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THE 'WATER-YIELD' RELATIONSHIP: MODEL CALIBRATION IN THE CASE OF RASPBERRY (Rubus Idaeus)

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Abstract

Irrigation is a key factor for improving raspberry fruit production, especially under summer droughts characteristic of lowlands. However, when the available irrigation water is insufficient to meet crop water use, a kind of regulated deficit irrigation has to be applied. In such cases it is important to determine the limit of the water application reduction, during the whole vegetation period or in specific phenological phases, to provide reasonable levels of the yield, respectively of the net incomes from irrigation. For that purpose, there are empirical parametric equations (models) developed in order to describe the relationship between the yield and the water application rate. These equations, however, must be calibrated for each crop and towards the site specific soil and climate conditions. In the present paper, three independent models of the 'water-yield' relationship are calibrated and compared. The experimental work was carried out during an eight-year period (third to tenth vegetation) in a 400 m^2 raspberry plantation of the primocane-fruiting Lyulin cultivar. Seven irrigation treatments were studied in four replications. During the main phenophases –intensive growth (F1); blossom (F2); and fruiting (F3) – the water was applied in amounts recovering 100%, 75% and 50% of ET_C respectively. Fertilizers were applied through the irrigation system, the fertilization dose being the same in all treatments. According to the obtained results, the relationship between the yield and the water application rate was approximated with high reliability by all studied models, but the equation parameters were different each year. The averaged over all experimental years'data show that the raspberry susceptibility to reduction of the water application rates was comparable in the phases of blossom and fruiting. The raspberry susceptibility was significantly lower during the phase of intensive growth, probably because of the larger rainfall amounts during that period. It can be concluded that when the examined models were calibrated by years they approximated the 'water-yield' relationship with high reliability (R=0.71÷0.98). The models were more universal when calibrated using averaged over all experimental years' data, but in that case their precision was relatively lower.

Key words: drip irrigation, RDI, primocane-fruiting cultivar, parametric equations.

INTRODUCTION

Yield and fruit quality of primocane-fruiting raspberry cultivars, as well as their biological characteristics are associated with series of technological and economic advantages, which keep up the interest of fruit growers (Hristov, 1983; Boycheva, 1984; Yaneva, 1990; Barney et al., 1999; Dickerson, 2005; Stiles et al., 2002). In Bulgaria, the raspberry-growing technology was developed for the mountainous and hilly conditions of the natural raspberry habitat (Ivanov et al., 1981; Yaneva, 1990; Stanchev, 1991). In lowlands, however, raspberry can be grown only with irrigation because of the frequent summer droughts characterized by unfavourably high air temperatures and low air humidity (Dana and Goulart, 1991; Bushway and Pritts, 2008b; Geohring, 2008; Petrovich and Leposavich, 2011; Stanton, 2013).

Today, microirrigation is widely used in raspberry production because of the efficient water delivery in the plantation and even for a single plant (Bucks et al., 1982). Growth and yield of many fruit crops can be optimized by Regulated Deficit Irrigation (RDI). This is when the maximum application rate is reduced on behalf of developing moderate water-stress levels in plants with acceptable decrease in yield and fruit quality (Chalmers et al., 1984; Behboudian and Mills, 1997; GeertsansRaes, 2009). RDI is practiced also in drought periods when the available irrigation-water amount is not sufficient to meet the crop water needs. It is important to properly estimate the extent of reduction of the application rates, annually or only in a critical phenological phase, in order to minimize the loss of yield and net income, respectively. For that purpose, empirical parametric equations have been developed describing the relationship “application rate – yield”. They, however, need to be calibrated for each crop, soil and climatic conditions (Davidov, 1982; Varlev, 1983; Popov et al., 1984; Varlev and Popova, 1999; Varlev, 2008). The present paper objective is to calibrate three of these equations for the ‘Lyulin’ primocane-fruiting cultivar grown under RDI. Reported results are part of a larger investigation on raspberry production in lowland conditions.

MATERIALS AND METHODS

The study was carried out from 2001 till 2008 on the territory of Fruit Growing Institute – Plovdiv, in a 400 m2 plantation of the ‘Lyulin’ cultivar established with distance between rows 2.3 m and 0.5 m plant spacing in the rows. The soil was sandy loam. Plants were supplied with water and fertilizers by drip irrigation system. Seven variants of irrigation regimes, each in four replications, were investigated. During the main phenological phases – intensive growth (F1), blossoming (F2), and fruiting (F3) – the water applications were regulated as follows: VC-100 – recovering 100% of the crop evapotranspiration, control; V1-75 – 75% of VC-100 in F1; V1-50 – 50% of VC-100 in F1; V2-75 – 75% of VC-100 in F2; V2-50 – 50% of VC-100 in F2; V3-75 – 75% of VC-100 in F3; and V3-50 – 50% of VC-100 in F3. The raspberry plantation was managed for only one, autumn crop.

Three independent models, describing the “annual application rate – yield” relationship, were calibrated and compared on the basis of eight-year results from the studied seven variants of irrigation:

quadratic polynomial:

$$Y = ax^2 + bx + c, \qquad (1)$$

exponential equation (Davidov, 1982):

$$Y = 1 - (1 - Y_C)(1 - x)^n, \qquad (2)$$

quadratic equation (Varlev, 1983):

$$Y = Y_C + (1 - Y_C)(2x - x^2), \qquad (3)$$

where Y is the relative yield under irrigation, YC is the relative yield without irrigation, and x is the relative annual application rate. Because there were no variants without irrigation provided in the experimental setup, the values of the intercept (c) of equation (1) were ascribed to YC of equations (2) and (3) for each experimental year. Regression analysis was used to calibrate equation (1) while equation (2) was calibrated using the “YIELD” software product (Davidov, 1994).

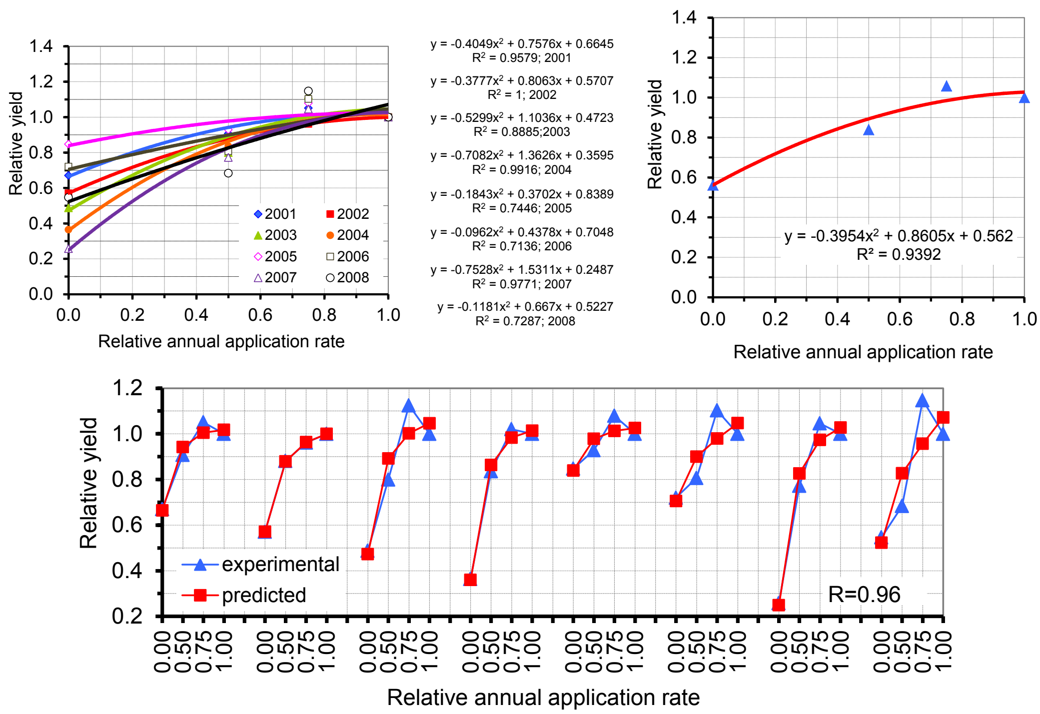

Fig. 1. *Quadratic polynomial approximation of the “annual application rate – yield” relationship; above left – regression lines and equations, above right – averaged over the experimental years, below – experimental versus predicted values by years*

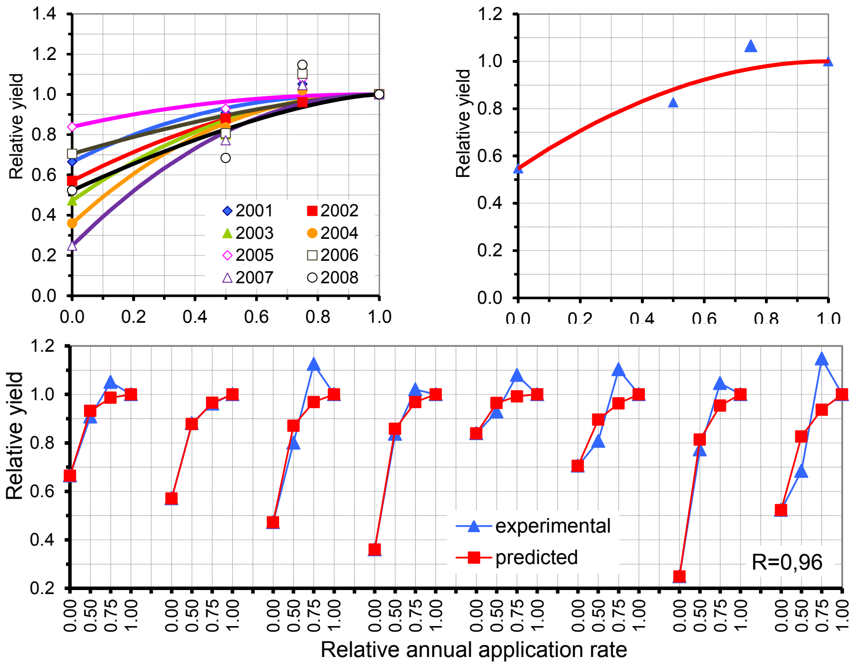

Fig. 2. *Davidov's approximation of the "annual application rate – yield" relationship; above left – regression lines, above right – averaged over the experimental years, below – experimental versus predicted values by years*

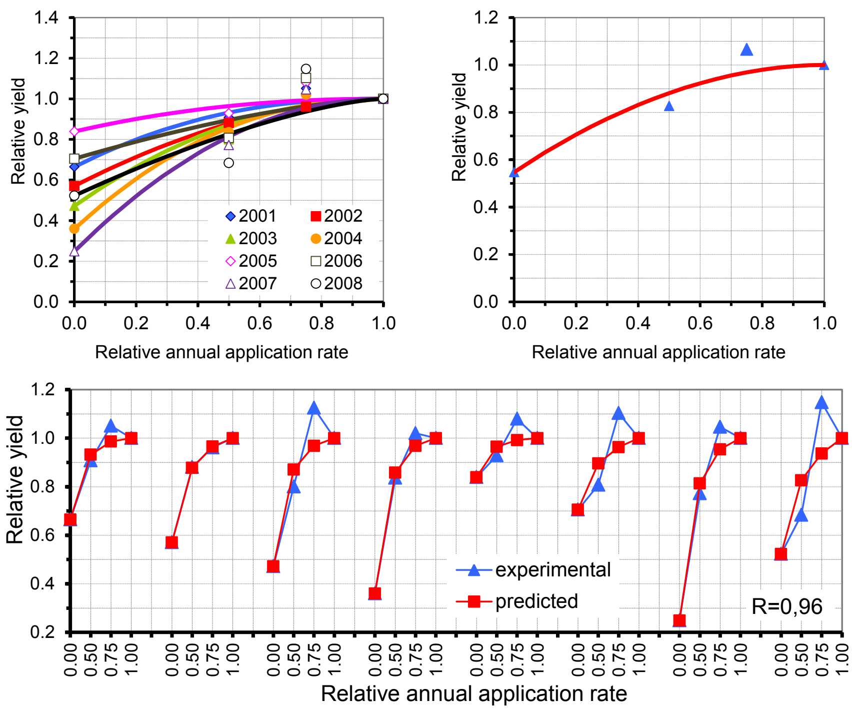

Fig. 3. *Varlev's approximation of the "annual application rate – yield" relationship; above left – regression lines, above right – averaged over the experimental years, below – experimental versus predicted values by years*

Table 1. Calibrated equations of the three studied models, describing by phenophases the relationship "annual application rate (x) – yield(Y)" of the 'Lyulin' primocane-fruiting raspberry cultivar grown in lowland conditions

Phenological Phase	Equation	R
Quadratic Polynomial		
Intensive growth (F1)	$Y = -0.5409x^2 + 0.7142x + 0.78$	0.71
Blossoming (F2)	$Y = -0.1953x^2 + 0.6244x + 0.57$	0.98
Fruit ripening (F3)	$Y = -0.3954x^2 + 0.8605x + 0.56$	0.96
Davidov		
Intensive growth (F1)	$Y = 1 - 0.2242(1 - x)^{5.2}$	0.90
Blossoming (F2)	$Y = 1 - 0.4233(1 - x)^{1.35}$	0.98
Fruit ripening (F3)	$Y = 1 - 0.4523(1 - x)^{1.93}$	0.96
Varlev		
Intensive growth (F1)	$Y = 0.78 + 0.2242(2x - x^2)$	0.83
Blossoming (F2)	$Y = 0.58 + 0.4233(2x - x^2)$	0.95
Fruit ripening (F3)	$Y = 0.55 + 0.4523(2x - x^2)$	0.95

RESULTS AND DISCUSSION

The calibration of the studied models (1), (2) and (3) describing the "annual application rate – yield" relationship in phenophase F2 is illustrated in Figures 1, 2, and 3, respectively. It could be seen that all three equations approximated the relationship with high precision but the equation parameters were different in each experimental year. The results of phenophases F1 and F3 (not shown here) were similar. According to the averaged over the experimental years data, raspberry plants showed similar sensibility to eventual reduction in the annual application rates in the "blossoming" (F2) and "fruit ripening" (F3) phenophases. Significantly lesser sensibility to irrigation water reduction was observed in the "intensive growth" (F1) phenophase, probably because of the larger rainfall amounts in that period.

The calibrated equations of the three studied models, describing the relationship "annual application rate – yield", are shown in Table 1 by the three main phenophases of the 'Lyulin' primocane-fruiting raspberry cultivar.

CONCLUSIONS

1. The relationship between the yield and the annual water application rate was approximated with high precision (R = 0.71÷0.98) by all studied models, but the equation parameters were different in each experimental year and phenological phase.

2. When the equations were calibrated over all experimental years, they lost precision but gained universality.

3. Raspberry plants showed similar sensibility to eventual reduction in the annual application rates in the "blossoming" (F2) and "fruit ripening" (F3) phenophases.

4. Significantly lesser sensibility to irrigation water reduction was observed in the "intensive growth" (F1) phenophase, probably because of the larger rainfall amounts in that period.

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