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Parameters of the Evapotranspiration-Yield Relationship in a Grass Mixture of English Ryegrass and Red Fescue

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ABSTRACT

The study aims to establish the parameters of the relationship "Cumulative Evapotranspiration (ET) - yield from aboveground biomass" in a grass mixture of English ryegrass (*Lolium perenne* L.) and Red fescue (*Festuca rubra* L.). The results are necessary for the needs of landscaping in urbanized areas. Data from an experiment with the application of a regulated water deficit, carried out in the period 2009-2011 at the University of Forestry - Sofia on anthropogenic bulk soil, were used. Data on relative ET and relative yield were processed by the method of least squares, using three types of formulas - linear (FAO), power, and two-power. The most accurate is the two-power formula, which describes the dependence through an S-shaped curve at (raport of correlation) R=0.989. It has the following form: $Y=[1-(1-x)^{1.74}]^{5.29}$, where Y is the relative yield at the corresponding ET, which is denoted by *x*. High accuracy also shows the power formula, which has the following form: $Y=1-2.23(1-x)^{1.28}$ and R=0.976. The FAO linear formula represents the relationship at R=0.805. It has the following form: Y=1–1.62(1–x).

Keywords: grass mixtures, irrigation regime, water stress, evapotranspiration, yield, water-yield relationship.

INTRODUCTION

Evapotranspiration (ET) is the only expenditure component in the water balance of all cultivated plants, but at the same time, it is specific to different crops. It is influenced by many factors - mainly physiological and climatic, and also by the level of agricultural technology. When the water in the soil is sufficient in quantity, transpiration reaches intensity close to the maximum for the relevant conditions, keeping the plant temperature within optimal limits. This is decisive for the normal course of processes in the plant organism, and from there for the quantity and quality of the harvest. In crops that go through the entire vegetation cycle, the intensity of ET depends to a large extent on the water requirements of the plants during the different phenophases. This makes it possible to create optimization models describing the relationship between ET and yield, according to these requirements. In per-cutting crops, the plants do not reach their reproductive period, because the accumulated above-ground biomass is periodically removed. In these crops, ET depends on the climatic conditions and the development of the leaf mass, and not on the specificity of the phenophases, i.e. it can vary widely during the growing season. For example, the alfalfa seasonal evapotranspiration (ETc) was estimated between 800 and 1600 mm depending on climate and length of growing period (Montazar and Putman, 2023). Concerning climate is very important to take in consideration the intensification of the water stress in many area of the world (Petcu et al., 2019). Which makes it necessary to search for the exact parameters of the "Yield-ET" relationship, corresponding to the specificity of each type of crops. In the specialized scientific literature, this relationship is insufficiently studied, and mainly regression equations valid for alfalfa are presented. According to the results published by Guitjens (1982), the yield is proportional to the ET, and this applies both to the whole vegetation and to the individual swaths.

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Hanson and Putnam (2000) found that the relationship between the absolute values of these two components is linear, specifying that it had different parameters depending on the growing conditions. The authors do not recommend reducing irrigation rates and limiting ET during the formation of the first swath. This can be applied during the second half of the growing season. Grimes et al. (1992) reported a total yield of up to 1 t/da, its relationship with ET being linear and expressed by a regression equation at r^2=0.82. Lindenmayer et al. (2011) confirmed the linear type of the "Yield-ET" relationship, according to which, under conditions of water deficit, relative ET decreases up to 30% faster than relative yield. Currently, there is an increase in the area occupied by grass mixtures, especially in urbanized areas, and also for fodder production. Knowing the relationship parameters between ET and the amount of above-ground biomass formed in conditions of irrigation water shortage would help to optimize irrigation in conditions of limited water resources, without significantly affecting the amount of biomass and the quality of grasslands in the urbanized territories.

The work aims to establish the parameters of the relationship "Cumulative evapotranspiration - above-ground biomass" in a grass mixture of English ryegrass and Red fescue, for landscaping in populated areas. With some updating, the results of the study can also be used in forage production of irrigated areas to predict yields in conditions of limited water resources.

MATERIAL AND METHODS

The relationship between the cumulative ET and the total above-ground biomass was established using data from an experiment conducted in the period 2009-2011 at the Forestry University - Sofia on anthropogenic bulk soil. A grass mixture of Red fescue (*Festuca rubra* L.) and English (pasture) ryegrass (*Lolium perenne* L.) was used. The variants of the experiment were:

1) Irrigation at pre-irrigation soil moisture of 80% FC (field capacity) for the layer 0-30 cm;
2) Irrigation with a 40% reduction in irrigation rates;
3) Irrigation with a 60% reduction in irrigation rates;
4) No irrigation.

All variants of the experiment were laid out in three replicates by the method of long plots. The dynamic of soil moisture was monitored using the weight method at a depth of up to 60 cm, layer by layer through 10 cm in all variants of the experiment. ET was calculated according to the balance method based on the data on the dynamics of soil moisture, the used precipitation, and irrigation rates. Irrigation was carried out by sprinkling, using a stationary "Hunter" sprinkler system. The amount of irrigation rates for the optimal variant 1 is calculated according to the formula:

$$m=10H\alpha[\delta^{FC}- \delta^{min}] \text{ (mm)}$$

where:

m - is the irrigation rate, *H* - active soil layer, *α* - volume density of the soil, δ^{FC} soil moisture at FC (field capacity), δ^{min} soil moisture before irrigation application.

The parameters of the relationship "Seasonal ET - aboveground biomass" were established by the method of least squares, through a specialized computer program "YIELD" (Davidov, 1994a), using the data for relative yield (dry biomass) and relative total evapotranspiration by variants and years. Existing formulas for the purpose are applied as follows: FAO formula - linear relationship between yield and evapotranspiration (Doorenbos and Kassam, 1979)

$$Y=1-K_c(1-x)$$

where:

Y - is the relative yield (dry above-ground biomass), x - its corresponding relative ET, Kc - the yield coefficient.

Power formula (Kalaidzhieva, 2014)

$$Y=1-a(1-x)^n$$

where:

a - is the yield coefficient; n - the power indicator.

Two-power formula (Davidov 1994b, 1998, 2001)

$$Y=[1-(1-x)^N]^M$$

where:

N - power indicator for the all vegetation period; M - a culture-specific power indicator.

RESULTS AND DISCUSSION

The output data for determining the parameters of the relationship between the cumulative ET and the yield of dry biomass according to the three formulas are presented in Table 1.

Table 1. Output data for determination of the "Yield - ET" relationship

Variant	Absolute		Relative		Absolute		Relative	
	ET (mm)	Yield kg.da^{-1}	ET	Yield	ET (mm)	Yield kg.da^{-1}	ET	Yield
1	2	3	4	5	2	3	4	5
2009					**2011**			
dry	299.7	89.4	0.533	0.186	299.1	100.1	0.522	0.188
40%m	429.7	283.2	0.764	0.588	392.5	268.0	0.685	0.505
60%m	470.0	415.1	0.836	0.862	444.7	376.5	0.776	0.709
100%m	562.5	481.5	1.000	1.000	573.1	531.1	1.000	1.000
2010					**The average for 2009-2011**			
dry	281.8	108.4	0.461	0.158	293.5	99.3	0.504	0.175
40%m	437.7	318.7	0.716	0.464	420.0	290.0	0.721	0.512
60%m	497.3	479.1	0.814	0.697	470.7	423.6	0.808	0.747
100%m	611.2	687.5	1.000	1.000	582.3	566.7	1.000	1.000
m - *maximum irrigation rate*								

Relationship "Yield - cumulative ET" according to the linear formula of FAO. Figure 1 shows the experimental points separately by year and in total for all three years, being averaged using the linear formula of FAO.

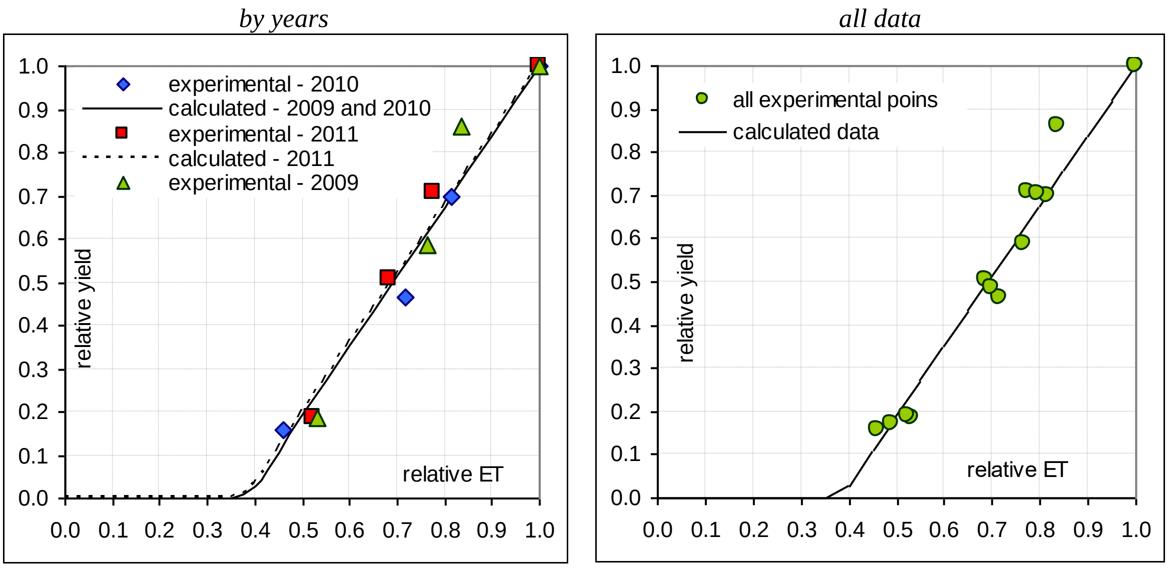

Figure 1. Linear relationship "Yield - cumulative ET"

For the conditions of the experiment, the relationship parameters according to this formula practically coincide, therefore the equation Y=1–1.62(1–x), which is valid in general for all experimental variants and years, can be considered representative at R=0.805. By the years, the correlation coefficient values are very high (R=0.97), but this is also due to a significant extent to the smaller number of experimental points. According to the proposed relationship, in order to obtain a minimum yield, at least 40% of the total ET must be provided at optimal irrigation, and at 70% of it, the yield is about 50% of the maximum.

The linear formula of FAO is confirmed, both by scientific circles and in practice, which is also proven in the present work. Figure 2 shows the experimental and calculated yields based on this formula, and Figure 3 shows the relationship between them at R=0.989. In both graphs, it is clear that the variation is relatively weak, and this is supported by the data from Table 2. More significant deviations are observed in the non-irrigated variant (from -19.6 to +31.1%), while in the irrigated variants the deviations rarely exceed 10%.

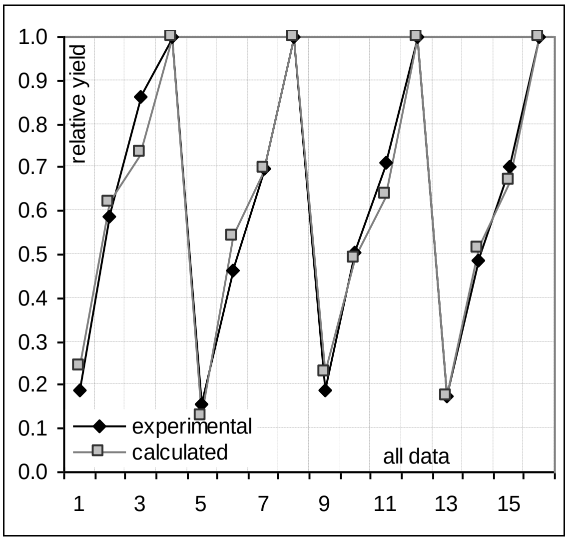

Figure 2. Experimental and calculated yield using linear FAO's formula

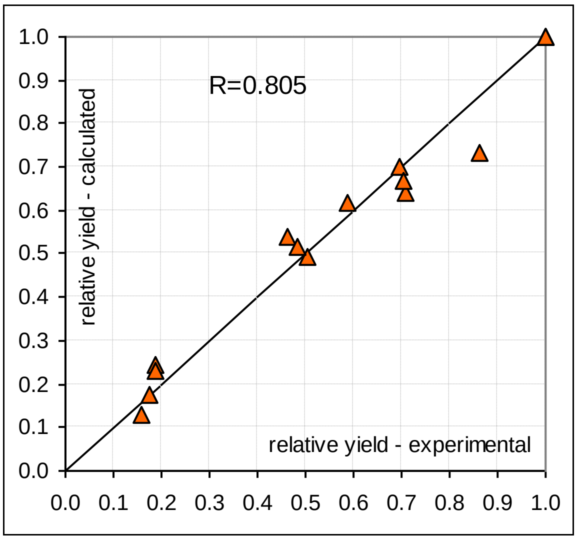

Figure 3. Relationship between experimental and calculated data

Table 2. Experimental and calculated yield by linear FAO's formula and differences between them

Experimental yield		Calculated yield		Differences		
Absolute	Relative	Absolute	Relative	±	%	±%
89.4	0.186	117.2	0.243	27.8	131.1	31.1
283.2	0.588	297.4	0.618	14.2	105.0	5.0
415.1	0.862	353.6	0.734	-61.5	85.2	-14.8
481.5	1.000	481.5	1.000	0.0	100.0	0.0
108.4	0.158	87.2	0.127	-21.2	80.4	-19.6
318.7	0.464	371.2	0.540	52.5	116.5	16.5
479.1	0.697	480.3	0.699	1.2	100.3	0.3
687.5	1.000	687.5	1.000	0.0	100.0	0.0
100.1	0.188	122.4	0.230	22.3	122.3	22.3
268.0	0.505	261.8	0.493	-6.2	97.7	-2.3
376.5	0.709	339.6	0.639	-36.9	90.2	-9.8
531.1	1.000	531.1	1.000	0.0	100.0	0.0

Power relationship "Yield - cumulative ET"

On the one hand, the power formula can be considered as an advanced version of the FAO formula, since with the same structure a variable power indicator has been introduced, which makes it possible to increase the accuracy. On the other hand, the FAO formula can be considered as a special case of the power formula by n=1.

Figure 4 shows the experimental points plotted separately and in total for the three experimental years and averaged according to the power formula. And here the parameters by years are very close. The coefficient **a** varies from 2.19 to 2.28, and the power indicator **n** - from 1.23 to 1.33. This gives reason to consider the equation: $Y=1–2.23(1–x)^{1.28}$, which is valid in general for all variants and years, as representative. It approximates the experimental points at a very high correlation coefficient (R=0.976), exceeding that obtained with the FAO's formula. For each of the experimental years, as well as averaged over the experimental period, the correlation coefficient values are also very high (R=0.97). According to the proposed relationship, in order to obtain a minimum yield, at least 45-50% of the optimal cumulative ET should be provided, and when providing 65-70% of it, the yield should amount to about 50% of the maximum. These values are within the limits of the real ones and correspond to the biological characteristics of the plant species included in the composition of this grass mixture.

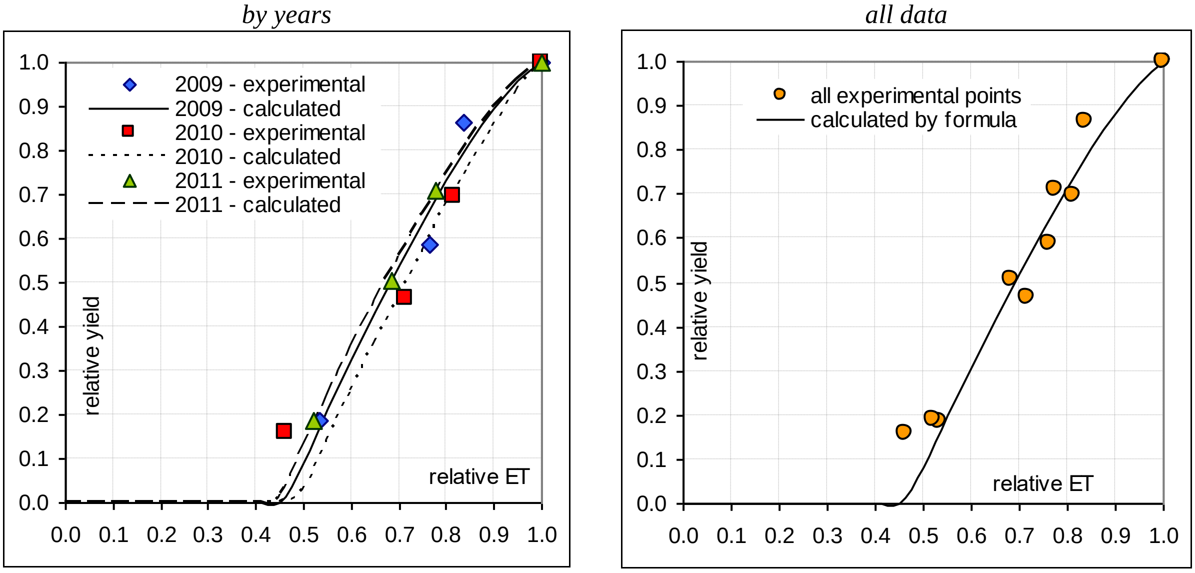

Figure 4. Power relationship “Yield - cumulative ET”

Table 3. Experimental and calculated yield by power formula and differences between them

Experimental yield		Calculated yield		Differences		
Absolute	Relative	Absolute	Absolute	Relative	Absolute	Absolute
89.4	0.186	82.7	0.172	-6.7	92.5	-7.5
283.2	0.588	320.6	0.666	37.4	113.2	13.2
415.1	0.862	382.4	0.794	-32.7	92.1	-7.9
481.5	1.000	481.5	1.000	0.0	100.0	0.0
108.4	0.158	0.0	0.000	-108.4	0.0	-100.0
318.7	0.464	345.0	0.502	26.3	108.3	8.3
479.1	0.697	479.7	0.698	0.6	100.1	0.1
687.5	1.000	687.5	1.000	0.0	100.0	0.0
100.1	0.188	95.3	0.179	-4.8	95.2	-4.8
268.0	0.505	280.9	0.529	12.9	104.8	4.8
376.5	0.709	372.1	0.701	-4.4	98.8	-1.2
531.1	1.000	531.1	1.000	0.0	100.0	0.0

Figure 5 shows the experimental and calculated yields based on this formula, and Figure 6 shows the relationship between them at R=0.985. In general, the deviations in the calculated yield compared to the experimental yield are relatively weak, and again in the dry variant the differences are more significant (Figure 5), but considering that irrigation is mandatory when growing this grass mixture, these discrepancies can be largely ignored. Table 3 shows the absolute and relative values of the experimental and calculated total yield for all options and years, as well as the difference between them. Compared to the linear formula, here in only two of the cases, the deviations exceed 10%, in half of them they are up to 5%.

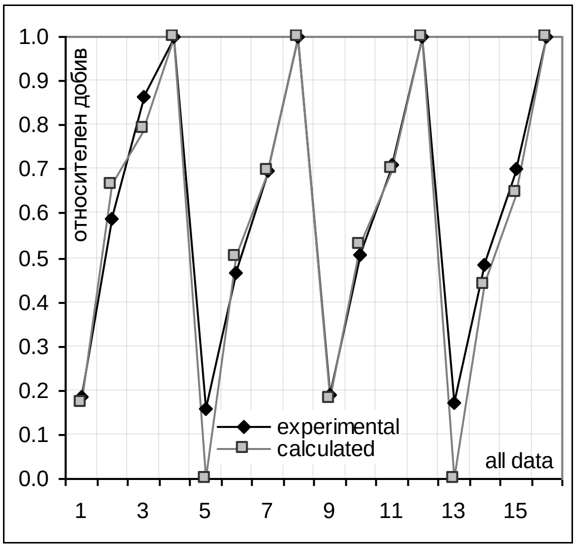

Figure 5. Experimental and calculated yield using power formula

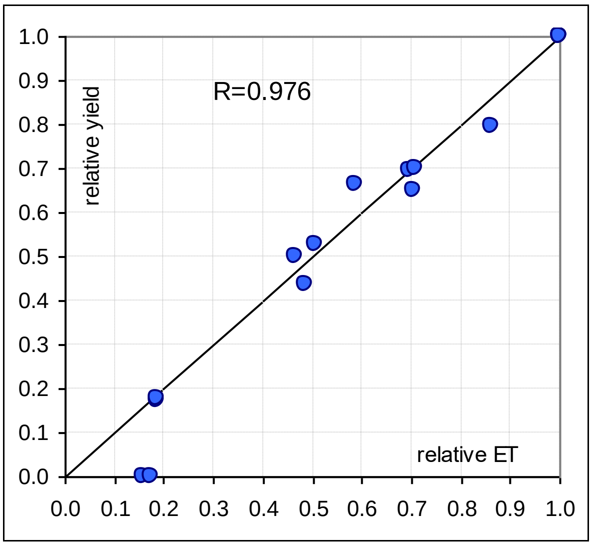

Figure 6. Relationship between experimental and calculated data

Two-power relationship "Yield - cumulative ET"

Figure 7 shows the relationship "Yield - cumulative ET", established according to the two-power formula. The two variable power indicators in this formula enable an even more accurate interpretation of the experimental data since its characteristic S-shaped curve very smoothly describes the change in yield with the increase of the total ET. This formula approximates the experimental points with extremely high accuracy, and as shown in Table 5, and clearly visible in the graph, the curves practically pass through them. As a result, the correlation coefficient R is in the narrow range of 0.99-1.00.

The equation: $Y=[1-(1-x)^{1.74}]^{5.29}$, which simultaneously averages all test points at R=0.989, can be considered representative of the conditions of the experiment. This is supported by the graphs in Figures 8 and 9, where the experimental and calculated yields based on the two-power formula are visually presented, and the relationship between them.

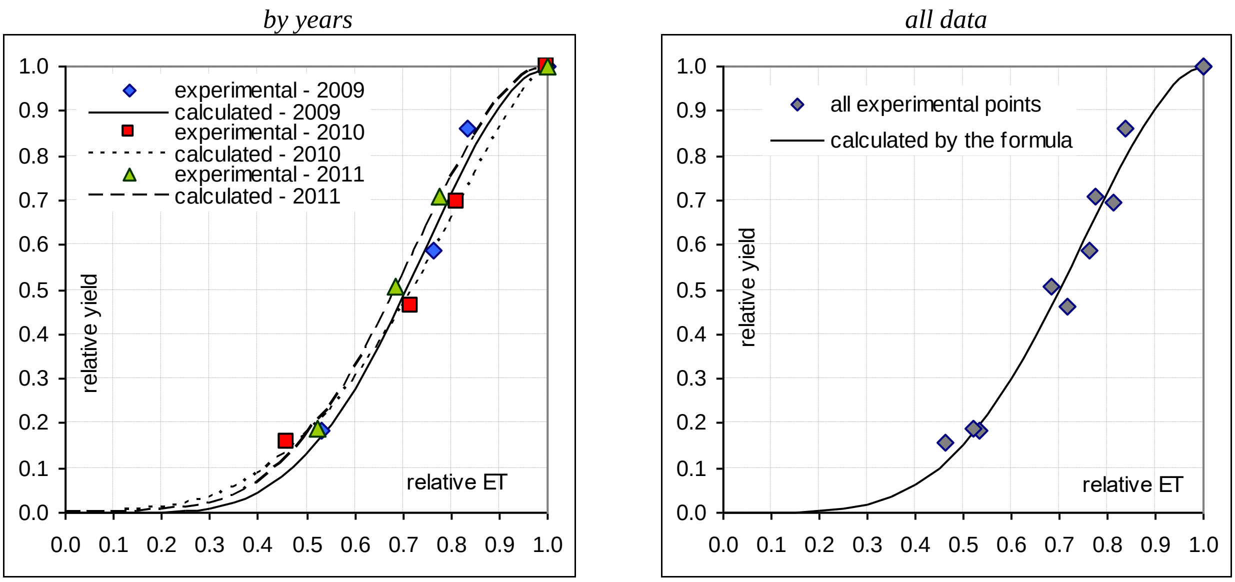

Figure 7. Two-power relationship "Yield - cumulative ET"

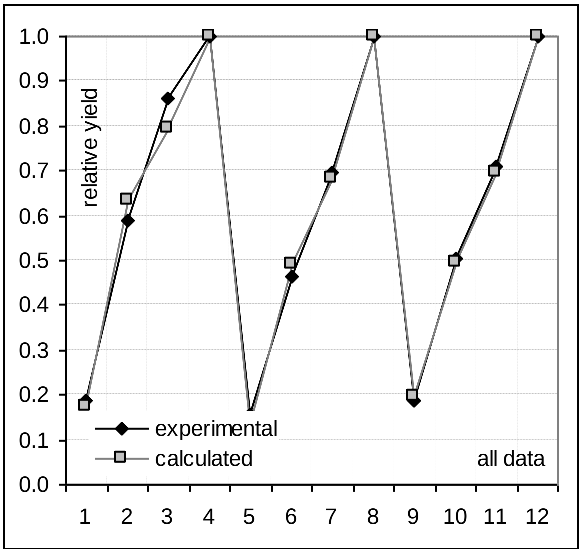

Figure 8. Experimental and calculated yield using two-power formula

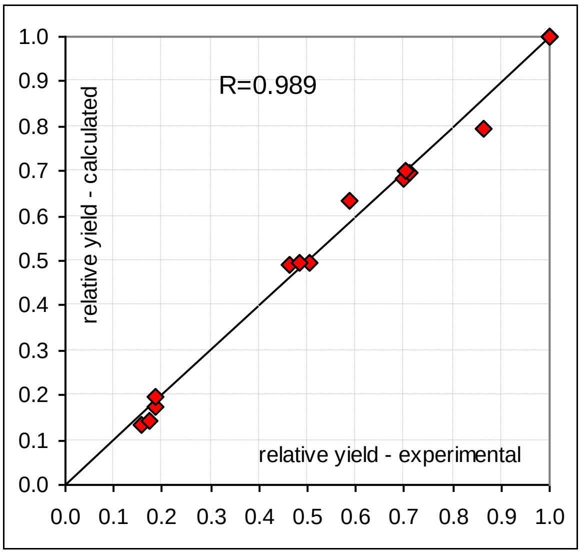

Figure 9. Relationship between experimental and calculated data

Table 4. Experimental and calculated yield by two-power formula and differences between them

Yield experimental		Yield calculated		Calculated to experimental		
kg/da	relative	kg/da	relative	±	%	±%
89.4	0.186	83.3	0.173	-6.1	93.2	-6.8
283.2	0.588	305.7	0.635	22.5	108.0	8.0
415.1	0.862	382.9	0.795	-32.2	92.2	-7.8
481.5	1.000	481.5	1.000	0.0	100.0	0.0
108.4	0.158	91.5	0.133	-16.9	84.5	-15.5
318.7	0.464	339.1	0.493	20.4	106.4	6.4
479.1	0.697	470.8	0.685	-8.3	98.3	-1.7
687.5	1.000	687.5	1.000	0.0	100.0	0.0
100.1	0.188	103.2	0.194	3.1	103.1	3.1
268.0	0.505	264.2	0.498	-3.8	98.6	-1.4
376.5	0.709	370.3	0.697	-6.2	98.4	-1.6
531.1	1.000	531.1	1.000	0.0	100.0	0.0

Table 5. Parameters of the relationship “Yield-cumulative ET”

Year	Linear		One-power			Two-power		
	Kc	R	A	N	R	N	M	R
2009	1.62	0.972	2.28	1.33	0.989	1.83	6.15	0.990
2010	1.62	0.990	2.20	1.23	0.975	1.37	3.60	0.998
2011	1.61	0.990	2.19	1.33	0.999	1.85	5.56	1.000
All data	1.62	0.805	2.23	1.28	0.976	1.74	5.29	0.989

Undoubtedly, of the three formulas used for the purpose, the two-power formula is the most accurate, with the deviation between the calculated and experimental total yields exceeding 10% in only one of the cases (again under non-irrigated conditions) (Table 4).

CONCLUSIONS

The three formulas used show sufficiently high accuracy that the presented parameters can be used directly for predictive and design purposes when it comes to the English ryegrass and red fescue grass mixture.

When choosing a formula for the "Yield - cumulative ET" relationship, priority should be given to the two-power formula, because through the two variable power indicators, it most accurately represents the relationship, in view of the values of R and the small deviations of the calculated compared to the experimental yield. Secondly, the one-power formula is recommended, which through the variable power indicator makes it possible to achieve sufficiently high accuracy. Although the FAO's linear formula has been established for a long time in scientific circles and for the conditions of the experiment it gives good results, in terms of accuracy it is inferior to the power and two-power formulas, and this should be taken into account when using it.

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