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نشریه ماشین‌های کشاورزی
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Short Paper

Application of MS Excel to Estimate Power Needs of Tillage Tools

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Abstract

This study deals with the application of the Microsoft Excel for the estimation of the power requirements of some tillage implements. The mathematical formulas embedded in the spreadsheet file have been developed in the previously published papers; however, those formulas were augmented herein in order to contain some agricultural mechanization issues. Another feature of this article is the ability of the spreadsheet to generate trend curves automatically. The comparison of the power expenditure aspects of different tillage implements as well as the inspection of the effect of an arbitrary selected input parameter on the spreadsheet outputs were effectively performed. Numerically, the specific work of the rotary tiller was estimated two times to five times higher than the specific work of drawing implements. Furthermore, as an example of trend curves derived in this article, the increase in disc angle in the range of 25° to 70° reduced the draft and power needs of the disc plow by 66% and 54%, respectively. However, it increased the disc plow specific draft and power by 34% and21%, respectively.

Keywords: Draft force, Excel software, Mechanical power, Tillage implements

Introduction

Spreadsheets are a scientific tool which eliminates the boring and repetitive computational tasks that may be carried out manually (Oke, 2004). It becomes increasingly popular in engineering because of their instinctive cell-based structure and simply applied capabilities. For example, Excel facilitates the user with numerous number of cells which intentionally can be linked and cooperated together. These cells along with built-in robust programming environment, i.e., Visual Basic for Applications or VBA, can be desirably customized to implement the models required for solving engineering problems. Getting involved to solve the problem using Excel helps the students discover the exact procedure working behind the solver programs. Graphical features of Excel also permit obtaining various plots which are appropriate for educational purposes (Niazkar and Afzali, 2015).

On the other hand, various advantages will be achieved if the mechanical power required for the operation of tillage implements is available. For example, proper matching of a machine with its prime mover as well as designing a new tillage implement depends on the availability of the power requirement of the machine. While the majority of researchers focused on the power prediction of a single tillage implement (Ahmadi and Beigi, 2018; Bentaher *et al.*, 2008; Okayasu *et al.*, 2012; Karmakar and Kushwaha, 2006; Shmulevich, 2010), very few of them examined the possibility of combining power prediction models of some tillage implements (Anpat and Raheman, 2017; Godwin and O'Dogherty, 2007).

Regarding the application of spreadsheets in Biosystems engineering, a pioneer study was conducted by Jones and Grisso (1992). They used a spreadsheet to maximize tractive efficiency of a two-wheel drive tractor as a function of wheel slip, and to determine the failure force exerted on a tillage tool as a function of the rupture angle of the soil. In another study, Zoz and Grisso (2003) have demonstrated that the use of spreadsheet templates is more efficient than the original iterative procedure used to predict the

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performance of 2WD and 4WD/MFWD tractors based on the Brixius model. Furthermore, Grisso *et al.* (2007) have demonstrated the use of a spreadsheet for matching tractors and implements. The spreadsheet was based on the ASABE Standard D497.5 and the Brixius Model to predict implement draft and tractor performance, respectively. The results showed that the spreadsheet can be used effectively to match implements with tractors.

The aim of this article is the presentation of an Excel spreadsheet file having the power estimation capability for some tillage implements. The mathematical formulas used here have been developed in the previously published papers. Therefore, this paper does not deal with the details of the development of the formulas; however, the utilization of the developed models is examined herein. Other features of this paper are as follows:

- The previous formulas were augmented herein in order to contain some agricultural mechanization issues (i.e. the estimation of the machine field capacity and the time required for a machine to till a field having a known area).
- The ability of the spreadsheet to generate trend curves automatically. A trend curve is a chart that shows the effect of an independent parameter of the model on the spreadsheet outputs. The trend curves can be used to determine optimum working conditions of a machine; therefore, the results derived from them can be interesting for a machine designer as well as a farmer.

The considered tillage implements contain: a chisel plow (Ahmadi, 2017b), a disc harrow (Ahmadi, 2018), a disc plow (Ahmadi, 2016a), a moldboard plow (Ahmadi, 2016b), a rotary tiller (Ahmadi, 2017a), and a subsoiler (Ahmadi, 2017c). The power estimator of each machine receives the values of its inputs and produces its outputs based on the dedicated mathematical formulas of that machine.

Materials and Methods

Excel spreadsheet file

Input parameters of the spreadsheet are classified into two groups: 1- Common parameters among all machines, that contain soil specifications and field conditions (soil cohesion, coefficient of soil internal friction, soil bulk density, field area and field efficiency of the machine), 2- Machine dedicated parameters which contain machine specifications and working conditions. Figure 1 depicts the working environment of the file. The examined Excel file has been attached to this paper as a supplementary material for inspection and utilization (please change the file name to "Augmented Excel file" in order to work correctly). After the file is executed, the operator faces the common parameters worksheet, where he/she can specify values for the soil properties and state parameters. Then, regarding the examined tillage implement, one of the bottom worksheets (highlighted in different colors) is selected and values of the machine and working condition parameters are specified. Finally, output parameters will be generated.

Tillage implements are also divided into two groups: 1- Drawn machines, also known as passive implements, which receive drawbar power, 2- Active implements, which receive rotary power. The file outputs for drawn machines are: draft force, drawbar power, specific draft and specific drawbar power (obtained from the ratio of draft force/drawbar power to the cross-sectional area of the affected soil), field capacity of the machine, and the time required for the machine to finish work. The file outputs for the active implement are: torque requirement, rotary power (specific rotary power), specific work (obtained from the ratio of work carried out by the machine to the volume of the affected soil), field capacity of the machine, and the time required for the operation. Because some Macros are embedded in the developed spreadsheet, the Macros should be enabled after the file was executed. This can be carried out using the “Security Warning” dialog box located below the ribbon of the Excel file (Figure 1).

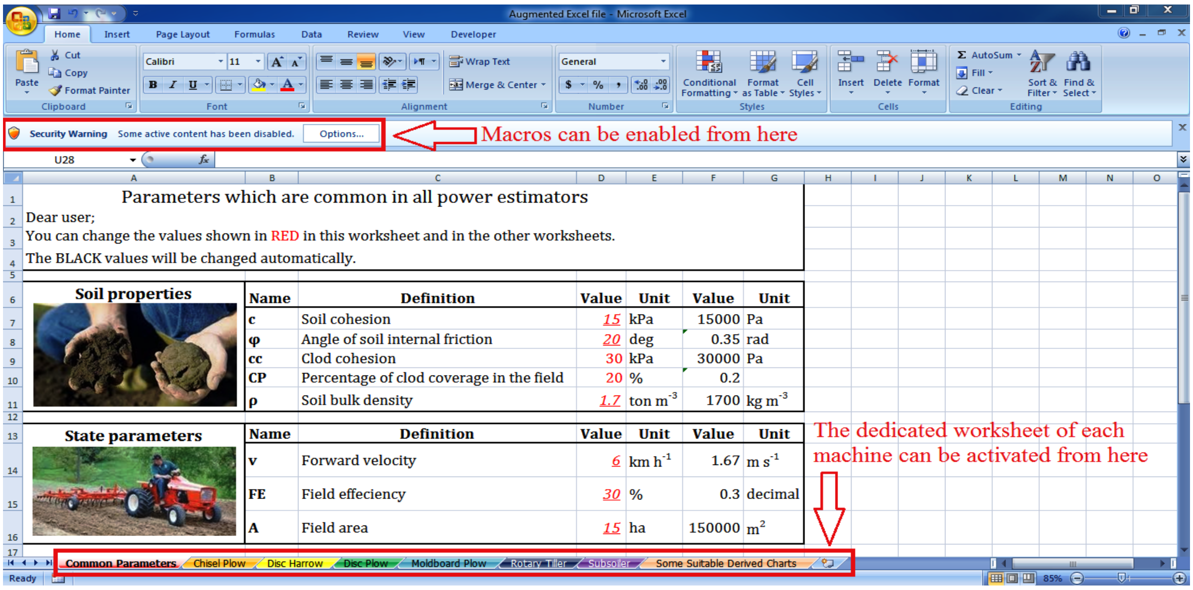

Fig.1. General view of the working environment of the spreadsheet

The spreadsheet offers two modes of operation: 1- To compare different tillage implements regarding their power needs. In order to cancel the effect of the cross-sectional area of the affected soil on a machine's power need, the file outputs having the prefix of “specific” should be utilized, 2- To inspect the effect of an input parameter on the estimator outputs. The optimum working conditions of the machine will be achieved, if the output curves showing the effect of each input parameter on the estimator outputs are generated. The instruction for obtaining trend curves is as follows:

- The name of the target parameter and its value should be introduced in the blue-bordered table.
- The Macro code that corresponds to the target parameter should be executed. The Macro name is available in the blue-bordered table when the parameter name is introduced. Pressing the ALT and F8 keys simultaneously, opens the Macro dialog box where you can select the appropriate Macro name. Clicking on the Run button is the last step to reach the trend curves.
- When the trend curves are generated, the value of the examined parameter in the black-bordered table should be converted to a new value manually, to avoid automatic re-altering of it.

Results and Discussion

Tables 1, 2 and 3 specify show the values of input parameters that are common in all power estimators, input parameters of drawn implements, and input parameters of the rotary tiller, respectively. Table 4 compares the examined tillage implements about the generated outputs.

Table 1- Input parameters shared among all power estimators

	Name	Definition (unit)	Value
Soil properties	c	Soil cohesion (kPa)	15
	cc	Clod cohesion (kPa)	30
	CP	Percentage of clod coverage in the field (%)	20
	ρ	Soil bulk density (g cm^{-3})	1.7
	φ	Angle of soil internal friction (°)	20
State parameters	A	Field area (ha)	15
	FE	Field efficiency (%)	30
	v	Forward velocity (km h^{-1})	6

Table 2- Input parameters of drawn implements

Name	Definition (unit)	Value
Δh	Soil vertical swell created by a subsoiler (cm)	3
An	Surface area of a subsoiler wing (cm^2)	150
b	Working width of a plow bottom (cm)	30
Dp	Depth of primary tillage before disc harrowing (cm)	25
h	Working depth of different implements (cm)	10, 20, 30, 80
M	The mass of soil engaging tool of an implement (kg)	10, 45, 150
N	Number of the chisel plow or subsoiler shanks	3, 5
Nb	Number of disc blades per gang	10
OPb	Overlap percentage of disc blades (width-ways) (%)	0, 30
OPs	Overlap percentage of the disturbed soil (%)	0, 30
R	Radius of a disc blade (cm)	15, 30
t	Thickness of a subsoiler shank (cm)	6
Ws	Width of the chisel plow or subsoiler shank (cm)	3, 10
Ww	Width of a subsoiler wing (cm)	30
α	Rake angle (°)	0, 15
δ	Angle of soil-metal friction (°)	20
η	Angle of soil displacement in horizontal plane (°)	48, 75
θ	Moldboard tail angle (°)	30
θd	Disc angle (°)	45, 70
θg	Disc gang angle (°)	20

Table 3- Input parameters of the rotary tiller

Name	Definition (unit)	Value
BL	Blade length (cm)	7
BW	Blade width (cm)	5
Nb	Number of blades per flange	3
Nf	Number of flanges of the rotary tiller	7
R	Radius of the rotor (cm)	24
ω	Angular velocity of the rotor (rad s^{-1})	30

Table 4- Comparison of the examined tillage implements based on the spreadsheet outputs (a: Chisel plow, b: Disc harrow, c: Disc plow, d: Moldboard plow, e: Rotary tiller, f: Subsoiler)

Name	Definition (unit)	a	b	c	d	e	f
DPR	Drawbar power requirement (kW)	49.6	13.69	18.45	28.05	-2.32	107.16
DPs	Specific power (W cm^{-2})	6.79	7.06	10.56	9.35	61.31	5.03
FC	Field capacity of the machine (ha h^{-1})	1.02	0.82	0.4	0.63	0.41	1.12
P	Draft force (kN)	29.73	8.2	11.05	16.78	-1.39	64.18
Ps	Specific draft (N cm^{-2})	4.07	4.23	6.32	5.59	-2.84	3.01
RP	Rotary power requirement (kW)	0	0	0	0	30.04	0
RT	The time required for the operation (h)	14.7	18.3	37.5	23.8	36.6	13.4
SW	Specific work (kJ m^{-3})	24.4	43.4	63.3	56	114.67	30.1
T	Required torque (Nm)	0	0	0	0	1001.28	0

The specific work of rotary tiller, which is two times to five times higher than the specific work of drawn implements, is the main point derived from Table 4. This result is in accordance with reports of other researchers (Srivastava *et al.*, 2006) including the negative draft produced by the active implement. The specific draft forces of drawn implements obtained herein are comparable to the corresponding outputs of the estimating formulas given in the ASAE standard (ASAE Standard D497.4) regarding the operation of the examined machine in an average textured soil.

Figure 2 shows the example trend curves derived from the spreadsheet file. Some suitable charts have been also gathered in the last worksheet of the supplementary material file.

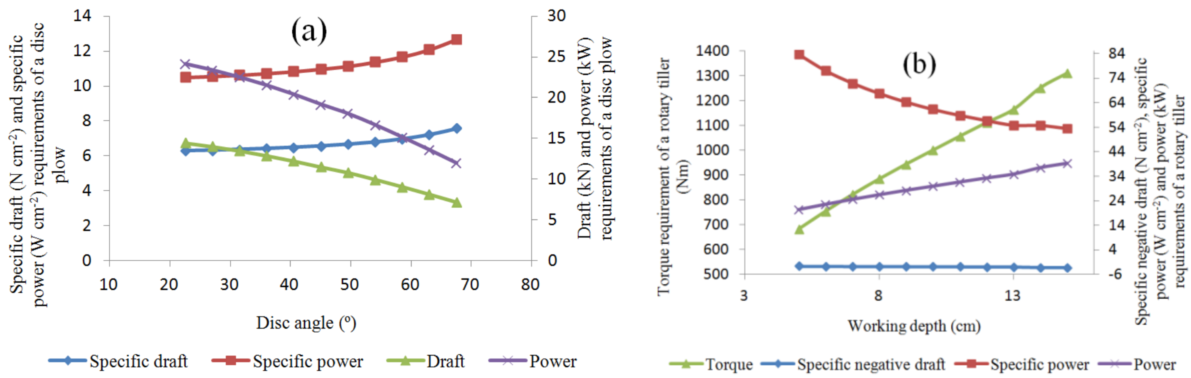

Fig.2. Example trend curves obtained from the developed spreadsheet

Figure 2a shows the variation of the disc plow draft and power, as well as specific draft and power as a function of disc angle. The increase in disc angle between 25° to 70° reduces the draft and power needs of the disc plow by 66% and 54%, respectively. However, it increases the specific draft and power by 34% and 21%, respectively. Therefore, if the available mechanical power is the restricting criterion to design a disc plow, the machine must have a higher disc angle; otherwise, it is better to design the machine with a lower disc angle. Figure 2b depicts the variation of the rotary tiller torque and power, as well as specific negative draft and power as a function of the machine working depth. Increasing the working depth of the rotary tiller between 5 cm to 15 cm, increases the torque and rotary power requirements of the machine by 64% and 50%, respectively. However, it decreases the specific power of the machine by 43%. Therefore, at the expense of the increase in torque and power requirements of a rotary tiller, it is advisable to increase the working depth of the machine as much as possible.

As another example of the application of the spreadsheet for the comparison of similar tillage implements with regard to their power needs, the trend curves of a disc plow and a disc harrow is shown in Figure 3a and 3b, respectively.

To have a fair comparison, the radius of disc blade is considered 20 *cm* in both machines. Table 5 shows the results of this.

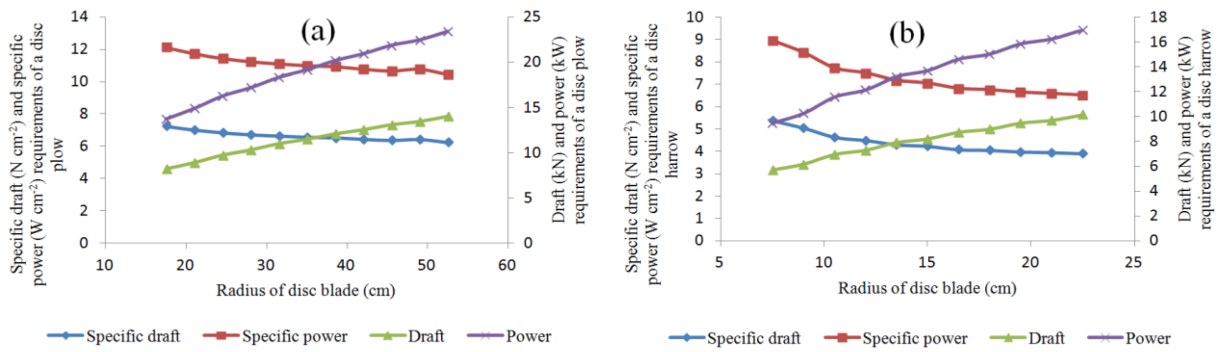

Fig.3. Effect of radius of disc blade on the power needs of a disc plow and a disc harrow

Table 5- Comparison of a disc plow and a disc harrow regarding their power needs (radius of disc blade is 20 cm)

	Disc plow	Disc harrow
Draft (kN)	8	9
Power (kW)	16	17
Specific draft (N cm^{-2})	7	4
Specific power (W cm^{-2})	13	7

Table 5 demonstrates that although the examined disc plow and harrow almost have the same draft and power requirements, the specific draft and power of the disc harrow is almost half of the disc plow i.e. the disc harrow affects the soil cross-sectional area twice in comparison with the disc plow. This result is expected due to the value of the disc gang of a disc harrow (20°) in comparison with the disc angle of a disc plow (45°)

Conclusions

1. The spreadsheet developed based on the mathematical formulas given in the previously published papers could effectively predict power needs of some tillage implements.
2. The comparison of power expenditure aspects of different tillage implements as well as the inspection of the effect of an arbitrary selected input parameter on the estimator outputs were effectively performed using the spreadsheet developed herein.
3. The spreadsheet effectively estimated field capacity of the examined machines, too.

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مقاله کوتاه پژوهشی

کاربرد نرم‌افزار اکسل برای تخمین نیاز توان مکانیکی ادوات خاک‌ورزی

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چکیده

این مطالعه راجع به کاربرد نرم‌افزار مایکروسافت اکسل در تخمین نیازهای توانی برخی از ادوات خاک‌ورزی است. فرمول‌های ریاضی به‌کار رفته در فایل صفحه گسترده، در مقالات منتشر شده قبلی توسعه یافته بودند؛ به هر حال آن فرمول‌ها در این مقاله در جهت شمول برخی موضوعات مکانیزاسیون کشاورزی تکمیل شدند. ویژگی دیگر این مقاله توانایی صفحه گسترده در تولید خودکار نمودارهای روندنما است. مقایسه ادوات خاک‌ورزی مختلف از نقطه نظر نیازهای توانی، همچنین مطالعه اثر یک پارامتر ورودی دلخواه روی خروجی‌های صفحه گسترده به‌طور مؤثری در این مقاله صورت پذیرفت. از نظر عددی تخمین زده شد که مقدار کار ویژه گاوآهن دوار ۲ تا ۵ برابر کار ویژه ادوات خاک‌ورزی کشیدنی است. به علاوه، به‌عنوان مثالی از نمودارهای روند نمای به‌دست آمده از این مقاله، افزایش زاویه بشقاب در بازه ۲۵ تا ۷۰ درجه، نیازهای مقاومت و توان کششی گاوآهن بشقابی را به‌ترتیب ۶۶ و ۵۴ درصد کاهش داد؛ هر چند این کار به افزایش ۳۴ و ۲۱ درصدی به‌ترتیب مقاومت کششی ویژه و توان کششی ویژه این گاوآهن منجر شد.

واژه‌های کلیدی: ادوات خاک‌ورزی، توان مکانیکی، مقاومت کششی، نرم‌افزار اکسل

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