ISSN : 0974 - 7435 Volume 8 Issue 1

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 8(1), 2013 [102-108]

Irrigated water use index system and its application in agricultural water management

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ABSTRACT

In order to increase efficiency of irrigation water use and alleviate conflict between water demand and supply, this paper studies the composition of irrigated water index system from mechanism, design, application and management level, analyzes the relationship among crop water requirements, irrigated quota and irrigated water quota, and its corresponding influence factors, then puts forward some agricultural water management ideas and measures that based on the irrigated water quota management and ET control management. The case study in the end shows that water-saving irrigation scheme based on ET monitoring control has obvious utility to agricultural water production efficiency.

KEYWORDS

Irrigated water use index;
Influence factors;
ET;
Agricultural water management.

INTRODUCTION

Water shortage has become a major obstacle resources and environment problems that restricts the economic development of our country, its negative effects on irrigated water and agriculture development directly threat to China's food security, it becomes a new subject in agricultural water management to speed up to solve the problems of agricultural irrigation water shortage and unreasonable situation of regional water distribution now. In order to improve the efficiency of agricultural irrigation water, relieve the contradiction between supply and demand of water resources, Department of Rural Water Resources in Ministry of Water Resources conducted a compiling work on irrigated water quota throughout the country in 2003. In recent years, "natural - artificial" binary water cycle pattern and gradually matured theory on "ET management" that academician Wang Hao[1] proposed have great significance on how to improve the utility of agricultural water management. This paper analyzes the influence factors of crop water requirement and irrigation water, the concept and connotation of irrigated water quota, etc. Put forward preliminary irrigated water use index system, irrigated water quota management and agricultural water management based on ET control, finally analyze the instances whether there is any effect on water saving through agricultural water management based on ET control.

COMPOSITION OF IRRIGATED WATER INDEX SYSTEM

Irrigated water index analysis and irrigated water quota are the foundations of agricultural water management, in general, agricultural water index analysis mainly refers to determining the water use quota of field crops. Crop water requirements, irrigated quota, irrigated water quota are the connotations of agricultural water, they together constitute the index system of irrigated water.

Crop water requirement

Water that crops need to consume in order to grow is the crop water requirement. It is the sum of crop transpiration water, evaporation of soil or water surface between crops and moisture of crop composition during the growing season. In fact, due to few moisture of crop composition (usually less than 1% of the total water consumption)and the influence factors of the small fraction influenced by complex factors are unable to accurately calculate, so negligible. We regard crop water requirement as the sum of crop transpiration and evaporation between plants, hereinafter referred to as ET (Evaportranspiration)[2,3].

Crop water requirement ET is main part of agricultural water consumption, reflects the real crop water requirement and water requirement rule, is the basis of formulating he irrigation system, but is not good at operating directly in practice. At present, with the development of remote sensing technology and distributed hydrological model, research on the rules of the crop water requirement no longer stay in the field trial stage, ET quantity has been able to be accurately calculated and simulated that provides a new platform for agricultural water management. In addition, the crop water requirement is also the typical basis of irrigation project for planning, design, management and implementation, it has direct influence on the development of water-saving agriculture[3,4]. Because the crop transpiration and evaporation between plants directly involve in the transformation of four water, we apply crop water requirement directly to the management, in line with the basic requirement "comparable" of the irrigated quota management, meanwhile real crop water requirement data can reflect the rationality of the regional distribution of water and scientificalness of irrigation water management.

Irrigated quota

As one of foundations for planning and design, irrigated quota is an important part of irrigation technology, it is all the sum of irrigation water per unit area in pre-planting and the whole growth period. Irrigation quota, according to crop water requirement, effective rainfall and groundwater utilization, determine the supplementary water of soil moisture to satisfy crop need, it is divided into net irrigated quota and gross irrigated quota. Net irrigated quota is the sum of net field irrigated requirement and additional water (bubble field and salt leaching, etc.) in the whole growth period; Gross irrigated quota is based on the net irrigated quota, allowing for water conveyance loss and the field irrigation water loss, converts to irrigation requirement per acre of canal head; The ratio of the net irrigated quota and gross irrigated quota is irrigation water use coefficient, it is a indicator that can measure water use efficiency and water-saving level[5,6].

Net irrigated quota is most closely related to crop water requirement, it keeps the regularity that crop water requirement is influenced by regional natural geography, climate conditions and the status of the underlying surface, it can effectively separate different irrigated quota between regions caused by different objective conditions; Irrigated quota considers the losses of irrigation water occurring in the process of transmission and distribution, considers the whole process of the irrigation which is reflected by irrigation water use coefficient. During planning and designing irrigation system, when consider whether to meet the demand of crop water requirement, we use the net irrigated quota, and when design canal head and pumping station we use gross irrigated quota. In fact, irrigated quota, as a planning and design parameter, objectively inherited scientificalness and regularity of the crop water requirement,which could be used as a guide for its irrigation practice work. But due to difficulty of direct measurement of net irrigation quota, and gross irrigated quota cannot be used for water management in a single irrigation event, irrigated quota management has a weak operability from the function of agricultural water management.

Irrigated water quota

Irrigated water quota is a new concept that put forward by agricultural water management for the fact that it should meet the demand of strengthening the irrigation water management whose background is industry, tertiary industry and domestic water quota, should be based on crop water requirement and irrigated quota, and draw lessons from the successful experience of water management in other industries, the basic requirement of irrigated water quota is a direct determination and objective appraisal, its main function is directly applied for agricultural water management. In essence irrigated water quota belongs to the category of gross irrigated quota.

Irrigated water quota and irrigation quota both connection and difference, irrigated quota is mainly as a basis for planning and design of the project, while irrigated water quota are mainly used for assessing agricultural irrigation water management which is microcosmic index and basic principle used to measure and compare scientificalness, rationality and sophistication of irrigation water. Irrigated water quota consider the influence factors of irrigation water, such as different crop water requirements, water transportation forms and consumption, and diversion channel features, etc. It emphasizes the objective demand that irrigation water must satisfy, and is more operable and manageable compared with the irrigated quota. irrigated water quota is a universal and objective standard of comparison that is similar to other industry water quota, and is the direct basis and assessment standard of agricultural water quota management[6].

Crop water requirement, net irrigated quota, irrigated quota, irrigated water quota respectively reflect the constitution of agricultural water index system from mechanism, design, application and management level, agricultural water management can be examined through conducting the organic combination of remote sensing and distributed hydrological model[7]. Agricultural water use index system composition and mutual relations are shown in figure 1.

INFLUENCING FACTORS OF IRRIGATED WATER INDEX

With many influence factors, Irrigated water index, in general, can be divided into three categories: (1) basic factors: means the inherent influence factors that basically have no choice, such as crop species, meteorological conditions, soil conditions, etc; (2) hard influence factors: means the influence factors that can be changed by investing largely, such as water resource conditions, irrigation project types, irrigation area scale, etc; (3) soft influence factors: means the influence factors generally without input or with a certain but could be conducted by users themselves, such as agronomic measures, field managements and water use customs, etc. The influence factors of irrigated water index can be seen in figure 2.

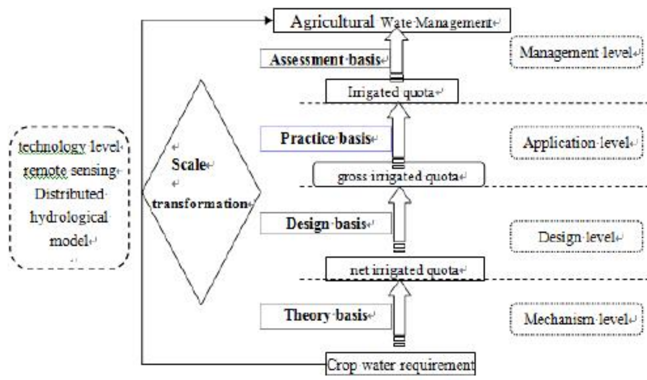


Fig.1 Agricultural water use index system and mutual relationship

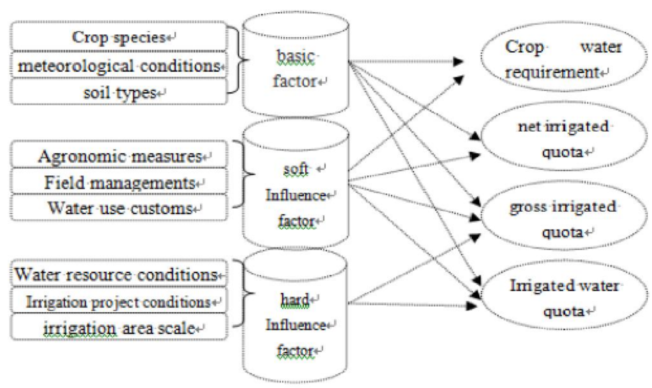


Fig.2 Influence factors of agricultural water use index

Crop evapotranspiration consumption is a continuous transmission process through the soil-plant-atmosphere system, and the atmosphere, soil and crop of the three components of any part of the relevant factors could affect the amount of the crop water requirement, at the same time, soft factors also have important influence on crops evapotranspiration, for example, with water-saving irrigation mode and under the sufficient irrigation crop evapotranspiration will change greatly. Soil evaporation capacity between plants will be greatly reduced if we use plastic covering and straw mulching, etc. Net irrigated quota is numeric equivalent of net irrigation water requirement and additional water in crop whole growth period. Gross irrigated quota consider irrigation water use coefficient on the basis of the net irrigated quota, irrigation water use coefficient is related to irrigation area, canal bed soil, seepage control measures, channel length, field project and irrigation technology level or other hard factors or soft influence factors. Different from influence factors of crop evapotranspiration consumption, irrigated water quota is also affected by hard factors, water resource conditions in different river basin or region is both unable to select and able to improved, for example, improve water resources carrying capacity by water-saving irrigation, and could use lower irrigation water quota in the region of water shortages but with better economic conditions, facilitate to transfer agricultural water appropriately to the high-efficiency water industry.

AGRICULTURAL WATER ANAGEMENT

Based on the irrigated water quota management

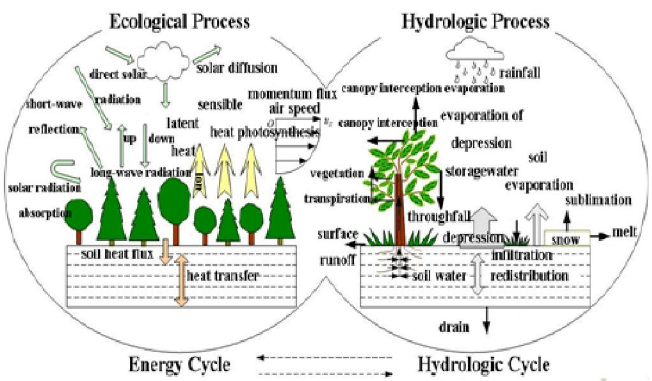
Water quota management is an important part of the water resources management, water quota determination can not only regulate water use, but more important is to guide the whole society to improve water use efficiency and then to realize the sustainable utilization of water resources. Different areas or river basin have different water resources condition and water use efficiency, water quota, as a guideline for water use in a certain region or basin, determines the quota standards according to regional or basin economic and technological conditions, precipitation level, degrees of water resource utilization and other factors influencing water use level. Water quota can not simply base on theoretical calculation and experimental data, and must consider the region or river basin difference, influence factor difference of water use, etc. There are no universally applicable water quota and its measure method.

Irrigated water quota is essentially gross quota, it is not a water standard of one agricultural production links, but concludes water standard of every part. When establish irrigated water quota, in order to meet the current executable scale of irrigation water, we use the method of field sampling to survey directly crops per acre water use of the typical irrigation unit as the fundamental data of irrigated water quota to determine, at the same time to use existing irrigation test data for checking. Irrigated water quota, as the basis of scientific distribution of agricultural water, should be positioned as "average" of many years from management point of view. But from the perspective of the actual irrigation water requirement, irrigation water use is more obviously different from itself in a wet year, which requires the irrigated water quota should be dynamically adjustable in practical application. To implement quota management also need corresponding engineering and non-engineering measures, to formulate related laws and regulations and expand coverage for irrigation channels and canal system, at the same time to improve the field matched water-saving facilities. Through the execution of irrigated water quota, scientific irrigation, dynamic management, rationalize and maximize the value of agricultural water.

Based on ET control management

Under the background of serious water shortages, only to pay attention to seeking for sources, namely, to increases land water system input and water-saving process, has been unable to fully improve effective utility of water resources in the process of the dynamic conversion. Evapotranspiration, as the main consumption of water circulation system, has great influence on effective utility of water resource. ET management is the water resources management based on water consumption control and a concrete implementation that transform "water-offering management" into "water demand management", On the basis of the accurate estimation of regional or basin evaporation quantity, parsing evaporation composition, it reasonably evaluates low-efficient and high-efficient components in the process of water consumption, which is theoretical basis and technical support of application of ET water resource management. ET involves water cycle process,energy cycle process and material cycle process along with physical, chemical and biological reactions, the related role process is shown in figure 3. ET, as the main components of the regional water balance and energy balance, play an important role in the process of water and energy circulation, and also is the important link of ecological and hydrological process.

Irrigated quota is a direct application in agriculture production, irrigated water quota emerges at the request of agricultural water management. When use irrigated water quota, we often adopt adjustment coefficient to calculate the irrigation water use existing in the actual irrigation under different combination of irrigation, improper adjustment coefficient selection often can cause larger error for estimating. ET reflect the rules of crop water requirement from mechanism, through advanced technology such as remote sensing monitoring, invert for different crops ET on different land types, further take reasonable irrigation measures. The actual water consumption is regarded as an important index to measure agricultural water-saving effect, increase agricultural output meanwhile reduce ET, namely reduce water consumption from farmland irrigation, especially reduce groundwater exploration in order to realize the sustainable utilization of water resources, so as to realize regional ET management[7,8]. ET control applied in the management of water resources provides a new idea for agricultural water management. Agricultural water management core based on ET control is to reduce the invalid ET and reduce inefficient ET, mainly realize the measures through the following two aspects:



$$Rn = H + \lambda E + G \qquad P = R + E + \Delta S$$

Fig.3 Interaction of water cycle and energy cycle in region or river basin

In the region level, we can select water-saving and high yield varieties according to the regional development planning and the local water resources condition, adjust reasonable agricultural planting structure to realize water and drought simultaneously, explore three-dimensional planting mode, give full play to the farmland use of precipitation, improve crop farming system, use physical methods to retain water for preserving soil moisture, such as tectorial cultivation, planting along the plastic films, straw mulching, straw returning and so on, and reduce evaporation between crops[9]; Research to promote the advanced irrigation system, give full play to the crop's own regulating function and the ability to adapt, according to the need of different crops in different growth period on the water sensitivity, timely and appropriate supply water scientifically, make it maintain in both a certain level of transpiration and cooling effect and a certain level of stomatal activity state through photosynthesis to adjust crop physiological and ecological status, and inhibit plant ineffective tillers and the invalid of transpiration.In the process of energy cycle: Rn,H,λE and G are respectively region/river basin average net radiation, sensible heat flux, latent heat flux and soil heat flux; In the process of hydrologic cycle: P, E, R and ΔS are respectively region/watershed average annual precipitation, evaporation and transpiration, average runoff and river basin water resources storage variation.

In the technical level, after reduction of water use, we should formulate corresponding water-saving measures and improve water-saving technology to ensure agricultural production (or without reduction of output) and increasing farmers' income. For example, apply model of soil moisture to calculate the typical crop ET quota of different irrigation modes, and with the help of a distributed hydrological model analysis, count planting areas of all kinds of crop and ET quota under respective optimized water-saving irrigation conditions to calculate irrigation farmland ET, finally determine water scheme that meet ET allocation of regional target. Irrigation water should ensure that it can both control water use and also minimize the invalid evaporation to improve agricultural water productivity and reduce regional ET, and then factually realize management goals of water-saving and maximizing water utility.

CASE STUDY BASED ON ET IRRIGATION MANAGEMENT

Irrigation based on ET is to allocate field consumable ET according to the regional ET goals, to make full use of soil water storage function, and to improve the effective utilization of irrigation water as far as possible. Its specific method is to determine reasonably control index of irrigated soil moisture content, according to the soil moisture to decide whether need to water, consider about the level of water requirement in crop various growth stages and storage function of soil water to determine irrigated quota and irrigation frequency. Based on the composition and mechanism of farmland evaporation, we can reduce field ET for irrigation management can be implemented from the following three aspects: (1) select scientific methods of irrigation and irrigation mechanism, control water use and water consumption from time and water; (2) implement farming methods, such as no-fallow, no-tillage and mulching cultivation, etc; (3) use measures, for instance, change planting structure, improve crop seeds and so on[10].

To take choosing scientific irrigation mechanism as an example, high-efficiency water-saving irrigation mechanism is a ET management method which reduce the lower limit of suitable soil water content and the field capacity from 65% ~ 70% to 55%~60% to ensure the normal growth of crops for acquiring the ideal production. Suitable soil moisture condition of all kinds of crops in each stage of growth period in different region is slightly different, specific data can be seen in Chinese ecosystem research network. In GEF project[10] in Tianjin, it set up two scenarios concluding the basic irrigation schemes and water-saving irrigation scheme based on lower field capacity, use distributed hydrological model to simulate ET for crop irrigation in the study area, analysis and study the impact on water requirement for high-efficiency irrigation mechanism based on ET. Under two kinds of solution, data concluding surface evaporation of different crops, plant transpiration, canopy interception, total evaporation, each sub-evaporation and integrated ET of crop and the whole region and so on is shown in TABLE 1.

Table1 Influence of Irrigation system on various crop ET and its component

schemes	Subentries	Rice /mm	Sunflower /mm	Vegetables /mm	Cotton /mm	Soybean /mm	Wheat /mm	Corn /mm	Integrated (dry land) /mm	Integrated (Crop) /mm	Integrated (all-region) /mm	Total evapotranspiration /10^8m^3
Basic scheme	land surface evaporation	399	375	304	310	280	198	179	329	341	403	42.94
	Plant transpiration	239	124	322	191	132	297	182	330	315	206	21.97
	Canopy interception	14	4	22	8	9	3	6	13	13	14	1.44
	Total	651	503	648	509	421	498	368	673	669	622	66.35
Water-saving scheme	land surface evaporation	385	196	262	224	206	179	175	278	296	375	40.04
	Plant transpiration	223	222	323	183	199	269	178	323	306	200	21.37
	Canopy interception	13	14	22	11	12	3	6	15	14	14	1.52
	Total	621	432	607	418	418	452	359	615	616	590	62.93

Data in the table shows that paddy field ET throughout the year could drop from original 651mm to 621mm, was reduced by 30mm and decreased by 4.6%; Composite dry field ET dropped from original 673mm to 615mm, was reduced by 58mm and decreased by 8.6%; Integrated crop dropped from original 669mm to 616mm, was reduced by 53mm and decreased by 7.9%; Integrated ET in the whole study area dropped from original 622mm to 590mm, total amount of evaporation in the study area dropped from 6.635 billion m3 to 6.293 billion m3, was reduced by 5.2%. Field evaporation between crops dropped from 341mm to 296mm, while evaporation between crops in the whole area dropped from the original 2.196 billion m3 to 1.906 billion m3, was reduced by 290 million m3 and decreased by 13.2%; Agricultural ET in the whole study area accounted for the proportion of integrated ET with reduction of 63.0% from 65.0%; High-efficiency evaporation rate increase from 66.9% to 69.7% and low-efficiency evaporation rate reduced to 30.3% from 33.1%.

From the perspective of influence of water-saving scheme about field capacity reduction on total ET, cotton ET has great potentials for reduction with drop of 18.0%, sunflower comes second with decline of 14.2%, followed by subsequent wheat, vegetables, rice, soybeans and corn with lower reduction amplitude of ET. it is mainly because this two kinds of crop in growth periods have high temperature, strong sunshine and abundant rainfall to give birth to the higher soil moisture, from this level, a high-efficiency water-saving irrigation mechanism have little impact on total ET of corn and soybeans, but still has a certain significance in enhancing ET efficiency; In terms of improving the efficiency of ET through efficient water-saving irrigation mechanism, sunflower is first with a doubling of improvement, then soybean has increased by half, the proportion of total ET of cotton and vegetables transpiration also have vary degrees to increase which are 16.4% and 7.0% respectively. However, by the way of water-saving scheme, high-efficiency utilizations of rice, wheat and corn have little change, thus it illustrates that research on high-efficiency water-saving irrigation mechanism of the economic crops plays an important role for improving the utilizations efficiency of ET.

CONCLUSION

Irrigated water quota system implements ÿtotal amount control and quota managementÿof irrigation water, raise the foundation of agricultural water management level, is the important basis of scientific distribution and effective management of water resources.

Use ET monitoring values to establish reasonable regional irrigated water quota and improve surface water and groundwater monitoring and management level, we can make realistic assessment of agricultural water use efficiency, irrigation management, water-saving effect for reasonable adjustment of crop planting structure and providing a scientific basis for water-saving irrigation. At the time of the increasingly serious "bottleneck" constraints of water resources, index system of irrigation water and agricultural water management concept based on irrigated water quota management and ET control management constructed in this paper have important practical significance on reasonable allocation and utilization of water resources, improvement of irrigation water use efficiency, promoting agricultural water management level and implementing the most stringent water resource management system.

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