Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XXXVIII
Broj 2, 2013.
Strane: 13 – 22

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XXXVIII
No. 2, 2013.
pp: 13 – 22

UDK: 631.51.01

Originalni naučni rad
Original scientific paper

SOIL MOISTURE INFLUENCE ON THE ENERGY OF AGRICULTURAL PROCESSES

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Abstract: This article exposes the results related to one of the issues left open after a series of articles mentioned in the bibliography, which occurred in the years 2011-2013. A series of articles that were mentioned before reconsidered the workflow optimization problem of agricultural aggregates developing fundamental calculation in the 1950-1980s literature. Some open problems still arise from the theoretical and empirical reasoning. A solution to one of these problems is given in this article. The solution exposes an input mode of the soil moisture influence on the existence and quantification of possible optimal point in the space energy workflow of agricultural aggregates.

Key words: *soil, moisture, optimal points, influence, agriculture, processes*

INTRODUCTION

The importance of the working regime optimization issue of agricultural processes is not appropriate to be highlighted in this paper. The importance of this problem is exacerbated by the need to reduce fossil fuel consumption and pollutant emissions, but on the other hand, the need to increase food production and safety, generated in turn by rising of the global population.

In this context, anticipating less severity these phenomena, the optimal research from the last half of the twentieth century, opened a number of issues, solved in theory and using computation techniques within the reach during those years. After 1990, and especially in recent years, I reopened this issue, due to the identification of interesting and deeper ways. The main direction of these deeper studies was determined by more

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advanced computing compared to the one available at the time when the problem appeared. With the birth of computers, it enabled the use of numerical experiments (simulations) in computation and thus the use of very time consuming optimization techniques. In addition to these directions of study, a fundamental problem appeared not only in mathematical terms but also as a physical theory of optimal points existence. It is well known that in general the dynamic processes described by linear operators don't have critical points in operation and in this regard, it was quite clear that the classical models of the work processes of agricultural aggregates were less likely to naturally give optimal points as minimal - maximal results of functions that are natural for the following processes: force, power, energy, fuel, ability to work, or combinations thereof. Articles [1] - [6], [9], [10] include our efforts in the two fields: to deepen the computational study in the sense of natural optimizing based on the above objective function and finding physical causes that lead to nonlinearities in describing the concerned processes, generators of some optimal natural points (obtained as a result of minimizing or maximizing some of the aforementioned objective functions).

In [11], [12], [13] and [14], for example, such nonlinearities were introduced in some drag opposing components of agricultural machinery, without a precise physical link. Such coefficients were introduced without a physical interpretation but only to obtain optimal points that are deductible using classical mathematical analysis tools.

In [2], [3], [4], [5] and [6] we extended the calculation for classical optimization and for some aggregate types for which it was not developed. We constantly tried to develop a common method for all units, computing differences were only given by each specific work process. We also permanently tried expressing the methods in a classical language of discrete mechanical systems and continuum mechanics. All results related to the same problems are presented in [7] and [8].

Starting with [2], [3], [4], [5], [6] emerged the question of physical grounding nonlinearities introduced in optimal calculation, i.e. placing them in friction expressions and soil resistance to deformation, also possibly to power-take-off resistance. In [9] and [10], this nonlinear problem is treated as the main subject and the as possible effects. In these last works it is shown that expressions terms coefficients that express resistances of various types may depend on soil moisture and crop residues and other physical and chemical characteristics of the soil and vegetation.

This article gives many examples of modeling the influence of humidity on energy optimization of agricultural aggregates work processes.

MATERIAL AND METHODS

The material from which construction starts is introduced based on (1) or on [9], formulas (3). These formulas have been used for energy optimizing work processes listed in the bibliography. The list of the parameters involved in the models appear in Table 1. Description of soil moisture introduction method in nonlinear expressions of resistance is given in this article only for the friction formula between wheels and ground (tractor wheel and agricultural machinery wheel). The other extensions will undergo similar transformations. The formulas for nonlinear functions of soil friction and resistance to deformation are:

Table 1. Significance of the parameters of the mathematical models

Parameters	*Notation*	*Unit*
Function of friction between the tractor wheels and the ground	f	-
Function of sliding friction of the machine with the ground	μ	-
Function of soil deformation resistance	k	$N\cdot m^{-2}$
Coefficients defining the critical points of the function of friction f	f_0, f_1	-
Coefficients defining the critical points of the function of friction μ	$\mu_0,\ \mu_1$	-
Coefficients defining the critical points of the function of soil deformation resistance, k	$k_0,\ k_1$	$N\cdot m^{-2}$
Coefficients defining the critical points of friction and resistance functions, f, μ, k (speed significance)	$v_f,\ v_{f0},\ v_{f1},\ v_\mu,\ v_{\mu 0},\ v_{\mu 1},\ v_k,\ v_{k0},\ v_{k1}$	$m\cdot s^{-1}$
Coefficients defining the critical points of friction and resistance functions, f, μ, k (moisture significance) in terms of soil moisture	$u_{f00}, u_{f01},\ u_{f10},\ u_{f11},\ u_{v00},\ u_{v01},\ u_{v10},\ u_{v11}$	-
Coefficients which produce the function critical point deviation cauzed by the moisture	$\delta,\ \delta_{f0},\ \delta_{f1},\ \delta_v,\ \delta_{v0},\ \delta_{v1}$	-
Soil moisture influence function	W	$N\cdot m^{-2}$
Minimum and maximum values of the influence function	$W_0,\ W_1$	
Minimum and maximum soil moisture of influence function	$u_0,\ u_1$	-
Coefficient of amplitude of soil moisture influence function	α	-
Soil moisture	u	-

$$f(v) = f_0 + 2\frac{f_1 - f_0}{v_f}v + \frac{f_0 - f_1}{v_f^2}v^2,$$
$$\mu(v) = \mu_0 + 2\frac{\mu_1 - \mu_0}{v_\mu}v + \frac{\mu_0 - \mu_1}{v_\mu^2}v^2, \tag{1}$$
$$k(v) = k_0 + 2\frac{k_1 - k_0}{v_k}v + \frac{k_0 - k_1}{v_k^2}v^2$$

or the formulas proposed in [9]:

$$f(v) = f_1\left\{1 - \exp\left[-\frac{2v^3 - 3\left(v_{f1} + v_{f0}\right)v^2 + 6v_{f0}v_{f1}v}{v_{f0}^2\left(v_{f0} - 3v_{f1}\right)}\ln\left(1 - \frac{f_0}{f_1}\right)\right]\right\},$$
$$\mu(v) = \mu_1\left\{1 - \exp\left[-\frac{2v^3 - 3\left(v_{\mu 1} + v_{\mu 0}\right)v^2 + 6v_{\mu 0}v_{\mu 1}v}{v_{\mu 0}^2\left(v_{\mu 0} - 3v_{\mu 1}\right)}\ln\left(1 - \frac{\mu_0}{\mu_1}\right)\right]\right\}, \tag{2}$$
$$k(v) = k_1\left\{1 - \exp\left[-\frac{2v^3 - 3\left(v_{k1} + v_{k0}\right)v^2 + 6v_{k0}v_{k1}v}{v_{k0}^2\left(v_{k0} - 3v_{k1}\right)}\ln\left(1 - \frac{k_0}{k_1}\right)\right]\right\}$$

The method of introducing moisture dependence is simple: formula coefficients (1) or (2) all or a part of them, turn from constant to moisture functions. In order to introduce moisture in functions (1) and (2) a very simple formula for moisture influence is used:

$$W(u)=\frac{W_0+W_1}{2}+\frac{\alpha\cdot\left(W_1-W_0\right)}{2}\sin\left(\frac{3\pi u}{u_0+u_1+2\delta}\right) \tag{3}$$

The function W can be the same for all parameters involved in the formula of a friction function or different for each one. The form (3) of a function humidity influence function is not necessary. The authors can modify the model to achieve as fair as possible representation of reality using experimental data and the method of the smallest squares. Moisture influence function for each formula parameter (1) and (2) will be specified by moving the W function to index, in this article, the general form (3) being considered for all parameters.

RESULTS AND DISCUSSION

As a transformation example it will only be given the first formula in (1) and (2) the other formulas being similar. In the first stage, the first formula from (1) turns into:

$$f\left(v,u\right)=F_0\left(u\right)+2\frac{F_1\left(u\right)-F_0\left(u\right)}{V_f\left(u\right)}v+\frac{F_0\left(u\right)-F_1\left(u\right)}{V_f^2\left(u\right)}v^2 \tag{4}$$

where the constants are replaced by the moisture influence functions:

$$\begin{aligned}
F_0(u)&=\frac{f_{00}+f_{01}}{2}+\frac{\alpha\cdot\left(f_{01}-f_{00}\right)}{2}\sin\left(\frac{3\pi u}{u_{f00}+u_{f01}+2\delta_{f0}}\right),\\
F_1(u)&=\frac{f_{10}+f_{11}}{2}+\frac{\alpha\cdot\left(f_{11}-f_{10}\right)}{2}\sin\left(\frac{3\pi u}{u_{f10}+u_{f11}+2\delta_{f1}}\right),\\
V_f(u)&=\frac{v_{f0}+v_{f1}}{2}+\frac{\alpha\cdot\left(v_{f0}-v_{f1}\right)}{2}\sin\left(\frac{3\pi u}{u_{v10}+u_{v11}+2\delta_v}\right)
\end{aligned} \tag{5}$$

For the first nonlinear expression (2), instead of the last relation in (5) two similar relationships appear:

$$V_{f0}(u)=\frac{v_{f00}+v_{f01}}{2}+\frac{\alpha\cdot\left(v_{f00}-v_{f01}\right)}{2}\sin\left(\frac{3\pi u}{u_{v00}+u_{v01}+2\delta_{v0}}\right),$$
$$V_{f1}(u)=\frac{v_{f10}+v_{f11}}{2}+\frac{\alpha\cdot\left(v_{f10}-v_{f11}\right)}{2}\sin\left(\frac{3\pi u}{u_{v10}+u_{v11}+2\delta_{v1}}\right) \quad (6)$$

When the friction function expression relations (2) take the next form:

$$f(v,u)=F_1(u)\cdot\left\{1-\exp\left[-\frac{2v^3-3\left(V_{f1}(u)+V_{f0}(u)\right)v^2+6V_{f0}(u)V_{f1}(u)v}{V_{f0}^2(u)\left(V_{f0}(u)-3V_{f1}(u)\right)}\ln\left(1-\frac{F_0(u)}{F_1(u)}\right)\right]\right\} \quad (7)$$

The behavior of the friction function, modeled by (6) is plotted in Fig. 1, 2 and 3.

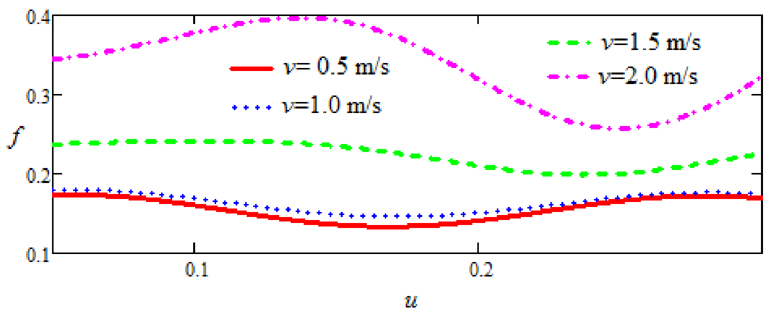

Figure 1. Dependence of f on the soil moisture, u for four values of speed, version (1)

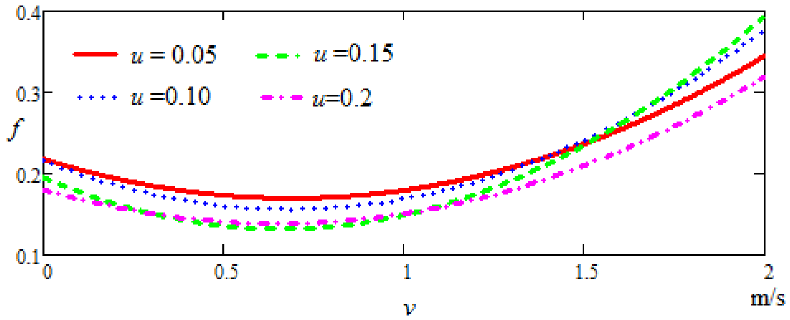

Figure 2. Dependence of f on the working speed for four moisture values, version (1)

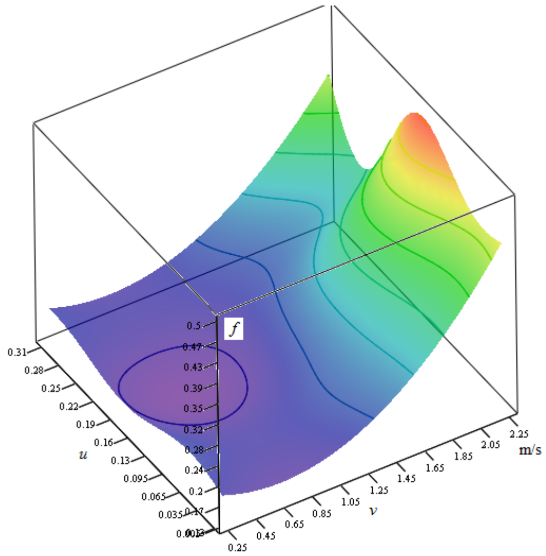

Figure 3. Dependence of friction function, f on the working speed and soil moisture, version (1)

The dependence of the friction function between the wheels and ground unit and/or the vegetation on soil moisture and working speed, shaped by function (7), is plotted in Fig. 4, 5 and 6.

It is noted that the variation of parameters defining the dependency of velocity for the friction function, relative to humidity, leads to changes in optimal points: their displacement and / or quantitative changes. In addition special qualitative phenomena can occur: the disappearance of optimal points or transformation of minimum points in maximum points.

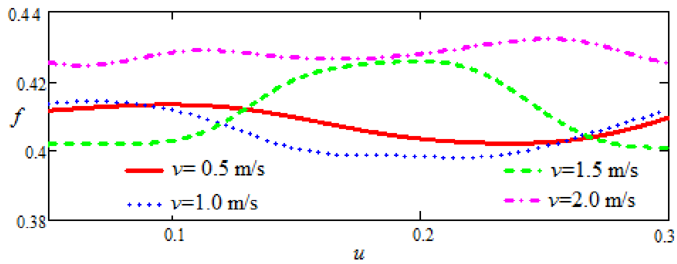

Figure 4. Dependence of f on the soil moisture for four values of working speed, version (2)

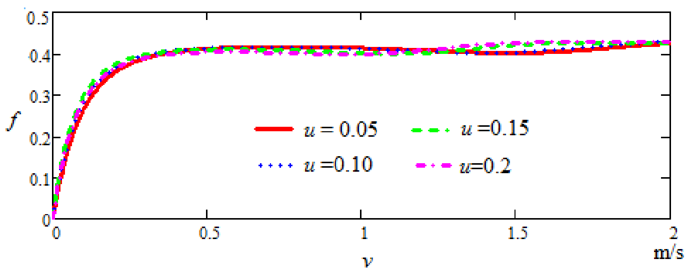

Figure 5. Dependence of f on the working speed for four moisture values, version (2)

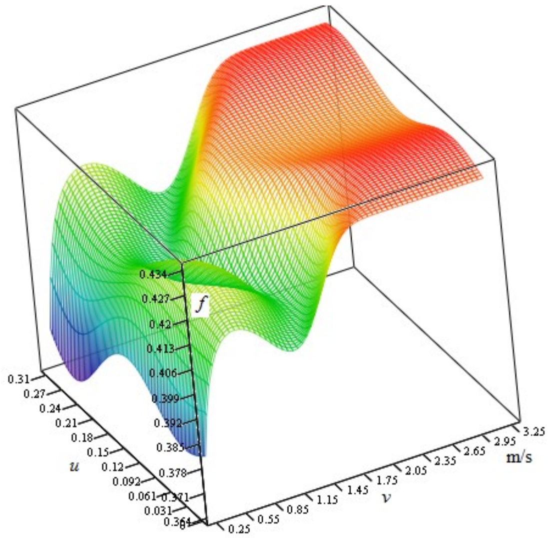

Figure 6. Variation of friction function on speed and soil moisture, version (2)

The above results were used in the optimization process as described in [2] and [10], for example. Optimization was performed for the work process of the U-650 M tractor - FP7 chisel plow unit. The results are concentrated in Table 2, for all the four objective functions that are used and described, for example, in [10]. Note that these results are superior to those from [2] and [10], because they contain an optimal information in addition: optimal humidity to achieve the optimal value for the objective process.

Table 2. Results of optimal calculus for the aggregate tractor U-650 M - plow PC7

Process parameters / *The objective function (optimization criteria)*	*Optimal values*						
	Working speed $[m \cdot s^{-1}]$	*Backing speed* $[m \cdot s^{-1}]$	*Travel speed* $[m \cdot s^{-1}]$	*Moisture*	*Energy consumption* $[kWh \cdot ha^{-1}]$	*Working capacity* $[ha \cdot h^{-1}]$	*Fuel consumption* $[l \cdot ha^{-1}]$
Energy consumption (minimal)	*0.975*	*0.967*	*0.971*	*0.207*	*149.166*	*0.149*	*14.064*
Working capacity (minimal)	*1.640*	*2.222*	*2.222*	*0.207*	*162.89*	*0.258*	*15.735*
Fuel consumption (minimal)	*0.987*	*0.963*	*0.966*	*0.205*	*149.177*	*0.151*	*14.063*
Global criteria (minimal value)	*1.944*	*5.983*	*4.559*	*0.062*	*161.567*	*0.318*	*15.718*

The models of agricultural aggregates workflow that perform such optimizations are very complicated. These models extend to include some a large number of parameters

(30-100 and more) and a large number of relationships, many of them non-linear (tens). For these reasons, this article cannot detail such a model. Mathematical models are constructed and used in the articles mentioned in the bibliography. Access to these items is free.

CONCLUSIONS

Nonlinear resistance functions in relation to the speed of travel, which contributes greatly to the existence and location of optimal points in space energy workflow of agricultural aggregates, depending on other parameters of the work process, among which one of the most important is soil humidity.

In this paper we presented a construction method of the dependence of moisture resistance functions (speed dependent) developed in previous works. The method and the results are just a proposal that needs addressing and improving within a wide circle of specialists. Improvement can be made only by major experimental studies, because functions of resistance depend on other parameters that characterize the physicochemical properties of the soil.

The use of friction and soil deformation resistance functions, allowed the insertion of an essential parameter for soil (moisture) in the set of parameters from the operation of agricultural aggregates energy optimization. The introduction in the calculation of this parameter was expected because the sphere of agricultural management concepts, optimal humidity favorable to various work processes in agriculture is an old and natural concept. The quantification and its influence in the work were the main contributions to the research from which the results were presented in this article.

From the two versions of the proposed strength functions formulas, the first is simpler, more stable, but in the case of aggregate dynamics study, it must be filled with a Heaviside factor type in speed, otherwise leading to abnormalities in the transient motion phase. For this reason, the second equation version of resistance function is more natural, in which, for zero speed, the resistance functions are canceled.

Therefore, the results presented in this article represent a link in the chain of results that follow the research conducted in the last two years and whose origins come from the optimal research of the twentieth century. But this research is not yet over.

The first direction is further optimized recalculation using the resistance functions proposed in this article and the influence estimation of the moisture parameter.

On the horizon, there are researches that must resume full optimization calculation in an ever more realistic way. This framework will be a high scientific level, that should include aggregate dynamics restrictions on the machine’s traction limits, the topology of the work field. Furthermore, in this context the aggregate dynamics is not a simple one, addressed as in classical mechanics of material point motion. Aggregate dynamics is coupled with control functions developed by the operator, functions that give traction strength and direction of the field.

Objective functions (power, fuel consumption, work capacity) remain the same, but this time optimization parameters will not be numerical, but functions (speed) of certain parameters, form a functional space. Thus, the problem is transferred from the classical mathematical analysis in the functional analysis, more complex and with results that are difficult to interpret. This is the targeted direction at this time, direction in which the presented results in this article will surely be used.

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UTICAJ VLAŽNOSTI ZEMLJIŠTA NA ENERGIJU PROCESA U POLJOPRIVREDI

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Sažetak: U ovom radu su prikazani rezultati istraživanja u jednoj oblasti koja je ostala otvorena i posle serije izvora pomenutih u literature, a dobijeni su u periodu 2011-2013. Pomenuti radovi razmatrali su ponovo optimizaciju toka radnih procesa poljoprivrednih agregata razvijajući fundamentalni obračun u periodu 1950 - 1980. Neki otvoreni problemi i dalje nastaju iz teorijskih i empirijskih razloga. Rešenje jednog od ovih problema je dato u ovom radu. Rešenje prikazuje unos uticaja vlage u zemljištu na postojanje i kvantifikaciju mogu
poljoprivrednih agregata.

Ključne reči: *zemljište, vlažnost, optimalne tačke, uticaj, poljoprivredni procesi*

Prijavljen: *Submitted*:	11.06.2013.
Ispravljen: *Revised*:	12.06.2013.
Prihvaćen: *Accepted*:	17.06.2013.