Significance of the Water-Yield Relation in Water Deficit

용수부족시의 물-수확량 관계의 중요성

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요 약

농업에서의 용수부족 문제는 불가리아 뿐만 아니라, 여러나라에서 발생하고 있다. 그리고 에너지 비용이 커지므로 관개에 소요되는 비용도 점점 증가하고 있다. 용수 부족과 고비용은 용수의 효율적 이용을 요하며 이 문제를 위해서는 용수와 수량관계가 중요하다.

여기에서는 전통적으로 불가리아에서 재배되는 옥수수, 사탕무우, 자주개자리 및 포도의 증발산량대 수량 관계와 관개에 의한 중수량대 관개량 관계에 대하여 검토하였다.

용수부족시의 수량을 구하기 위해서는 FAO와 불가리아의 D.Davidov가 만든 공식, 그리고 본고에 소개된 공식을 사용할 수 있다.

In the past decades the problem of water deficiency, especially in agriculture, became more pressing all over the world. Population growth is increasingly dependent on the construction of irrigation systems and efficient use of water for irrigation.

On the other side, development of the irrigation farming is hampered by water deficiency and growing irrigation costs. Recurrent deficiency of water for irrigation has been already experienced in different parts of the world. The expected global warming of the earth climate will change the need for irrigation water - in some regions it will be on the increase, in others on the decrease.

The prospect of plant growing in water deficit seems quite real. It necessitates a comprehensive development of the problem of efficient water use, which is of exceptional importance both to designing and construction of irrigation systems, and their operation.

In countries such as Bulgaria** having fluctuating precipitation by quantity and location, water is a restrictive factor in obtaining higher yields for many of the farm crops. That's why, it is necessary to have in-depth knowledge of the water-yield relation in order to solve problems of different nature, including determination of the optimum economic yields that contribute to efficient use of

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** Climatic conditions in Bulgaria are described in detail in KCID Journal, 1995, 12, vol. 2, No 2, p.206

water for irrigation.

In the study of the water-yield relation evapotranspiration (ET) is most often used as an integrated indicator. Establishment of the relation between ET and yield is required first of all in order to determine the size of produce that can be produced by controlling distribution and use of irrigation water.

Therefore, the word is not for maximum yields, but rather economically feasible yields per unit area on condition that all remaining production factors are being used in a manner that will make them maximum efficient.

The interrelation between yield and ET is rather complicated because of the influence of many factors of most various nature. Some of these factors are inherent in the crops -type, sort, level of agrotechnics, fertilization, usable part of products considered as yield. The remaining factors are mainly natural conditions - geographic location of the region, meteorologic changes in the years and during the vegetation period (Stewart and Hagan, 1969, 1974, 1975 ; Downey, 1972 ; Gorbacheva, 1996).

For the successful application of the models of this relation in the solving of optimization tasks, experimentally established parameters for respective crops in the certain regions will be required. To this purpose, the study of this problem in Bulgaria started as early as 1972 and is still being carried on at the present.

This paper makes an attempt to summarize and present an analysis of the data published from experiments carried out employing uniform techniques in different regions in Bulgaria in the period 1972~1990. The aim of the studies was to determine the effect of water deficit on the size of the yield (and product loss, respectively) in two main directions ; 1) Effect of the total deficit expressed as a percentage decrease of each irrigation rate (from 0 to 60%) which brings about the same decrease in the irrigation rate, on the total yield from a certain crop ; 2) Effect of water deficit throughout the different stages of growth, realized by cancellation of irrigation upon established need for irrigation, also of the total yield.

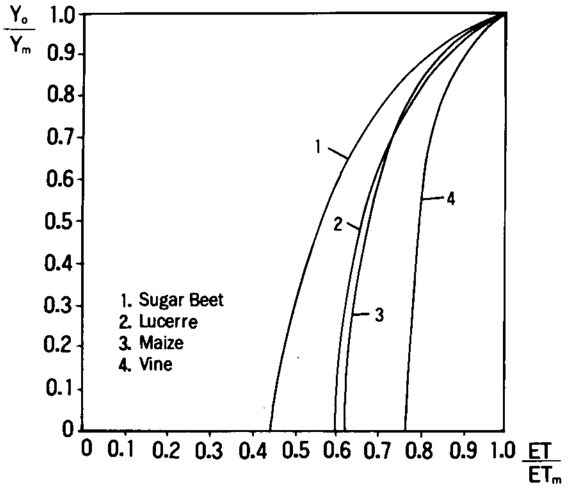
The optimun irrigation rate was assumed to be 600㎥/ha, the same as in the design.

The optimum pre-irrigation moisture was consistent with the concrete water-physical properties of the type of soil on which the experiments were carried out and was in the range of 70~80% of the field capacity. The size of the irrigation rate by years and crops was different depending on quantity and distribution of precipitation during the vegetation period.

In all experiments the principle of the only difference was observed, i.e. all controllable technological factors such as soil treatment, fertilization, crop density, suitable sorts, plant protection, were made optimum available except for water which was in deficiency in different versions.

ET was determined by the method of the water balance. Irrigation was by gravity or sprinkling, and in both cases irrigation rates were measured with automatic watermeters.

In 〈Fig. 1〉 are shown the results from the yield-ET relation in four traditional Bulgarian crops-maize, sugar beet, lucerne and vine. As seen, this is a curved line relation similar to the results obtained by other authors (Stewart and Hagan, 1969,



〈Fig. 1〉 Yield-Evapotranspiration relation

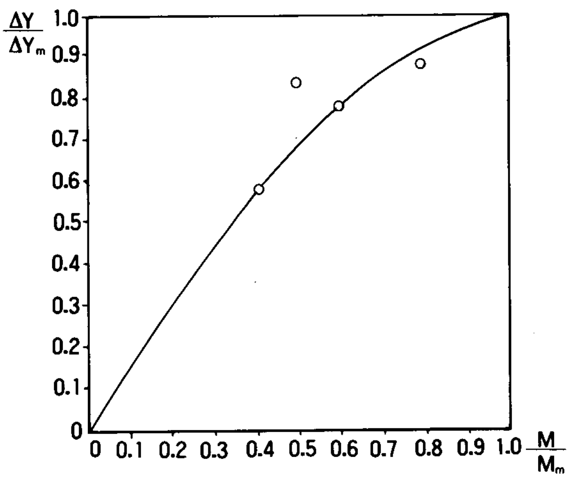
1974, 1975 ; Follet and al., 1978 ; English and Nakamura, 1982 ; Fapohunda and al., 1984). Moreover, the relation between ET at which maximum yield was obtained and ET in water deficiency, is a value varying in relatively narrow limits irrespective of type of crops and annual conditions. Water deficit formed by decrease of the irrigation rate in a wide range (from 0.0 to 60% of the optimum) would decrease ET in a narrow range (from 100 to 75~80% of the maximum). To obtain any yield without irrigation, it will be necessary to have at least 50% of the ET which will ensure a maximum yield. If the value is below 50% of the ET then the yield will be insignificant or there will be no yield at all. Consequently, in the case of these crops a significant part of the water used is necessary to the crops in order to reach the reproductive phase. If this quantity of water is not provided, there will be no yield. Downey (1972) reached the same conclusion after analyzing experimental data from various crops.

In the reverse case, when ET is increased from 50 to 70% of ET, ensuring maximum yield, for example, in maize, an yield of about 60% of the maximum will be obtained. However, the actual yield was from 30 to 60% of the maximum for the different years.

Should ET be increased at 80% of this ensuring maximum yield, the probable yield would be about 80% of the maximum. However, the actual was in the range from 40 to 95%. The presence of this range of yield fluctuation when using the same quantity of water can be only explained with different response of plants to soil moisture deficiency throughout the phases of growth.

The relation between irrigation rate and actual yield is of great importance in irrigation farming, too, as almost all crops grown in Bulgaria give certain yield without any irrigation, i.e. irrigation rate can create additional yield. Moreover, only this part of the balance equation for determination of ET is related to material costs.

In 〈Fig. 2〉 is shown the relation between irrigation rate-additional yield for grain maize in the region of Stara Zagora. And



〈Fig. 2〉 Additional yield-irrigation rate relation for grain maize in the region of Stara Zagora again this is a curved line relation. Yield decrease is not adequate to the decrease in the irrigation rate, i.e. it is not consistent with the value of the created water deficiency. The less the irrigation rate decrease, the narrower the range of fluctuation throughout years with differently present meteorologic factors, and vice versa.

Decrease in yield due to water deficiency is depending mostly on quantity and distribution of precipitation.

Many formulae for expression of the water -yield relation can be found in literature. Selection for practical purposes will depend most often on available experimental data. Therefore, we have chosen a FAO formula (1979) for the yield-evapotranspiration relation to calculate the yield in the presence of water deficiency, although this is a straight line relation according to it :

$$1-\frac{Y_o}{Y_m}=K_y(1-\frac{ET_o}{ET_m})$$

where

Y_o : yield in water deficiency

Y_m : maximum yield

ET_o : evapotranspiration at which Y_o is obtained

ET_m : maximum evapotranspiration

K_y : yield factor

The available data makes calculation of K_y possible, while a formulae including an exponent and expressing a curved line relation will require data not obtained in Bulgaria until now.

In ⟨Table 1⟩ are shown the values of K_y for maize, sugar beet, lucerne and vine. When compared no significant differences are found, however, crop requirements of water can be seen.

In all cases the values of K_y for Bulgaria are lower compared to these of FAO.

⟨Table 1⟩ Values of K_y factor

	Crops	Experimental FAO	data from Bulgaria
1	Maize	1.25	0.72
2	Suger beet	0.7~1.1	0.62
3	Lucerne	0.7~0.1	0.68
4	Vine	0.85	0.72

We used Davidov's formula (1982) to calculate the additional yield resulting from irrigation in constant water deficiency, i.e. at decrease of irrigation rates :

$$\Delta Y=\Delta Y_m[1-(1-\frac{M}{M_m})^{2n}]$$

where

ΔY : additional yield at decreased irrigation rate

ΔY_m : maximum additional yield at maximum irrigation rate, M_m

M : decreased irrigation rate

n : parameter depending on the crop

The values of n factor for each crop and region from where experimental data were obtained were calculated with the kind assistance of the author of the formula. For example, the average value of factor for maize in the conutry is about 0.90 ; sugar beet-0.50 ; lucerne-0.70 ; vine-0.50.

Yields calculated by the formulae and yields obtained experimentally were very close which shows that both relations found by us, and these mathematical models are applicable.

The following more important conclusions can be made form results obtained and their practical application :

1. The relation between the maximum

ET under which maximum yields are obtained and ET in water deficit, is a value that changes in narrow limits irrespective of the type of crop and meteorological profile of the year.

2. To obtain a maximum yield from any crop it will be necessary to use a certain quantity of water-no less than 50% of the quantity required for a maximum yield.

3. Plants will respond differently to soil moisture deficit throughout the phases of their growth which accounts for the wide range of yield fluctuations when using the same quantity of water.

4. The relation between yield and evapo t-ranspiration, and between additional yield and irrigation rate under the conditio ns of the experiments is of the curved line type.

5. The yield-evapotranspiration and additional yield-irrigation rate relations found by us can be used in the design and operation of irrigation systems and solving of optimizatio n tasks in irrigation waterdeficit.

6. The FAO formula for the yield-evapotranspiration relation and Davidov's formula for the additional yield-irrigation rate relation are equally applicable and have enough accuracy.

7. The additional yield-irrigation rate relation is more suitable for Bulgaria as more experimental data from different regions are available for it.

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