ABOUT SELECTION OF MACHINERY FOR COMBINED FIELD AND TRANSPORT PROCESSES IN SMALL FARMS

Chavdar Vezirov, Atanas Atanasov
University of Ruse, Bulgaria
vezirov@uni-ruse.bg, aatanasov@uni-ruse.bg

Abstract. A method is suggested for reasonable choice of tractors, agricultural machines and vehicles to implement linked field and transport processes based on easily accessible generalized available experimental data. Results of such procedure are site specific solutions appropriate for small farms. Basics of this method are power and forces balances for each definite possible machine and tractor unit. Resistant draft force is predicted according to the terrain, work period, tractor and machine undercarriage, weight of the unit and goods in the storage bunker, hopper, tank. Fuel consumption is estimated for all regimes: stopped engine, standby, unit idle, turning without productivity, work with or without movement, unit transit to a place for loading or unloading of the machine storage volume (bunker, trailer, lorry bodywork). Time utilization is calculated for two main cases – summary for the shift and for each working cycle. Each time expenditure is included in the shift duration base on official recommendations, experimental data and simple formulas. The above mentioned equations take into account the traveled distance in one cycle, field speed, amount of gathered product from the field or spreading product for a specific area. Particularly for transportation forward speed is calculated as a function of engine and transmission potential, terrain surface, road width, distance between places for passing of vehicles, traffic intensity. Selection is made by comparing of field and transportation capacity, fuel and labor consumption. For comparison, the working capacity is shown in the services area for a shift. Some differences of combined field and transport operations in cases of continuous and interrupted processes are considered.

Keywords: selection, farm machinery, field process.

Introduction

As it is well-known agricultural transportation is a crucial factor in improving agricultural productivity. In addition, its features in small farms makes this activity more difficult. In general, data on expected costs and revenues are needed for a correct decision. Especially in agriculture, it is easier to determine in advance the necessary technical and human resources, land, fuels, pesticides. With established technologies for growing, harvesting and storing plant products from the field, it is important to determine what time costs, fuel, labour we will need and how much work with the desired quality we will get. The requirements for the solution are the execution of all work on time in order to create appropriate conditions for the development of plants at a reasonably low cost. For mobile agricultural machinery the main indicators are the field capacity and fuel consumption.

Among the main well-tested sources prescribing the methods for determining such indicators for agriculture are [1-5]. Unfortunately, they do not contain enough data to determine the field capacity and fuel consumption during transportation. It is recommended that the calculation of vehicles be based on the weight of the trailers and the load in them. In the real world, however, there is a great variety of conditions, especially in agriculture. For example, vehicles have to travel on paved or unpaved roads, on dirt roads and off-road. Moreover, specific motion resistance, the angle of slope of the ground surface and the radius of curvature width often change for the same road. This, together with the presence of natural obstacles, road signs, traffic intensity and many other specific conditions change the possibilities of movement and especially the speed limit.

Another difficulty in determining the field capacity and fuel consumption stems from the need to repeatedly make the necessary calculations for different conditions. Usually specialists are limited to general, principled recommendations [6-8]. Other proposals in this area partially solve this problem [9-12]. Their main drawback is the lack of specific data and dependencies for their calculation.

The influence of management mode of transportation in agriculture is very rarely considered. The publications in this area are related mainly to specific conditions [13-15]. However, experience shows that transport services in agriculture can be effective either in direct transport or in indirect transport, or in the use of trailers pulled in the field by tractors and in roads - by lorry cars, etc. [16; 17]. The issue of determining fuel consumption is also important. It is usually based on outdated official documents [18] or on the basis of the specific cost of rated engine power. Existing proposals for accounting for the engine load and the ability to work under the rule gear up, throttle down require additional information [1; 19].

In the aspect of the identified problems, the task was set to propose an approach and a practical procedure for determining field capacity and fuel consumption as the main indicators for the selection of means for the implementation of related field and transport processes in small farms.

Method

It is a common truth that the choices we make determine our future. A well-founded choice facilitates the provision of the necessary finances, project preparation and implementation. We assume that the formation of the machine-tractor fleet by type and quantity will be based on a global extremum. Given the complexity of the task and the large amount of information about optimization, we use a heuristic approach, objectified and facilitated by programmed automated calculations based on spreadsheets. In this way it will be possible to evaluate enough practically possible solutions and to present them with their numerical indicators.

For a reasonable solution in this case, in addition to a correct simulation model, reliable input data are needed - field capacity and fuel consumption. The wide variety of conditions and means for the execution of works can be alleviated, if the areas of search for solutions are narrowed in advance. For example, to specify in advance the means for carrying out the field work and especially the most complex of them - linked field and transport processes. One relatively simple way to solve this problem is to use easily accessible generalised available experimental data, i.e. from [1; 5]. Below is presented a procedure for determining the field capacity and fuel consumption suitable for the wide variety of agricultural machinery and farm management. It includes the following basic steps: selection of energy units according to the grown crops and their areaS, selection of implements, selection of the management mode of transportation, input of necessary data, comparing of the obtained results as a basis for further determination of machinery for the farm. This procedure is described in more details in [20; 21].

When determining the specific fuel consumption Sfc, the dependence [1; 19] is used.

$$Sfc = \left(0.22 + \frac{0.096}{X}\right)\left[1 - \left(\frac{\omega_{pt}}{\omega_{ft}} - 1\right)(0.45X - 0.877)\right], \quad (1)$$

where $X = P/P_{rated}$;
ω_{pt} – partial throttle engine speed;
ω_{ft} – full throttle engine speed;
P – equivalent PTO draft and rotary power required by current operation;
$Prated$ – rated PTO power available.

$$P \approx a + W * b + (F_i * A * W * T + c * W) * S + F_i * B * W * T * S^2 + F_i * C * W * T * S^3, \quad (2)$$

where F_i – dimensionless soil texture adjustment parameter, i is 1 for fine, 2 for medium and 3 for coarse textured soils;
A, B, C, a, b, c – machine-specific parameters [1]; A, B, C – for calculation of required rotary power; a, b, c – for calculation of PTO draft;
S – working forward field speed;
W – machine working width, or number of rows or tools;
T – tillage depth for major tools, or 1 for some minor implements.

Relations between the engine power and engine speed are presented by the 3rd polynomial, Leiderman-Khlistov equations [22]. The coefficients are calculated by the Excel method. The equations are compiled according to [23] with information about the rated power, rated engine speed, maximum torque and engine speed at maximum torque. Then from equivalent PTO power it is possible to find a real solution of cubic equations by Cardano method. It is especially important for the engine mode, when tractor engine is not heavily loaded. Otherwise some other solutions are recommended, it is possible to replace the machine with another with a larger width, increasing the number of machines by adding the squadron hitch, adding one more trailer, etc. When an overload is supposed, it is possible to reduce the number of machines, their width, goods in the trailer, or the forward ground speed.

Various algorithms for calculating the field capacity and fuel consumption based on one or more modes for unit operation have been developed. Each of them is compared by the need for consolidated data, the way of summarizing the information in a smaller number of calculation steps and obtained results. The calculation procedure is based on the length of the road traveled or the cultivated area. Spreadsheets have been selected for the calculations. In this case, it is necessary due to: the need to repeat the calculations, convenience of editing and revision, use of very repetitive data and clarity.

Comparing of algorithms for computing of the field capacity and fuel consumption can also be made taking into account the memory and time used.

Results and discussions

Only a small part of the obtained results is presented below. The reason is that the multitude of applied technologies and equipment in agriculture is huge and difficult to show comprehensively. The example of several typical aggregates for farms will illustrate the main features in determining the field capacity and fuel consumption, ways and possibilities for obtaining data with acceptable accuracy.

In Fig. 1 the results of the calculations for transportation of mineral fertilizer to the fertilization units in the field can be seen. The trailer is loaded in a farmyard with an electric hoist, and unloaded – with a big-bag lifter, mounted on a tractor.

	A	B	C	D	E	BZ	CA	CC	CD
12	agricultural operations	distance of transportation, km	fertilization, spraying, sowing rate, yield, t/dka	tractors, power, other machines		Wcм	g	for linked operations	
13				brand, model. modification		km/ shift	g/km		
14								Wcм, dka/ shift	g, g/dka
15	Travel from field empty on asphalt road	3.1				181	170		
16	Travel from field empty on dirty road	4.3				169	270		
17	Travel from field empty off road	0.5				103	530		
18	Travel to field full with fertilizer on asphalt road	3.1	0.12	Tractor ZF	Trailer, two axles, 12 m³	177	230		
19	Travel to field full with fertilizer on dirty road	4.3				169	730		
20	Travel to field full with fertilizer off road	0.5				79	1660		
21	Travel to and from field (forth and back)	15.8						826	73
22									
23	Travel from field empty	7.9				172	240		
24	Travel to field full with fertilizer	7.9	0.12	Tractor ZF	Trailer, two axles, 12 m³	170	510		
25	Travel to and from field (forth and back)	15.8						864	74
26									
27	Travel to and from field (forth and back)	15.8	0.12	Tractor ZF	Trailer, two axles, 12 m³	170	370	861	73
28									

Fig. 1. **Part of spreadsheet for calculation of field capacity and fuel consumption for tractor and trailer unit, transport fertilizer on asphalt road, dirty road and in field**

The columns BZ and CA show preliminary results for each mode of actions, and the columns CC and CD – for a shift. The results are similar apart from in how many rows are calculated. Such outcomes are possible owing to the way of summarizing information. For example, the specific motion resistance in the row 27 was calculated as a weighted average value for asphalt, dirty roads and off-road.

Another example – Fig. 2, refers to fertilizing. The tractor and spreader unit travel to the field boundary where they are loaded from lorry cars. Because of their high tire pressure on soil, lorry cars do not enter the field. Since in this case travel of the unit is only in the field, it is not necessary to summarize data for specific motion resistance. Here it is important to determine the right values for distance for each of unit activities. In a similar way it is significant to fix values for other events in the shift time, not connected directly to the main work, i.e., fertilizing. They are like the machine preparation time at the farmstead, in the field, adjustment, maintenance and repair time, operators, personnel time. Usually they are taken from an official document like [22]. Otherwise, the error may be greater than 10%, which is unacceptable.

A special problem in such procedure is connected with the unit work at low engine load. First, relationship between the diesel engine speed and fuel consumption is too sophisticated and it is different for the power droop curve and torque rise curve. It also changes as a function of the throttle down rate.

Larger deviation from the rated power leads to even greater deviations in the specific fuel consumption. In this case even use of "gear up, throttle down" control does not guarantee enough fuel savings. The cause is that the vehicle travels empty, which is typical for transportation in agriculture.

Most complex is the description of interaction between vehicles and agricultural machinery – Fig. 2.

	A	B	C	D	E	BZ	CA	CC	CD
12				tractors, power, other machines		Wсм	g	for linked operations	
13	agricultural operations	distance of transportation, km	fertilization, spraying, sowing rate, yield, t/dka	brand, model. modification		km/ shift	g/km		
14								Wсм, dka/ shift	g, g/dka
15	Fertilizing at forward speed and full width	3.1	0.12	Tractor ZF	Fertilizer spreader 6t	50	1050		
16	Turning at headland	0.2				50	990		
17	Travel to road of lorry car route	0.5	0.12			82	530		
18	Travel back to end of last fertilization	0.5	0.12			82	1340		
19	Loading of fertilizer				Big bag lifter				
20								441	105
21	Fertilizing	3.3	0.12	Tractor ZF	Fertilizer spreader 6t	48	1050		
22	Travel to road of lorry car route and back	1.0	0.12			78	790		
23	Loading of fertilizer				Big bag lifter				
24								430	101
25									
26	Fertilizing, travel and load	4.3	0.12	Tractor ZF	Fertilizer spreader 6t & Big bag lifter	38	1240	442	107
27									

Fig. 2. **Part of spreadsheet for calculation of field capacity and fuel consumption for tractor and spreader unit, transport fertilizer on asphalt road, dirty road and in field**

	A	B	C	D	E	BZ	CA	CC	CD
12				tractors, power, other machines		Wсм	g	for linked operations	
13	agricultural operations	distance of transportation, km	fertilization, spraying, sowing rate, yield, t/dka	brand, model. modification		km/ shift or dka/ shift	g/km		
14								Wсм, dka/ shift	g, g/dka
15	Loading of fertilizer and travel to field	1.25	0.05	Tractor 60 kW	Trailer 4 t	227	240		
16	Travel back to farm yard	1.25	0.05			123	500	2554	23
17	Fertilizing		0.05		Fertilizer spreader 2.5 m³	1382	50		
18								1382	73
19									
20	Loading of fertilizer and travel to field	1.25	0.05	Tractor 60 kW	Fertilizer spreader 2.5 m³	194	180		
21	Travel back to farm yard	1.25	0.05			123	340	1206	33
22	Fertilizing		0.05			1555	50	679	83
23									
24	Travel to field empty	2.50	1.5	Tractor 60 kW	Trailer 4 t	219	410		
25	Travel back to farmyard	2.50	1.5			93	970	35	2547
26	Travel parallel to harvester and loading		1.5			73	840	24	3387
27	Harvest of Jerusalem artichoke		1.5		Harvester 2.1 m	126	520		

Fig. 3. **Part of spreadsheet for calculation of field capacity and fuel consumption for combined processes: transportation by trailer and fertilizing; transportation and fertilization by spreader; harvest of Jerusalem artichoke and loading a trailer at the same time**

In case of transportation by the trailer, loading the spreader and fertilization first indices for vehicle are calculated – cells CC15 and CD 16, and then for combined process – cells CC18 and CD 18. It is obvious that one tractor and trailer unit can supply two tractor and spreader units. In case of transportation and fertilization by the spreader first indices are calculated – cells CC21 and CD 21, and then for combined process – cells CC22 and CD 22. Two tractors and tractor drivers are necessary in the first case and one tractor and tractor driver in the second one. This means that the productivity in both cases is approximately equal. The third case illustrates harvest of Jerusalem artichoke by a draft harvester without a bunker. A tractor and trailer unit have to travel parallel with the same ground speed as the harvester. Indices of the vehicle are calculated in two steps – in rows 25 and 26. The numbers in cells CC26 and CD26 are final. These examples show a possibility to calculate the field capacity and fuel consumption in the proposed spreadsheets. It is clear that determining the main performance indicators of machinery in combined processes is enough complex. That is why we attempt to obtain some equations between the machinery parameter field capacity and fuel consumption. Unfortunately, the relationships were too complicated – i.e., Fig. 4. In this example appropriate approximating curves can be presented by polynomial equations. One of the causes was described above and concerns calculation of the fuel consumption as a function of the power load and throttle down rate. The other one is a need to drive at a lower ground speed, so as not to overload the tractor engine for transport.

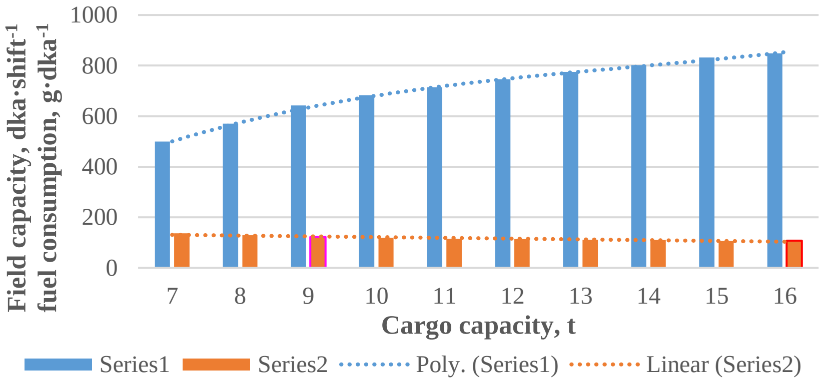

Fig 4. **Relationship between cargo capacity of tractor trailer and field capacity – in blue colour, and fuel consumption – in orange colour. Poly corresponds to approximate curve of a third degree polynomial, Linear - of a straight line**

Necessary memory and time for computing are not significantly different, that is why they are not important in the algorithm selection process. The information obtained in this way is satisfactorily detailed, with acceptable accuracy and can be used to determine the need for small farm machinery [24]. That is why automation of calculations with proposed spreadsheets may be a prerequisite for accessible, easy and accurate rationalization of the choice of the necessary machinery in small farms.

Conclusions

The choice of the algorithm for determination of the field capacity and fuel consumption of mobile machinery for implementing of combined field and transport processes depends on available facts and desired accuracy. The smaller number of steps in the calculation requires more complex dependencies to summarize the information. The calculation error in one step (in a row) compared to two, three, four and five steps is less than 12% for the specific fuel consumption and less than 5% for the field capacity. The data for the permissible forward speed, resistance forces and field efficiency should be specified with particular care. Application of spreadsheets for such computation makes the process easier, quicker, well-founded and enough detailed compared to regression equations.

Acknowledgements

This research is supported by contract 2021-FNI-01, funded by the Research Fund of the University of Ruse.

References

[1] ASAE 497.7. Agricultural Machinery Management Date. 2011
[2] ГОСТ 17460-72. Транспортно-производственные процессы в механизированном сельскохозяйственном производстве. Классификация, оценка и методы расчета. (Transport manufacture processes in mechanized agricultural production. Classification, estimation methods and calculation). (In Russian).
[3] Hunt D., Wilson D. (2016). Farm power and machinery management.
[4] Macmillan R. H. The mechanics of tractor – implement performance. 2002.
[5] Пособие по эксплуатации машинно-тракторного парка. (Tutorial for machine and tractor fleet exploitation). 1978. (In Russian).

[6] Иванов С. Тонкости подбора тракторных прицепов. (Finesse of tractor trailers selection). 2019. [online][21.03.2021] Available at: https://zen.yandex.ru/media/russianengineering/tonkosti-podbora-traktornyh-pricepov-5cae4deb7c77b000b28b81a0. (In Russian).
[7] Расчет эксплуатационных, технико-экономических и технологических показателей работы машинно-тракторных агрегатов. (Calculation of operational, technical, economic and technological indicators of machine and tractor units). 2011. (In Russian).
[8] Szpica D. New Leiderman–Khlystov Coefficients for Estimating Engine Full Load Characteristics and Performance. Chinese Journal of Mechanical Engineering, Volume 32. Issue 6. 2019.
[9] Aboukarima A. M. Interactive computer application for predicting performance indicators of a tractor-chisel plow system in C-sharp environment. Misr Journal of Agricultural Engineering, Volume 33, Issue 3, Summer 2016, pp. 751-788.
[10] Kamal L., Philip C. J., and Barrett W. T. Harvest Logistics in Agricultural Systems with Multiple, Independent Producers and No On-Farm Storage. [online][21.03.2021] Available at: https://myweb.uiowa.edu/bthoa/iowa/Research_files/HarvestNoStorage_posted.pdf
[11] Šumanovac L., Sebastijanović S., Kiš D., Transport u poljoprivredi. 2011. (In Croation).
[12] Cupiał M. and Kowalczyk Z. Optimization of selection of the machinery park in sustainable agriculture. Sustainability, 2020, 12 (4), 1380.
[13] Пехутов А. С. Обеспечение транспортно-технологического обслуживания АПК в Сибирском федеральном округе. (Transport and technological services for the agro-industrial complex in the Siberian Federal District). Диссертация. 2016. (In Russian).
[14] Евтушенков Н. Е., Курбанов Р. К. Технологии перевозок зерна и картофеля в сельском хозяйстве. (Technologies for transportation of grain and potatoes in agriculture). [online][21.03.2021] Available at: https://cyberleninka.ru/article/n/tehnologii-perevozok-zerna-i-kartofelya-v-selskom-hozyaystve/viewer. (In Russian).
[15] Чулков А. С. Методы исследований технологических схем транспортного обслуживания уборочных агрегатов. (Research methods for transport service technological schemes of harvesting units). [online][21.03.2021] Available at: https://cyberleninka.ru/article/n/metody-issledovaniy-tehnologicheskih-shem-transportnogo-obslu-zhivaniya-uborochnyh-agregatov. (In Russian).
[16] Левин В. Ф. Эксплуатация автомобильного транспорта в сельской местности. (Exploitation of road transport in rural areas). 1991. (In Russian).
[17] Комплекс эффективных решений для сельского хозяйства. (A set of effective solutions for agriculture). [online][21.03.2021] Available at: http://asm-altay.ru/images/pdf/cat_liliani.pdf. (In Russian).
[18] Типовые нормы выработки и расхода топлива на тракторно-транспортные работы в сельском хозяйстве. (Standard norms of production per shift and specific fuel consumption for tractor transportions in agriculture). 1989. (In Russian).
[19] Grisso R. Predicting Tractor Diesel Fuel Consumption. 2016. [online][21.03.2021] Available at: https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/442/442-073/BSE-328.pdf
[20] Vezirov Ch., Atanasov At., Vladut V. Calculation of field capacity and fuel consumption of mobile machinery with bunkers, tanks or other containers for agricultural goods. INMATEH, vol. 62, No 3, 2020.
[21] Vezirov Ch. Atanasov At., Hristov Hr. Ginchev G. Determination of resources necessities in agricultural production. Proceedings of the 41. International symposium on Agricultural engineering, Actual Tasks on Agricultural Engineering. 2013. pp. 24-33
[22] Steckel T. Entwicklung einer kontextbasierten Systemarchitektur zur Verbesserung des kooperativen Einsatzesmobiler Arbeitsmaschinen. Dissertation. 2018. (In German).
[23] Сидоров В.Н., Царёв О.А., Голубина С.А. Расчет внешней скоростмой характеристики двигателя внутреннего сгорания. (Calculation of external speed characteristic of an internal combustion engine). Современные проблемы науки и образования. 2015. № 1. (In Russian).
[24] Spiridonov V. About informed choice of machinery for field crop growing, (За информирания избор на техника за полевъдството). 57th Science Conference of Ruse University, Bulgaria. 2018. (In Bulgarian).