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EVALUATION OF THE APPLICABILITY OF SOME CLIMATIC INDICES OF POTENTIAL EVAPOTRANSPIRATION IN THE DETERMINATION OF ACTUAL EVAPDTRANSPIRATION OF MEADOWS IN THE LOWER VISTULA VALLEY

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S y n o p s i s. The author makes a statistical analysis of values of actual evapotranspiration of meadows determined by means of the ETr = k • ETp formula. The seasonal index k is calculated on the basis of 10 years' lysimetric experiments, as a mean value for the multi-year period. The potential evapotranspiration index, ET_p, is determined according to six methods on the basis of climatic data measured at the meadow site studeied. The ratio of the mean error of ETr calculated to the mean deviation of the values measured is adopted as the measure of applicability of the climatic indices. It is found that in April and May none of the ETp indices yields satisfactory results; in June, July, and August it is Penman's formula that is the most applicable, and in September - Bac's formula.

INTRODUCTION

Among the many methods for the determination of actual evapotranspiration of plants, the method based on seasonal plant indices is the easiest in practical application. It permits the actual evapotranspiration to be calculated on the basis of the formula

$$ETr = k \cdot ETp \qquad (1)$$

where:

ETr - actual evapotranspiration in millimeters,

ETp - index of potential evapotranspiration in millimeters,

k - seasonal index related to the phenological phase of the plant at good soil moisture conditions.

The k index is most frequently calculated for a given decade on the basis of multi-year experiments as a mean value of the ratio of actual evapotranspiration to the index of potential evapotranspiration. The value of actual evapotranspiration calculated in the above manner carries a certain error, the value of which depends primarily on the climatic index of potential evapotranspiration used, and on its variability.

The objective of the study was to select the best index of potential evapotranspiration, that is an index that would permit for the actual evapotranspiration to be calculated with the least possible error. The problem was approached by evaluating the accuracy of calculations of actual evapotranspiration using statistical methods.

METHOD

Material for calculations was constituted by results of lysimetric measurements of the actual evapotranspiration of a highly productive 3-crop irrigated meadow (average hay yield of 15 tons per hectare) during a period of 6 months (April through September), and results of meteorological measurements taken at the lysimetric station at Grabów in the lower Vistula Valley during the period of 1971-1980.

Actual evapotranspiration was measured in lysimeters every decade. Calculations of actual evapotranspiration were carried out using decade values of k indices and potential evapotranspiration indices determined on the basis of meteorological measurements according to the formulae:

- Penman formula in French modification I,
- Penman formula in FAO modification,
- Matul formula,
- Turc formula,
- Bac formula for index evaporation,
- evaporation from water surface measured by means of an evaporometer of a surface area of 0.2 m^2, placed in the soil so that its upper rim was at the level of the topsoil surface.

The value of the k index for a given decade was calculated as a multi-year mean value of the ratio of a measured decade sum of actual evapotranspiration to a decade sum of a corresponding index of potential evapotranspiration:

$$k = \frac{\sum_{i=1}^{N} \frac{ETri}{ETpi}}{N} \qquad (2)$$

Evaluation of the accuracy of the actual evapotranspiration assessment according to formula (1) on the basis of the various indices of potential evapotranspiration was carried out by comparing the values of errors calculated as a mean value of the mean error of assessment, in the form:

$$EV = s_{ow}\sqrt{\frac{N+2}{N-2}} \tag{3}$$

where

$$s_{ow} = s_o\sqrt{1-r^2} = \sqrt{\frac{\sum_{i=1}^{N}(ETri - k \cdot ETpi)^2}{N}} \tag{4}$$

In the above formulae the following symbols were used:

N - number of years of observations,

ETr - evapotranspiration measured, in mm $\cdot$ decade^{-1},

ETp - potential evapotranspiration, in mm $\cdot$ decade^{-1},

s_{ow} - mean conditional deviation of ETr values calculated,

s_o - mean square deviation of ETr values measured,

r - coefficient of correlation between ETr and ETp.

Formula (3), after Kaczmarek [1], characterizes the effectiveness (accuracy) of actual evapotranspiration calculations based on the ETr = k $\cdot$ ETp formula. Error EV is a measure of the difference between the measured and calculated values of actual evapotranspiration, calculated on the basis of a series of measurements and increased by a value that includes the effect of other factors, left out of formula (1), as well as errors of the k index calculation, measurement errors, etc.

RESULTS

The first stage of the study consisted in the calculation of the mean decade k indices for the vegetation period (April through September) with relation to the various indices of potential evapotranspiration. Then the actual evapotranspiration was calculated according to formula (1). Errors of ETr assessment were calculated according to formula (3) for monthly periods, grass crops, and the whole vegetation season, as a result of summing up of the decade values of ETr. The shortest calculation period was one month due to the considerable variability of ETr sums in the decade periods, and the high values of errors determined, which resulted primarily from the relatively low power of the set of values measured (10 years).

Values of errors presented in Table 1 permit the evaluation of which of the ETp indices provides a better assessment of the actual evapotranspiration. For April, May, July, and the periods of the first and second grass crops and the vegetation season the Penman formula I is the best. In June, the least error of ETr assessment can be obtained using the Penman - FAO formula, this error being

Table 1

Errors of meadow actual evapotranspiration calculations according to the ETr = k • ETp formula, in millimetres

Period	Index of potential evapotranspiration					
	Penman I	FAO	Matul	Turc	Bac	Water evaporation
April	10.0	12.0	11.4	14.8	15.1	16.0
May	41.9	43.5	45.1	52.1	50.9	54.7
June	28.8	27.9	34.4	29.2	35.0	53.8
July	29.3	32.7	42.4	30.7	54.8	62.3
August	33.4	32.2	46.3	32.9	34.4	70.9
September	32.5	31.0	39.1	29.9	27.1	57.5
Grass crop I	46.3	49.1	46.9	60.7	58.2	57.4
Grass crop II	39.2	43.7	63.5	39.8	76.9	78.1
Grass crop III	60.7	58.3	78.4	57.4	58.7	105.8
Vegetation season	90.2	94.2	129.5	98.6	145.0	155.7

slightly lower than that obtained by means of the Penman I formula. In August the lowest value of error was obtained using the Penman - FAO formula, in September - the Bac formula, and for the period of the third grass crop - the Turc formula. For all the periods, the evaporation of water from an evaporometer turned out to be the least accurate index.

As can be seen from the results presented, it is difficult to single out one potential evapotranspiration formula that would be the most applicable for ETr calculations during the whole vegetation season. During the first four months of the vegetation season the Penman I formula is the best, while during August and September the Turc or Bac formulae.

The Penman-Fao formula, though it does provide the smallest error values in some months, is less applicable due to the lack of systematic measurements of certain meteorological elements, like for instance wind velocity during the night period.

The above comparison of errors points out to the formula whose error level is the lowest. There remains the question whether the assessment of actual evapotranspiration with that error level is sufficient. To provide an answer to the question it is necessary to carry out an absolute evaluation of the effectiveness of the ETp indices. This can be done by comparing the mean error EV with the mean deviation s_o of the measured values of ETr. The mean deviation s_o illustrates the natural variability of actual evapotranspiration. The measured values of ETr should be characterized by errors lower than the values of s_o. Otherwise they are of doubt-full usefulness. In such a case one would err less by adopting an ETr value equal to a multi-year mean value. The ETp index should be selected in such a way that formula (1) relates more than 50% of the total variability of ETr with values of ETp, i.e. $r^2 > 0.5$. This is a minimum conditions that should be met. A formula for which $r^2 > 0.8$ would be very good.

The ratio of the EV error to the mean deviation s_0 was adopted as means of an objective evaluation of the effectiveness of a given ETp index. Using formulae (3) and (4),we obtain the upper permissible limit of the ratio:

for $r^2 > 0.5$:

$$EV/s_0 < 0.87 \tag{5}$$

for $r^2 > 0.8$:

$$EV/s_0 < 0.55 \tag{6}$$

Table 2

Values of the EV/s_0 ratio

Period	Index of potential evapotranspiration					
	Penman I	FAO	Matul	Turc	Bac	Water evaporation
April	1.72	2.10	1.97	2.55	2.60	2.76
May	1.19	1.24	1.28	1.48	1.45	1.55
June	0.92	0.89	1.10	0.94	1.12	1.72
July	0.70	0.78	1.01	0.73	1.30	1.48
August	0.82	0.79	1.14	0.81	0.85	1.75
September	0.90	0.85	1.08	0.82	0.75	1.58
Grass crop I	1.30	1.38	1.31	1.70	1.63	1.61
Grass crop II	0.73	0.81	1.17	0.74	1.42	1.44
Grass crop III	0.87	0.83	1.12	0.82	0.84	1.51
Vegetation season	0.71	0.74	1.02	0.78	1.14	1.23

EV - mean error of ETr calculation,
s_0 - mean square deviation of measured ETr.

When the value of the ratio of EV to s_0 is greater than 1, the formula (1) is not applicable, and one will err less adopting the mean multi-year values of ETr.

The determination of the upper limit of the EV/s_0 ratio will permit the rejection of those ETp indices that result in ETr assessments with an excessive error. It can be seen from Table 2, specifying the values of the EV/s_0 ratio, that none of the ETp indices meets condition (6), that means none can be classified as a very good formula. For April and May, and the regrowth period following the first grass crop, the value of EV/s_0 is above 1. which results from the low correlation between ETr and the ETp indices. During these periods the mean multi-year value of ETr should be adopted. In June none of the indices meets condition (5), and the Penman-FAO formula turned out to be most effective. In the second half of the vegetation season some of the ETp indices describe the variability of actual evapotranspiration sufficiently well (meet condition (5)). In July the most effective is the Penman I formula, in August - the Penman- FAO formula, and, in second place, the Turc or Panman I formulae, and in September - the Bac formula. The lowest value of the EV/s_0 ratio during the regrowth period following the second grass crop, and during the vegetation season as a whole, is yielded by the Penman I formula, and during the regrowth period following the third grass crop - the Turc formula.

CONCLUSIONS

1. Values of actual evapotranspiration calculated using the ETr = k·ETp formula carry an error the value of which depends on the climatic index of potential evapotranspiration used.

2. It is not possible to single out one potential evapotranspiration formula that would minimize the error of actual evapotranspiration assessment in all the calculation periods.

3. For the lower Vistula Valley, to evaluate the actual evapotranspiration of meadows during April, May, and the first grass crop it is best to use the mean multi-year values obtained from lysimetric experiments. In June, July, August, the regrowth period following the second grass crop, and for the vegetation season as a whole, the Penman formula in the French modification turned out to be the most effective. In September the Bac formula is decidedly the most effective, and during the regrowth period following the third grass crop - the Turc formula or the Bac formula, though the latter yields somewhat worse results.

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L. Łabędzki

OCENA PRZYDATNOŚCI WSKAŹNIKÓW KLIMATYCZNYCH EWAPOTRANSPIRACJI POTENCJALNEJ DO OKREŚLANIA EWAPOTRANSPIRACJI RZECZYWISTEJ ŁĄK W DOLINIE DOLNEJ WISŁY

S t r e s z c z e n i e

W pracy przeprowadzono analizę statystyczną wyników określenia ewapotranspiracji rzeczywistej łąk według wzoru ETr = k · ETp. Współczynnik roślinny k wyznaczony był na podstawie 10-letnich badań lizymetrycznych jako wartość średnia z wielolecia. Wskaźnik ewapotranspiracji potencjalnej ETp był określony sześcioma metodami na podstawie danych klimatycznych zmierzonych w badanym siedlisku łąkowym. Jako miarę przydatności wskaźników klimatycznych zastosowano stosunek średniego błędu obliczenia ETr do średniego odchylenia wartości pomierzonych. Stwierdzono, że w kwietniu i maju żaden wskaźnik ETp nie daje zadowalających wyników, w czerwcu, lipcu i sierpniu najbardziej przydatny jest wzór Penmana, natomiast we wrześniu wzór Baca.

Л. Лабендски

ОЦЕНКА ПРИГОДНОСТИ КЛИМАТИЧЕСКИХ ПОКАЗАТЕЛЕЙ ПОТЕНЦИАЛЬНОЙ ЭВАПОТРАНСПИРАЦИИ К ОПРЕДЕЛЕНИЮ ДЕЙСТВИТЕЛЬНОЙ ЭВАПОТРАНСПИРАЦИИ В ДОЛИНЕ НИЖНЕЙ ВИСЛЫ

Р е з ю м е

В работе проведен статистический анализ результатов определения действительной эвапотранспирации лугов по формуле ETr = K·ETp. Растительный коэффициент к определено на основе 10-летних лизиметрических исследований как среднюю величину многолетия. Показатель потенциальной эвапотранспирации ETp определено 6 методами на основе климатических данных, измеренных в исследуемом луговом биотопе. В качестве меры пригодности климатических показателей применено отношение средней ошибки подсчета ETr к среднему отклонению измеренных величин. Отмечено, что в апреле и мае ни один показатель ETp не дает удовлетворяющих результатов, в июне, июле и августе наиболее пригодна формула Пенмана, в сентябре же - формула Баца.