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Statistical models for observation the uniformity of the working depth of machine-tractor unit during disking and cultivation depending on soil moisture

Petya Veleva* and Galya Hristova

*Department of Agricultural Engineering, Faculty of Agriculture, Trakia University, Stara Zagora, Bulgaria, e-mail:petyaveleva26@gmail.com

GOAL OF THE STUDY

The purpose of this experiment is to examine the uniformity of operation of the machine-tractor unit during disking and cultivation, influenced by the current soil moisture. To develop regression models describing the relations between them, and to trace their impact on the yield of wheat grown by conventional technology.

METHODOLOGY OF THE INVESTIGATION

1. Experimental design

The study has been conducted on an experimental field in the territory of the Chirpan region in the central part of the Republic of Bulgaria (42º08`04``N25º21`31``E). The technological operations applied in wheat production during the three agricultural years were traced and shown in Table 1. The area of the experimental field was 32400 m^2.

The technological operation disking was carried out with a machine-tractor unit consisting of: a 200 hp. tractor and a six-meter mounted disc harrow. The cultivator is eight meters aggregated to a tractor of 240 hp. The rolling is performed with rollers aggregated to a 100 hp. tractor.

The actual working depth, affected by the instantaneous soil moisture, was measured with a linear meter after the passage of the machine-tractor unit through the studied area - along the 100 m length and 50 m width.

Soil moisture was measured with soil moisture meter AM-128 SOIL before performing the tillage. During the harvest from the studied field, the following average yields were obtained: FAY-628 kg/da, SAY-603 kg/da, and TAY-545 kg/da.

Table 1. Table Technological operations carried out during the studied agricultural years.

YEAR	Technological operation	Depth of tillage (cm)
First agricultural year 2015-2016, (FAY)	Triple disking with cultivation	3-10
Second agricultural year 2017-2018, (SAY)	Double disking with rolling	6-10
Third agricultural year 2019-2020, (TAY)	Triple disking	2-8

2. Statistical data analysis

The studying of the effect of soil moisture on the uniformity of the machine - tractor unit consists of obtaining the main statistics (mean values –$\bar{x}$ and the Standard Deviations – SD) of the observed parameters (depths of the operations disking and cultivation for the three experimental years), correlation analysis between them, and an examination of the significant differences via Univariate ANOVA at significance level $p \leq 0.05$. Regression analysis was used to develop and compare three regression models (Linear (1), Quadratic (2), and Cubic (3)) describing the relation between moisture of the soil and depths of the investigated technological operations as follow:

$\mathbf{Y = ax + b}$ **(1);** $\mathbf{Y = a + b_1x + b_2x^2}$ **(2);** $\mathbf{Y = a + b_1x + b_2x^2 + b_3x^3}$ **(3)**

where Y are the observed parameters (depths of disking and cultivation), x are the values of the factor of influence - the moisture of the soil, and $a; b; b_1; b_2; b_3$ are the model coefficients. The impact of the disking depths on the yield of wheat grown by conventional technology was traced performing Post hoc Tukey test.

MAIN RESULTS FROM THE STUDY

Table 2. Pearson crosstab correlation between examined parameters Disking depth, Cultivation depth, and Soil moisture for the three investigated years.

	Soil moisture at FAY (%)	Soil moisture at SAY (%)	Soil moisture at TAY (%)
Disking depth at FAY, (cm)	0.937*	-	-
Disking depth at SAY, (cm)	-	0.769*	-
Disking depth at TAY, (cm)	-	-	0.790*
Cultivation depth at FAY, (cm)	-0.172	-	-

Table 3. Basic statistics and ANOVA of the observed parameters Soil moisture and Disking depth for the three experimental years.

Investigated Year	n	Soil moisture, (%)		Disking depth, (cm)	
		$\bar{x}$±SD	Sig.	$\bar{x}$±SD	Sig.
FAY	120	25.20±8.98 ^{a}	0.0001	5.73± 2.771^{c}	0.008
SAY	80	23.62±4.410 ^{b}		8.07 ± 1.253 ^{cd}	
TAY	120	16.06±3.163 ^{ab}		4.92 ± 1.709 ^{cd}	
		-		R^2 = 0.311	

^{a,b,c,d} Same superscripts within the same column represent significant differences at the level of significance $p < 0.05$; SD – Standard deviation; R^2 – Coefficients of determination based on observed means through Tukey test; n – number of the observations

Table 4. Model summary and parameter estimation showing the dependence of the Disking depth and the Cultivation depth from the moisture of the soil for the First agricultural year.

Parameter estimates	R^2	Sig.	Std. Err.	Equations
Disking depth, (cm)				
Linear	0.883	0.001	0.887	$Y = 0.291x - 1.613$
Quadratic	0.903	0.001	0.539	$\boldsymbol{Y = -7.02 + 0.74x - 0.008x^2}$
Cubic	0.903	0.001	0.941	$Y = -5.489 + 0.54x - 0.001x^3$
Cultivation depth, (cm)				
Linear	0.030	0.288	1.160	$Y = -0.06x + 9.635$
Quadratic	0.078	0.384	1.492	$Y = -42.22 + 2.446x - 0.03x^2$
Cubic	0.075	0.223	1.565	$Y = -9.08 + 0.03x^2 - 0.005x^3$

Table 5. Model summary and parameter estimation showing the dependence of the Disking depth from the moisture of the soil for the Second agricultural year.

Parameter estimates	R^2	Sig.	Std. Err.	Equations
Linear	0.591	0.001	0.113	$Y = -0.219x + 13.235$
Quadratic	0.617	0.001	0.061	$\boldsymbol{Y = 2.34 + 0.754x - 0.02x^2}$
Cubic	0.616	0.001	0.064	$Y = 6.11 + 0.263x - 0.0003x^3$

Table 6. Model summary and parameter estimation showing the dependence of the Disking depth from the moisture of the soil for the Third agricultural year.

Parameter estimates	R^2	Sig.	Std. Err.	Equations
Linear	0.623	0.001	0.195	$Y = 0.427x - 1.936$
Quadratic	0.656	0.001	0.116	$Y = -7.91 + 1.16x - 0.022x^2$
Cubic	0.667	0.001	0.077	$\boldsymbol{Y = -13.17 + 2.05x - 0.07x^2 + 0.01x^3}$

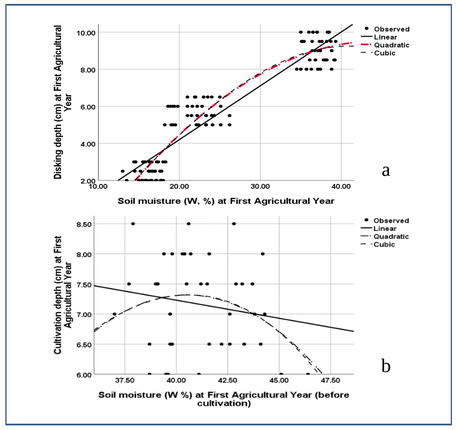

Fig. 1. Curves estimation of the regression models showing the influence of the soil moisture on the depth of technological operations Disking and Cultivation at the FAY

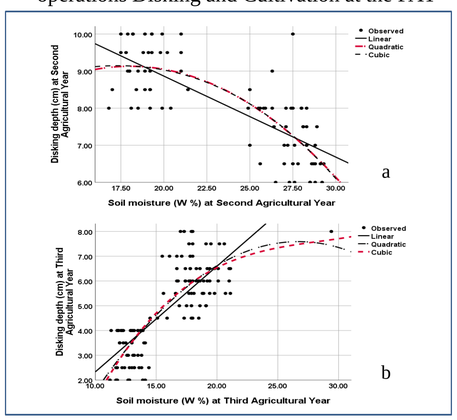

Fig. 2. Curves estimation of the regression models showing the influence of the soil moisture on the Disking depth at the SAY (a) and TAY (b)

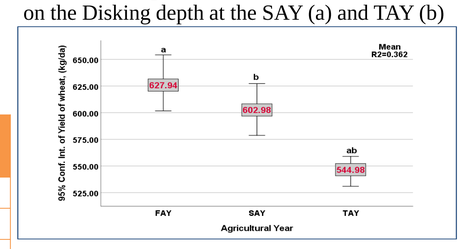

Fig. 3. Mean values of the yield of wheat (kg/da) for the three experimental years

CONCLUSIONS

- A very strong correlation between soil moisture during the three observed years and the depth of disking (r = 0.769; 0.790; 0.937) and a weak, negative correlation between the current soil moisture and the depth of cultivation were obtained (r = - 0.172).
- The statistically significant differences between the depths of disking for the three observed years justifies the creation of regression models.
- From all regression models composed for the first and second agricultural years, the Quadratic model best describes the influence of soil moisture on the depth of disking (R^2 = 0.903 and 0.617), and for the third agricultural year, the most suitable is the Cubic model (R^2 = 0.667).
- No statistically significant regression models describing the relation between instantaneous soil moisture and the depth of the technological operation cultivation were found.
- Statistically significant differences between the average yield in the first and third agricultural year, as well as between the second and third agricultural year were reported, i.e. the depth of disking affects the productivity of wheat grown by conventional technology by 36.2% (R^2 = 0.362).
- The developed models could be used by farmers to optimize the control systems of the machine-tractor units and to help with the choice of basic parameters of the soil tillage.