower, Wuhan University, Wuhan, 430072 and [2]Water Resource Bureau of Junan County, Junan, Shandong Province, China

A prototype decision support system (DSS) has been developed based on irrigation practices, water requirement calculations, real-time irrigation forecasts and real-time water allocation. It uses Visual Basic and the Access database software. The DSS prototype included database information system related to irrigation practices, real-time irrigation forecast system, real-time irrigation water allocation system and decision support system. This prototype is based on an integrated model, in which a lot of new models were used such as real-time irrigation forecast model. Conventional forecasts of crop water requirements are based on the application of historic data for typical years that are inappropriate for real-time irrigation forecasts. A new method for the real-time forecasting of crop water requirements is presented using real-time forecasts of four weather conditions (clear, cloudy, overcast and rain), together with real-time measurements of per cent leaf area coverage and soil moisture. The prototype was applied and validated in a large pilot irrigation district: Dou Shan Irrigation District of Junan County, Shandong Province. Results suggest that the DSS is effective, highly flexible and has the potential for use in other irrigation districts.

Key words: decision support system, real-time forecast, dynamic water allocation.

*E-mail: Mjg99@sohu.com

NO:3–061
Monitoring & evaluation networks for management system reform in Guanzhong Irrigation District of Shaanxi Province in China

Zhinong Wang[1,*], Mixia Wang[1], Xiaotao Hu[1], Hongxia Cao[1], Hujun Shang[1], Jianxin Xue[2], Dingwu Xue[2] and Anliang Zhou[2]

[1]Northwest Sci-Tech University of Agriculture & Forestry, Yangling, Shaanxi, 712100 and [2]Provincial Project Management Office of Guanzhong Irrigation Improvement Project of World Bank Loan, Xi'an, Shaanxi, 710036, China

The components, operating procedures, main problems and improving ideas in performance of monitoring & evaluation (M&E) networks for management system reform (MSR) have been introduced in Guanzhong Irrigation District (GID) of Shaanxi Province. The experiences of carrying out M&E networks have been summarized. The M&E networks have played an active role in guiding and promoting the MSR of nine irrigation districts in GID. The experiences and methods for setting up M&E networks will have a certainty of significance and reference value for other IDs at home and abroad.

Key words: irrigation management, management system reform, monitoring & evaluation networks, Guanzhong Irrigation District

*E-mail: wwzn@263.net

NO:3–062
Effect of polyacrylamide (PAM) on soil losses in furrow irrigation

T.M. Sohrabi* and B. Jahanjou

Department of Irrigation and Reclamation Engineering, Tehran University, Karaj, Iran

Furrow irrigation-induced soil erosion is a serious threat to sustainable irrigated agriculture globally, especially on agricultural lands that are susceptible to erosion and have a steep slope. Recently, field studies have demonstrated that a small concentration of polyacrylamide (PAM) dissolved in irrigation water appreciably reduces soil loss from irrigated furrows and increases net infiltration.

In order to study the effect of this material, an experiment was carried out, which employed the fractional method in block design, at the agricultural research station of Tehran University. This experiment included three levels of inflow rate (0.6 l s^{-1}, 0.8 l s^{-1} and 1 l s^{-1}) and three treatments with PAM (5 ppm, 10 ppm and control) with three replications on unplanted lands. The surface soil type of this study area was silt loam. Furrow length was about 140 m with 0.75 m spacing and 1.3% slope.

In this experiment, two irrigations were carried out. In the first, two different rates of PAM (5 ppm and 10 ppm) were added to the stream flow with special arrangement, then the effect of PAM on soil erosion and infiltration was investigated. In the second irrigation, the stream flow was without PAM; therefore, only the effect of added PAM in the first irrigation on soil erosion and infiltration was followed.

In the 5 ppm treatment, PAM was applied continuously to the stream flow until the stream flow reached the end of the furrow (advance time), then it was intermittently applied to inflow water with half an hour on and off-time. In the 10 ppm treatment, the duration of PAM application was two times the advance time and its application was discontinued thereafter.

The results of this study showed that the application of 10 ppm PAM is suitable for soil loss reduction and infiltration increment. In fact, PAM treatment at the 10 ppm rate reduced furrow soil losses by 87% and increased net infiltration by 46% as compared to the control treatment. In the second irrigation, which was without PAM, furrow soil loss was reduced by 55% due to the carry-over effect of PAM from the first irrigation.

Key words: infiltration, soil loss, polyacrylamide, furrow irrigation

*E-mail: tmsohrabi@yahoo.com

NO:3–063
The development of the model to simulate and optimize the rainwater-harvesting system for irrigation

Xinyan Zhang* and Huanjie Cai

Institute of Agricultural Soil and Water Engineering, Northwest Sci-Tech University of Agriculture and Forestry, Yangling, Shaanxi, 712100, China

The rainwater-harvesting system for irrigation has been studied from the technical and economic points of view, and thus a model to simulate and optimize the system has been developed. The system is composed of three subsystems: the rainwater-collecting subsystem, the rainwater-storing subsystem and the rainwater-utilizing subsystem. The model consists of four physical and ecological submodels: the analytical model of rainfall array, the estimating model for the amount of harvested rainwater, the model to optimize the distribution of irrigation water and the model to optimize the design of water-storing facilities. The hilly region of Liquan County was chosen for the case study for rainwater harvesting and utilization for the irrigation of field crops (wheat and corn). The model has been developed on the basis of reliable theories and methods, thereby having certain adaptability and practicability, and providing the theoretical base, model, and planning and designing methods for the system of rainwater harvesting and utilization for irrigation in the arid and semi-arid regions.

Key words: rainwater harvesting, irrigation, system optimization, model.

*E-mail: xnvxy@163.com or xnzxy@hotmail.com

NO:3–064

Study on field operating methods of controlled roots-divided alternate irrigation

Xiaotao Hu*, Shaozhong Kang and Fucang Zhang

Key Laboratory for Agricultural Soil and Water Engineering in Arid Area of Ministry of Education, Northwest Sci-Tech University of Agriculture and Forestry, Yangling, Shaanxi, 712100, China

The technique of controlled roots-divided alternate irrigation (CRAI) is a new idea for water-saving irrigation, which has some advantages of water-saving, increasing production and improving water-use efficiency. At present, the study of field-operating methods of CRAI is not enough and not systematic. The types, technical outlines and bestow conditions of field operating method were analyzed according to the characteristics of CRAI, and the methods adapting to the present status of our country's economy development were advanced. The field operating methods of CRAI partial irrigation methods, including furrow irrigation, drip irrigation, subsurface irrigation, subsurface drip irrigation, flow irrigation and socket irrigation. The crop using CRAI should have a greater root system, both in the direction of plane and uprightness, and be for wider row or deeper roots system and serried row planting. At present, alternate furrow irrigation is fit for filed wider row crop in northwest China. Crop root-divided alternate drip irrigation, alternate flow irrigation, alternate subsurface irrigation, alternate vertical drip and subsurface drip irrigation are base on ductwork, which have the disadvantage of requiring high investment and so can be used in industrial crops in developed regions. Fruit tree root-divided alternate socket irrigation is a simple and cheap operating method that is suitable for arid and semi-arid areas in northwest China. The invention of the mechanical and auto-control alternate valve has important meaning for advancing the science and technology content of CRAI and is convenient for expanding and application. Auto-control alternate of hair pipe microirrigation is based on the combined brake of electromagnetism valve and computer, studying and producing electromagnetism valve which is mini-sized, cheap, and suitable for installing on hair pipe will realize the auto-control of the kinds of field implement technology.

Key words: alternative irrigation, controlled roots-divided field operating method, water-saving.

E-mail: whuxiaotao@tom.com