华南农业大学学报　20(2)　1999:101～105
J. South China Agric. Univ.

Water Balance of Bioclimatic Method as a Functional Approach

——Crop Water Requirement Determination in Vojvodina Province, Yugoslavia

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Abstract To overcome the difficulty in determination of ETP, an easy, simple, reliable and practicable Bioclimatic approach was adopted. Based on local information (soil, climate and crop parameters) hydrophytothermic coefficients for maize were established and average value for growing season was found to be 0.15 mm/℃. Its application was found successful in Vojvodina Province. This method can be used in any region by establishing the hydrophytothermic coefficients for that region as the scope of its application is limited only to that specific region for which hydrophytothermic coefficients are established. Timing of irrigation to mitigate the occurrence of drought can also be determined by this method. The seasonal ETP for maize was 467 mm.

Key words crop water requirement (ETP); bioclimatic method; hydrophytothermic coefficient, maize; drought

The rapidly increasing population of the world increases food demand, but the challenge of the increasing food demand can be met by augmenting food production. Increase in food production cannot be achieved without providing optimal production conditions to crops. Availability of suitable moisture content in the soil during the whole growing season can provide higher production potential. The old traditional method of irrigation has been replaced by Scientific Irrigation System (SIS). This system is based on the knowlkedge, when to irrigate? how to irrigate? and how much to irrigate? SIS can make judicious use of limited and depleting water resources.

Several approaches have been developed to provide the basis for SIS e.g. crop water requirement (ET_{crop}), readily available moisture in the root zone, sprinkler and drip irrigation etc.. Crop water requirement and potential evapotranspiration (ETP) are the same and interchangeable terms in this study. ET_{crop} is the basis for all calculation in land reclamation operations i.e. irrigation and drainage and serve as an indispensable element of water balance, while determining the deficit or excess of precipitation during the vegetation period.

Under natural conditions, plants may use water available in the soil from pre-vegetative soil reserves, rainfall in vegetation period, underground water, etc., all depending upon the environmental, crop, aquifer and soil conditions. This means that the plants do not always satisfy their water requirements, due to limited water amounts. The total water amount, used for transpiration and evaporation indicates a real value of evapotranspiration (ETR).

Recieved　1999-01-18

If plants are provided with optimal water supply, they would exspend a maximal amount to satisfy their needs for achieving maximum yield. Crop water requirement is defined as "The depth of water needed to meet the water loss through evapotranspiration (ET_{crop}) of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility, and achieving full production potential under the given growing environment.

Actual ET_{crop} can be obtained through experiments. Direct measurements of the Potential evapotranspiration is not easy task, requiring specific equipment and installation. Some of these methods use only rainfall, others both the rainfall and irrigation or rainfall and underground water. The most famous methods are investigation using lysimeter and evaporimeter, field experiments, soil moisture investigations etc.. These prediction methods for crop water requirement are not commonly used owing to the difficulty of obtaining accurate field measurements. The very fact that there are many models for ETO calculation indicates that there is no universal model or method whether it is an empirical model or a model resulting from direct ETO investigation. ETO calculation for a particular region, involving the use of different models, results in different and diverging values (Vucic, 1986). All the methods have a local or regional character (Rehman, 1998). These models further require corrective coefficients for specific crops, which frequently brings various disagreements and errors in ET_{crop} calculation.

To overcome the difficulty of ET_{crop} determination, a simple, reliable and applicable approach based on bioclimatic method is introduced.

1 MATERIAL AND METHODS

Bioclimatic method is based upon the use of correlation between the evapotranspiration extent on one hand, and physical factors of evaporation and biological features on the other. Bioclimatic coefficients are obtained by dividing the total consumed water for an investigation period with the sum of any meteorological element e.g. the sum of temperature, the radiation etc.. It should be noted that the soil moisture during the investigation period, should be within the optimal range. It also means that the total amount of consumed water equals or approximates, in this case, the values of Potential evapotranspiration.

The bioclimatic method was established by Vucic (1971) for conditions in Vojvodina Province, a Province geographically located between 44° 38′ and 46° 10′ northern latitude and 18° 0′ and 21 ° 15′ eastern longitude and at an altitude of 66 ~ 88 m above mean sea level. Vojvodina Province covers the northern part of Serbia, North of the Sava and the Danube Rivers, representing the notheastern part of Yugoslavia.

If mean air temperature is used as the base for calculating ETP, the bioclimatic coefficient is called hydrophytothermic coefficient. The air temperature is suitable because of two reasons i.e. evapotranspiration represents a thermal process and its extent depends upon the amount of energy available, in this case, expressed as a sum of mean air temperature; secondly, the air temperature is not liable to great changes within a region. Due to this reason, the data of the nearest meteorological station can be used and there is no need to perform measurements on every irrigated field. Such a hydrophytothermic coefficient, determined for maize in Vojvodina Province to be 0.15 mm/℃, implies that for every degree of daily mean air temperature (℃) about 0.15 mm (1.5 m^3/hm^2) of water per hectare is consumed in evapotranspiration. Hydrophytothermic coefficients for the main agriculture crops in the Vojvodina Province were determined, being for maize 0.15 mm/℃, soybean 0.16 ~ 0.17 mm/℃, sugar beet 0.18 mm/℃, sunflower 0.16 mm/℃, alfalfa 0.20 mm/℃, hop 0.18 mm/℃ and potato 0.19 mm/℃ (Bosnjak, 1992).

Values of hydrophytothermic coefficients are not same during the vegetative season. They are less at the beginning and at the end of the vegetative season, but they are much higher during the fully grown crop stage. They are in correlation with plant growth stage and weather conditions which are variable and influence the use of water in evapotranspiration.

$$R_c = h \times t,$$

R_c = crop water requirement (mm) for investigation period(ET_{crop}),

h = hydrophytothermic coefficient (mm/℃),

t = mean air temperature (℃) for investigation period.

This model can be used not only for ET_{crop} determination, but also for determining the time of irrigation. Daily calculation of ETP and calculation of the state of readily available water in a depth of active risosphere (active rooting depth) are needed. Rainfall must be taken into consideration. When there is minimum readily available water in the active risosphere this is the time for irrigation. The same calculation is needed during whole period of irrigation.

$$R_{cd} = h \times t_d$$

R_{cd} = daily crop water requirement, DET_{crop}(mm),

h = hydrophytothermic coefficient (mm/℃),

t_d = mean daily air temperature (℃).

It can also be used to analyze drought, its duration and intensity i.e. to analyze agriculture production in conditions without irrigation. In that case water balance must be made for each crop separately, usually on monthly basis (Vucic et al, 1989).

$$R_{cm} = h \times t_m \times d,$$

R_{cm} = monthly crop water requirement, MET_{crop}(mm),

h = monthly hydrophytothermic coefficient (mm/℃),

t_m = monthly mean air temperature (℃),

d_m = number of days in the month.

Drought here is defined as shortage of readily available water when plants cannot satisfy their need on the level of potential evapotranspiration. Drought analysis can be conducted by using rainfall data of a local meteorological station.

The model described above was applied for ETP determination for maize. Maize is the main cereal crop in Vojvodina Province and covers an area of 653 000 hm^2 of arable land (42%) (Starcevic et al, 1991). The monthly hydrophytothermic values were established for the whole growing season. The rainfall occurrence data of the meteorological station located in the experimental field was used to analyze occurrence of drought periods and timing of irrigation.

2 RESULTS AND DISCUSSION

Monthly values of hydrophytothermic coefficient for maize were established and are presented in Table 1. The other values like ETP, monthly rainfall, monthly air temperature, occurrence of drought and its intensity, irrigation requirement are also presented in this table.

Table 1 Water balance for Maize at Rimski Sancevi experimental field (1993)

Parameter[1)]	Month					Growing season
	May	June	July	August	September	
$h/(mm \cdot ℃^{-1})$	0.11	0.18	0.18	0.18	0.11	0.15
t/℃	19.1	19.9	21.5	22.0	15.8	19.7
E_p/mm	65.0	107.0	120.0	123.0	52.0	467
P/mm	39.0	64.0	37.0	36.0	37.0	213
Δ	-26.0	-34.0	0	0	0	-
r/mm	60.0	34.0	0	0	0	-
E_{rp}/mm	65.0	98.0	37.0	36.0	37.0	273
deficit	0	9.0	83.0	87.0	15.0	194.0
suficit	0	0	0	0	0	0

1) h = hydrophytothermic coefficient (mm/℃), t = mean monthly air temperature (℃), E_p = potential evapotranspiration, ETP(mm), P = monthly rainfall (mm), Δ = ± difference in rainfall (P) and E_P, represents deficit or suficit after consuming or filling the reserve of readily available water (mm), r = reserve of readily available water in active risosphere (mm), E_{rp} = real potential evapotranspiration, ETR (mm)

Results indicated that the monthly average value of air temperature varied from 15.8 to 22 ℃ and that it directly efffected ETP value. It was also evident that ETP value at the beginning and at the end of growing season was less as compared to the value when the crop was at the fully grown stage. The first reason attributable to this variation was the variation in temperature and the second to the fact that the crop at fully grown stage required more water to satisfy its ETP for vegetative as well as reproductive needs. ETP in the month of September was lowest (52 mm) and in August was highest (123 mm). Seasonal ETP was 467 mm. ETR varied from 36 mm during August to 98 mm during June, accumulating to 273 mm for the whole growing season. Rainfall directly influenced ETR. The highest rainfall occurred in June (64 mm) and in other months of the growing period was about 37 mm. The deficit computed by water balance started in June at 9 mm, continued up to the end of growing season and was severe during July (83 mm) and August (87 mm). Deficit in September was 15 mm. Seasonal deficit was 194 mm, the average yield during the investigation period in Vojvodina Province was 3.7 t/hm^2 being less than the average yield during the last 30 years (5.12 t/hm^2). The reduction in yield is associated with moisture deficit.

3 CONCLUSIONS

Hydrophytothermic coefficients can provide reliable results for ETP determination. It can also be used to determine the time for irrigation, water deficit and to analyze drought duration and intensity. Drought severely reduced the yield of maize. Seasonal ETP of maize in Vojvojdina Province was 467 mm. Because of the simplicity of its application and satisfactory accuracy of ETP estimates it can be used in irrigation practices. It is concluded from the analysis of drought that deficit in readily avaiiable water started in June and continued throughout the whole vegetation period. To get optimum yield irrigation is inevitable during this period. It was also concluded that the irrigation requirement was 194 mm.

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生物气候方法水分平衡函数式的应用
——南斯拉夫伏霍基拉省作物需水量的确定

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摘要　为了克服确定作物需水量所遇到的困难,该文介绍一种简单、可靠、易掌握、实用的生物气候测定方法.该方法根据被测地的土壤、气候和作物参数,得到玉米在生长季节的光水热系数平均值为 0.15 mm/℃.该方法应用于南斯拉夫伏霍基拉省取得成功.由于光水热系数是由各地的特殊条件确定的,只要确定了该系数,该方法可在任何地方应用.灌溉时间和灌溉强度以及干旱的发生都可由该方法确定.玉米生长期的需水量为 467 mm.

关键词　作物需水量;生物气候方法;水光热系数;玉米;干旱

中图分类号　S 158.4

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