

# A way of estimating the intensity of connections between the parameters of a dynamic system

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*Abstract:* - In many cases, the influence of some of the characteristic parameters of some systems becomes important in relation to the influence of the other parameters, only when certain critical operating regimes are exceeded. These operating modes are often intangible in normal operation. In order not to endanger the system or to avoid the use of exaggerated power sources, the investigation of the influence of the parameters targeted in these critical operating regimes can be done by simulation, theoretical, experimental or mixed. The results are then subjected to a statistical analysis which may indicate a possible major change in the influence of some of the targeted parameters in the operation of the system. Specifically, the dynamic system considered is an agricultural machine for soil processing, consisting of a combinator and tractor. The simulation is done using a Goriacikin-type formula, which ensures complete theoretical control over the influence of the targeted parameters on the dynamic process of the machine. The parameters we focus on are working depth and working speed. The difference in intensity of the influence of each of the parameters is highlighted, trying an explanation for this difference. The explanations are useful for researchers who want to obtain information about the parameters whose influence on the functioning of the systems is small in the normal working regime but they can grow appreciably in the extra normal working regimes, even if for a short time.

*Key-Words:* - dynamic, system, parameters, connection, intensity, agricultural, machine

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## 1 Introduction

The influence of the working parameters of the dynamic tractor-combinator system, in the soil tillage process, is a very frequently researched subject, using statistical analysis and modelling, both in the last decades, [2-6] and further in time, [31,32, 36, 37]. Almost all researchers look for formulas that predict the soil tillage draft force and consider the following parameters of the working process: working depth and width, working speed, parameters that describe the condition of the soil, the coefficient of resistance to deformation, density, humidity, soil cohesion and adhesion, etc. Other researchers are looking for the link between the parameters of the tillage process, [5, 12-13, 15, 21, 37], as well as the quality of the processing performed or the harvest obtained, [11, 14]. A large number of researchers have deduced calculation formulas for the soil tillage draft force by summing predetermined terms (usually considered in the literature) using regressions (linear or nonlinear), [3, 16, 17, 18, 36, 38, 39, 40, 42, 43, 44, 45, 46, 47].

The authors [19] use the statistical analyses of linear regression, but also the theory of neural (or neural) networks, [41], to obtain the most accurate prediction relations for the soil tillage draft force. The authors [19] consider as working parameters the working depth, the soil moisture, the soil cone index, and the travel speed. The authors [23] constructed linear regressions for the soil tillage draft force and for the ground surface disturbed by a chisel working body, using as parameters the chisel width, working speed and working depth. Also, linear and nonlinear regressions, as well as comparisons between them, propose the authors [24], for a plough with mouldboard, having as independent process parameters soil moisture, working depth and working speed, the dependent parameter being the resistance force traction (soil tillage draft force). A comparative study of the predictions of the soil tillage draft force, obtained by neural networks and by multiple linear regressions, is presented in [25], using experiments performed with a tractor-subsoiler agricultural aggregate.

Artificial neural networks are also used in [35], to obtain formulas for predicting the qualitative parameters of soil tillage processes. The authors [25] use as a dependent parameter the soil tillage draft force and as independent parameters the working depth, soil density, penetration resistance and soil moisture, soil shear stress and cohesion. The authors [20] consider linear regressions formed with combinations of dimensionless parameters. The authors [26] present the results of the calculation of the coefficients of the classical calculation formula for the resistance force, given in [27], both on the direction of travel and on the vertical. The formula for calculating the soil tillage draft force assumes from the start that the exponent of the working speed is 2, as in the Goriacikin formula, [1].

In [28] we calculate, using experimental data, the coefficients of the formula for calculating the soil tillage draft force proposed in the ASABE standard, [29]. An extensive, analytical and experimental study, based on the soil tillage draft force formula of [27], is presented in [30]. In this version, [30], the formula in [27] requires a dependence on the square of the velocity. Regression formulas such as the one given in [29] have been proposed for soil tillage draft force and fuel consumption in the case of several tillage machines, [32, 34]. Linear regression formulas, which contain the working speed, are presented in [33]. Unlike the authors cited above, we tried, before the regression statistics stage, to somehow prioritize the various parameters in experiments or their combinations, in order to use the most favourable variants in regression studies. The authors [19, 23-25] do not make a study of the hierarchy of the influence of independent process parameters on the considered dependent parameter, in the sense we proposed in [2]. From this idea started the investigation whose results are described in [2]. I also suggested the use of dimensional analysis to obtain physically correct combinations.

In [2] we used experimental results to evaluate the influence of some of the parameters listed above on the soil tillage draft force of the combinator. In this study, we want to clarify the influence of working depth and working speed as free parameters of the process, on the soil tillage draft force. For increased data control, we produced "experimental data" by simulating the working process using a Goriacikin-type formula for soil tillage draft force, [1]. This procedure will allow obtaining reference results for the development in good conditions of the activity of processing the experimental data obtained in laboratories or in the field.

## 2 Problem Formulation

The subject of research is the dynamic working process of the tractor-soil tillage equipment agricultural unit. In order to bring the working data as close as possible to reality, we used, for the purpose of simulation, the parameters of the unit formed by a tractor with a power between 80 and 100 hp and a combinator from the VM range produced at Mecanica Ceahlau Agricultural machinery and equipment, more precisely, the model VM321. From these data, we specify: working depth  $a$ , between 2 and 12 cm, working width,  $b$ , 3.2 m (80 organs each 0.04 m wide each), working speed,  $v$ , between 5 and 8 km / h, the mass of the combinator being  $m = 950$  kg. For the soil and the contact between the soil and the metallic surfaces of the combinator, the values were taken:  $\mu = 0.6$ ,  $k = 35000$  N / m<sup>2</sup>,  $\rho = 1400$  kg / m<sup>3</sup>, a coefficient  $c = 1.5$  of traction [1]). The value of the gravitational acceleration  $g = 9.81$  m / s<sup>2</sup> is considered. Under these conditions we define the following components of the soil tillage draft force:

-friction component:

$$F_f(\mu, m) = \mu mg \quad (1)$$

-component of the resistance to soil deformation:

$$F_{rds}(k, a, b, n_c) = kabn_c \quad (2)$$

-dynamic component:

$$F_d(\rho, c, a, b, n_c, v) = cpabn_c v^2 \quad (3)$$

- for convenience in discussions and graphic representations, the *static component* is also introduced:

$$F_{st}(\mu, m, k, a, b, n_c) = F_f(\mu, m) + F_{rds}(k, a, b, n_c) \quad (4)$$

In the next reasoning and for the graphical representation of the components of the soil tillage draft force (the more general form of the formula in [1]) is useful the next definition:

$$R(\mu, m, k, a, b, n_c) = F_f(\mu, m) + F_{rds}(k, a, b, n_c) + F_d(\rho, c, a, b, n_c, v) \quad (5)$$

Figure 1 shows the components of the soil tillage draft force, not primarily for the observation of their variation with speed, but to facilitate the observation of three critical values with significance on the

intensity of the influence of the free parameter - working speed- on the dependent parameter - the soil tillage draft force.

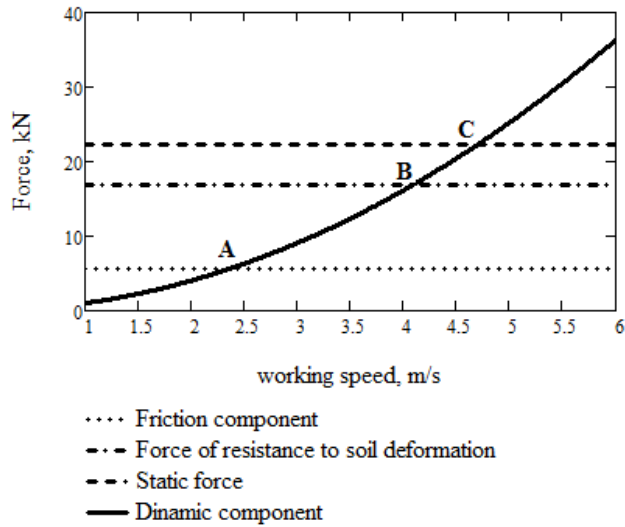


Fig. 1 The dependence on the working speed of the components of the soil tillage draft force in the hypothesis of the mathematical model [1].

In fig. 1 it is observed that the dynamic component is (in the hypotheses of the mathematical model [1] of the soil tillage draft force) the only component that varies with the working speed. In order to get from the last place in the hierarchy of components to the first, the dynamic component must equal and surpass in turn the friction component, the component given by the soil resistance to deformation and the static component. The three intersection points (A, B, C) have as abscissas three critical velocities:

- the speed which leads to the equality between the dynamic component and the friction component

$$v_f = \sqrt{\frac{F_f(\mu, m)}{cpabn_c}} \quad (6)$$

- the speed which leads to the equality between the dynamic component and the component given by the soil resistance to deformation

$$v_{rds} = \sqrt{\frac{F_{rds}(k, a, b, n_c)}{cpabn_c}} \quad (7)$$

- the speed which leads to the equality between the dynamic component and the static component

$$v_{st} = \sqrt{\frac{F_f(\mu, m) + F_{rds}(k, a, b, n_c)}{cpabn_c}} \quad (8)$$

For the numerical data considered in the example from this article, the following values of the three critical speeds are found:  $v_f = 2.355$  m/s (8.478 km/h),  $v_{rds} = 4.082$  m/s (14.695 km/h),  $v_{st} = 4.713$  m/s (16.967 km/h). It is found that the highest working speed indicated by the combiner manufacturer does not reach the value of the lowest critical speed,  $v_f$ . This result will be used to discuss the intensity of the influence of the soil tillage draft force components that contain the working speed of the tractor-combinator aggregate.

The method used is to estimate the intensity of the influence of the parameters of the dynamic systems on the quality parameters of the same systems, as defined in [2]. For this, using formulas (1) - (5), 40 numerical experiments were simulated in which the depth and speed of work were varied.

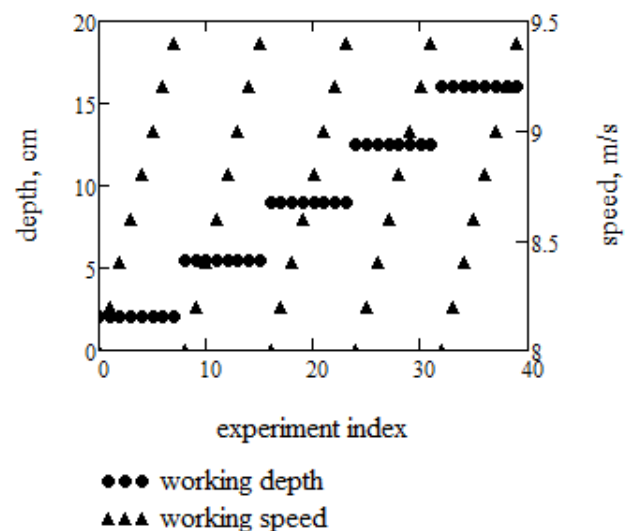


Fig. 2 The average values of the depth and speed of work corresponding to the index of the experiment were programmed in the experimental plan.

For the experimental data in fig. 2 working speed was between 1 and 2.4 m / s, with an average value of 1.7 m / s. In order to observe how the correlation coefficient depends between the soil tillage draft force and the working depth, respectively the

working speed, the "experiences" in fig. 2 were performed 18 times, increasing progressively but not linearly, the average working speed. These results are given in the next chapter.

### 3 Results

#### 3.1 Dependence of the correlation coefficient between the soil tillage draft force and the working depth, respectively the working speed, in relation to the average working speed per experiment

This result tries to characterize the correlation between the soil tillage draft force of the combiner and the various parameters by simulation: working depth and working speed. A very precise first result, using the method and technique described in [2] is that, for all experiments and regardless of the average working speed, the same exponent is obtained for the law  $R = R(a^x)$ ,  $x = 1$  and for the law  $R = R(v^x)$ ,  $x = 2$ . In other words, if  $R$  depends on the working depth, then it depends on its first power, respectively, if it depends on its working speed, then it depends on its second power. This result was predictable, as "experimental data" is obtained using the Goriacikin mathematical model of soil tillage draft force, in which the working depth appears at the first power and the working speed is at the second power.

A second result, perhaps more important than the first, is easier to understand by observing the graphical representations in figure 3. By repeated simulation, changing the working speed range and calculating each time the correlation coefficient and the optimal exponent, according to [2], we obtained the numerical dependencies of these two parameters of average working speed. The dependencies of the correlation coefficients between the soil tillage draft force and the working depth, respectively the working speed, of the average working speed, are given in fig. 3.

It is observed that there is an average working speed at which the correlation coefficient between the soil tillage draft force and the working speed is maximum. It is noted that for the same average value of the working speed, the correlation coefficient between the soil tillage draft force and the working depth becomes minimal. Moreover, it is observed that this critical velocity is in the vicinity of the critical velocity corresponding to the intersection between the dynamic and the static

component given by the resistance to soil deformation,  $v_{rds} = 4,082 \text{ m/s}$ .

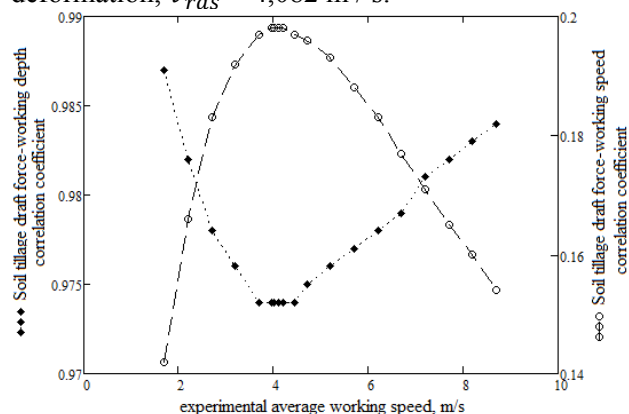


Fig. 3 Dependencies of the correlation coefficients between the soil tillage draft force and the working depth, respectively the working speed, the average working speed.

However, this speed is well outside the range of working speeds indicated by the manufacturer for the considered combine, [1,389, 2,222] m/s. In addition, it is observed that the correlation coefficient of the soil tillage draft force with the working speed has much lower values than the correlation coefficient of the soil tillage draft force with the working depth. The maximum value of the correlation coefficient of the soil tillage draft force with the working speed is 0.198, much lower than the minimum value of the correlation coefficient of the soil tillage draft force with the working depth, 0.974. This would be the theoretical reason why the dependence of the soil tillage draft force on the working speed is much more difficult to find through experimental studies. In addition, in general, the range of working speeds indicated by the manufacturers of such agricultural machines has a maximum value much lower than the critical speed at which the correlation coefficient between the soil tillage draft force and the working speed is maximized.

We emphasize once again that these results are valid numerically only for the simulation made on the basis of the Goriacikin model for soil tillage draft force. Similar theoretical studies can be made for each of the alternative models proposed in the literature for soil tillage draft force, [8 - 10].

#### 3.2 Dependence of the correlation coefficient and the corresponding exponent between the soil tillage draft force and the depth,

**respectively the working speed, in relation to the average working speed per experiment**

In this section, we will give the results regarding the variation with the working speed of the correlation coefficient and the corresponding exponential parameter, for some combinations more often found in the mathematical models of the soil tillage draft force. More precisely, we will give the variation of the correlation coefficient between the soil tillage draft force and the combinations:  $av, av^2, a^2v, a^2v^2$  respectively the variation of the exponents corresponding to the quantities:

$$\begin{aligned} &corr(R, (av)^x), corr(R, (av^2)^x), \\ &corr(R, (a^2v)^x), corr(R, (a^2v^2)^x). \end{aligned} \quad (9)$$

where  $corr(\cdot, \cdot)$  means the correlation coefficient between the two arguments, [2]. In fig. 4 represents graphically the dependence of the correlation coefficients (9), on the working speed of the agricultural aggregate. It is observed that, unlike the dependence of the correlation coefficients between the tensile strength and the simple variables  $a$  and  $v$ , represented graphically in fig. 3, the dependence of the correlation coefficients (9), increases with speed up to a value around that of the critical speed,  $v_{rds}$ , after which it has an asymptotic tendency at a very close value of 1.

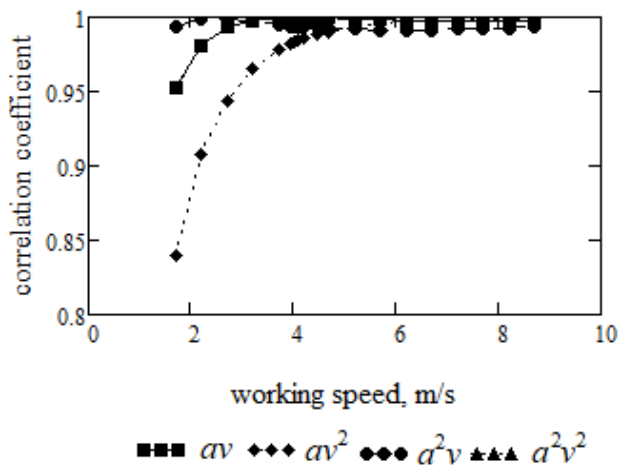


Fig. 4 Dependence of the correlation coefficient between the soil tillage draft force and the parametric combination considered, on the average speed of the set of experiments.

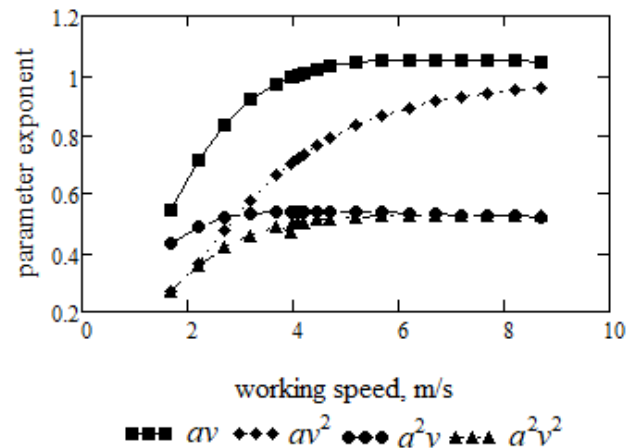


Fig. 5 Dependence of the exponential parameter of the relationship between the soil tillage draft force and the considered parametric combination, on the average speed of the set of experiments.

Unlike the correlations of the soil tillage draft force with the variables  $a$  and  $v$ , for which the exponent  $x$  is independent of speed, in the case of the correlation coefficients of the soil tillage draft force with the multiplicative combinations of variables, (9), it varies with working speed. These dependencies are described by curves similar to those of the dependencies of the correlation coefficients of the soil tillage draft force with the same combinations. The  $x$ -exponents increase faster to around  $v_{rds}$  of the working speed, after which they maintain an asymptotic tendency towards a maximum value (fig. 5). As can be seen for the correlations of the soil tillage draft force with simple parameters varied in numerical experiments (simulations), the important points of the speed dependencies of the studied combinations, occur starting with the value  $v_{rds} = 4,082$  m / s, which, in the case, the combiner whose data we used is almost double the maximum working speed indicated by the manufacturer, [7]. As a result, experimenters who comply with the working parameters required by agricultural machinery manufacturers have little chance of clearly highlighting the influence of working speed. Consequently, the experimental study of optimal points having as one of the parameters of optimization the working speed has little chance to find optimal working speeds as long as the working speed respects the interval indicated by the manufacturers. The fact that the travel speed is a parameter with a weak influence on the soil tillage draft force is also supported by some contributions that present statistical formulas (statistical mathematical models, regressions) in which the travel speed component has a negative

coefficient, [19]. This phenomenon is also supported by experimental works, [22], on the data of which, using the working method and technique from [2], we found the optimal correlation coefficient with the value 0.062, for the exponent  $x = -0.00006$ . The optimal correlation is similar (0.038) in the experiments described in [6], but the exponent  $x = 1.659$ , is significantly higher. The authors [25, 31] do not take into account the working speed in establishing the regressions that give the soil tillage draft force, the experiments being made for a subsoiler, with a working speed of 2.5 km /h. Remarkable and noteworthy is that the ASABE standard, [29] and not only, includes, in addition to the term dependent on the second power of the travel speed, a term dependent on the first power of the same speed. In this paper and in [2] we evaluated the intensity of the connection between the soil tillage draft force and the travel speed at both the first and the second power.

#### 4 Conclusion

Investigations into the influence of working speed on the intensity of the links between the main performance parameter (soil tillage draft force) and various process parameters (depth and working speed) show that speed has an appreciable influence on both the correlation coefficients between the soil tillage draft force and the depth and speed of work (and some combinations thereof), as well as on the exponents of the free parameters and their combinations, in the susceptible connection relations.

The correlation coefficients of the soil tillage draft force with simple parameters, working depth and working speed, vary with working speed, having an extreme point in the vicinity of a critical process speed. The maximum value of the correlation between the soil tillage draft force and the working speed is below 0.2, at a speed at which the correlation coefficient between the soil tillage draft force and the working depth has a minimum value, higher than 0.97. Under these conditions, it is obviously much more difficult to highlight the dependence of the soil tillage draft force on the working speed than on the working depth that characterizes the process. In addition, in general, the maximum values of the working speed indicated by the manufacturers are much lower than the critical speeds at which the maximization or minimization of some of the measures of the intensity of the connection between the soil tillage draft force and the working speed occurs.

It is noted that, in the case of the correlations between the soil tillage draft force and the simple parameters, depth and working speed, the optimal exponents of these parameters remain constant, at the value 1 for the working depth and 2 for the working speed. This is most likely due to the fact that the "experimental data" I worked with are obtained by simulation using a Goriacikin-type mathematical model.

The correlation coefficient of the soil tillage draft force with the working speed can be increased using multiplicative combinations with the working depth. In this case, the form of the dependence of the correlation coefficient between the soil tillage draft force and the working speed-working depth combinations no longer presents extreme points, other than the ends of the range of variation of the travel speed. Both the correlation coefficients and the  $x$ -exponents show a faster increase to a value close to  $v_{rds}$ , followed by an approximately asymptotic trajectory. This behaviour indicates to the experimenters that in order to highlight the influence of the working speed in the soil processing process, it is necessary to exceed appreciably the upper limit of the working speed indicated by the producers.

The increase of the working speed, in physical experiments, in the field, is limited by various obstacles: the characteristics of the soil, the terrain, the available traction power, but also the designed resistance of the load-bearing structures (load-bearing structure of the combinator and working body supports). Combinations between various working conditions can lead to damage to the resistance structure of the combinator, but also to the shutdown of the unit, in case the tractor cannot touch the desired speed.

As important directions for the continuation of this study, comparative research on "experimental data" produced by using other mathematical models of soil tillage draft force that are found in the literature is recommended. It is also recommended to exploit any published experimental data, to study the intensities of the relationship between soil tillage draft force and working depth, working speed, if possible, soil parameters, geometric parameters of working organs, etc. It is also considered to expand the area of statistical tools used in such investigations.



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