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ESTABLISHMENT OF THE PARAMETERS OF MACHINE-AND-TRACTOR UNITS AS THE BASIS FOR DEVELOPING MODELS OF TRACTORS AND AGRICULTURAL MACHINERY

by

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The objective of developing a classification system for tractors and agricultural machines is to enable a soundly-based choice to be made of the types of tractors and machines which will permit total mechanization of a given country's agriculture to be achieved with minimum labour requirements.

In the conditions prevailing in developing countries, it is particularly important to select from the very beginning types of tractors and agricultural machines which can immediately be used with the highest degree of efficiency in agriculture, but which can also be subsequently modified at minimum expense to satisfy the future requirements of a developing economy.

The term "type range" of tractors or agricultural machines means the set of types, sizes and models which, considered from a technical and economic point of view, can be assembled under the heading of a single application yet possess progressive features which take into account both existing and future requirements of the economy.

A type/size range of tractors or agricultural machines is a range or set of ranges of tractors or agricultural machines which are all designed for the same purpose (such as ploughing or tilling) and share the same main parameters.

A model is the actual manufactured version of a tractor or agricultural machine of a given type and size.

The basic steps which must be taken in the initial stage of developing types of tractors and agricultural machines are the development and verification of the economic soundness of machinery systems for the comprehensive mechanization of agriculture, the development of methods of putting into practice the appropriate machinery system (taking into account possible future changes in the technology of cultivation), the assembly of the necessary reliable data for making the economic calculations, and the execution of the economic calculations themselves.

Agriculture is quite different from industry, and the utilization of tractors and machinery in agriculture has its own special features.

Firstly, the cultivation of agricultural crops involves providing them with nourishment which is either already in the soil or is brought to them through the soil. In order to grow agricultural crops it is essential to have solar energy, which, however, falls uniformly over the whole illuminated area and, like plant nourishment, cannot be concentrated at isolated limited points. For this reason, agricultural activities must be spread over large areas of ground.

Secondly, the cultivation of agricultural crops involves the execution of a considerable number of different operations (working the soil, sowing, tending the plants, harvesting the crop, etc.). These operations can only be carried out by drawing agricultural machines through the fields so as to bring them to the points where the operations are to be carried out.

Thirdly, these operations cannot be carried out at arbitrary times. They must be carried out in accordance with agricultural technology at strictly defined times which depend on the location of the farm, the time of year, the soil chemistry, and the climatic and other conditions.

Fourthly, in carrying out the operations the machines must deal with living nature (plants, micro-organisms) whose state is constantly changing in accordance with biological laws.

All this means that there is a basic difference between agriculture and other branches of the economy, and this is the reason for the special conditions in which machinery has to be used in agriculture.

These conditions render impossible the arbitrary use in all countries of the same types of tractors and agricultural machinery, and special types of tractors and machinery must therefore be developed for the actual conditions of each country. The operations carried out in agriculture can be divided up into moving operations and stationary operations.

In moving or tractive operations, the machines are constantly moved through the fields by means of various tractive devices.

Stationary operations are carried out at places previously set aside for this purpose (threshing floors, silo trenches, silo towers, etc.) or else indoors, without any continuous movement of the machine through the fields.

As tractors and agricultural machines, joined together in machine-and-tractor units, are used primarily for the moving agricultural processes, the stationary processes will not be dealt with in this paper.

The moving (tractive) processes can be divided up, according to their function, into the following groups:

1. Clearing and improvement of agricultural land and preparation of fields;
2. Reclamation work;
3. Field protection work;
4. Crop spraying;
5. Working of the soil;
6. Application of manure and fertilizers;
7. Sowing and planting of agricultural crops;
8. Care of growing plants;
9. Harvesting of crops; and
10. Transport work.

The special features and level of development of agriculture in developing countries, the range of agricultural crops cultivated in those countries, and the geographical, soil and climatic conditions in which the crops are cultivated govern the extent to which any given moving process can be used.

These processes determine the special features of the tractors and agricultural machinery used to carry them out.

When we examine the process of cultivating any given agricultural crop, we find that all the operations making up the technical process of cultivation fall into one of three groups:

(a) Work of a general nature which is carried out not only in the cultivation of the crop in question but also in the cultivation of other crops (ploughing, harrowing, etc.);

(b) Special work carried out only in the cultivation of a given crop (planting, of beet, between-row cultivation, harvesting of maize, etc.);

(c) Auxiliary work, mainly transport and loading or unloading operations.

Different kinds of agricultural machines and tractors are required for carrying out these types of operations.

General-purpose agricultural machines are those for operations such as shallow ploughing, the loading and heavy application of manure and fertilizers, tilling operations, moisture retention and pre-sowing tillage.

Special machines are produced for planting and sowing, between-row cultivation, top dressing and harvesting. They are intended for use only in carrying out a given technological process.

In addition, transport equipment is needed for moving seeds, fertilizers and harvested products.

It can be seen from this list of machines that the operations involved in the cultivation of agricultural crops can be divided up into simple operations and complex operations. Among the simple operations are those such as ploughing, harrowing, and deep cultivation, while among the complex operations are sowing, planting, harvesting, and a number of other operations which actually consist of several joint operations.

If all the operations involved in the cultivation process are mechanized, then it can be stated that total mechanization of crop cultivation has been achieved. This definition is only really true, however, when such total mechanization is effected through systems of interlinked machines and when the following systems and sets of machines are used to carry out the cultivation process: (a) A system of general-purpose machines whose work capacity is determined by the conditions of the entire branch of crop cultivation in question, taken as a whole; (b) a complex of special cultivation machines whose working width and work capacity are determined in the light of the size of the fields planted with the crop they are designed to cultivate, and (c) a system of transport and loading and unloading equipment whose load and work capacity is determined by the requirements of all the branches of the farm in question.

In order to bring about the total mechanization of agricultural operations, it is necessary to have a system of machines based on the most effective utilization of the power sources - the tractors and other power units - of a particular farm. A very important factor in reducing the range of machines in a particular system is the versatility of the equipment, which permits machines belonging to a particular set to be used in the cultivation of several crops.

In selecting machinery and equipment with a view to total mechanization, it is therefore necessary to reduce the number of different types of tractors and machines to the minimum by ensuring that they are as versatile as possible.

In order to carry out the total volume of machine work it is necessary to have both sufficient machines and sufficient personnel to operate them.

In calculating the technical facilities required to carry out the total amount of work, calculations must be based on the agro-technical requirements, the natural and farming conditions, the area to be cultivated, the size of the expected harvest or sowing rates, etc., the average distance between the place of work of the equipment and its storage place, etc., and the work capacity of the machines and units.

At the present time, the main type of power sources for carrying out moving operations are tractors.

As the direct traction of machinery and equipment is effected by the contact of the driving members of the tractor with the ground, machine/tractor units have unlimited freedom of movement. The driving members of modern tractors are so designed that they give reliable traction and enable machine-and-tractor units to be used regardless of the state of the ground. This is one of the main reasons for the successful development and utilization of tractors in agriculture.

Agricultural tractors, like agricultural machines, can be divided up into general purpose, universal and special tractors. In addition, they may be divided up, according to their type of driving members, into tracklaying tractors, wheeled tractors with two driving wheels, and four-wheel-drive tractors.

Agricultural tractors must satisfy various requirements, depending on their purpose and type. This is due to the large variety of natural, climatic, farming and technical conditions in which tractors are used, as well as to the considerable complexity and variety of the requirements which tractors must satisfy in connexion with their role as the key factors in raising the level of mechanization of agricultural activities.

The operating properties of tractors can be divided up into three main groups: agro-technical, technico-economic and general technical properties. The properties which characterize a tractor's ability to satisfy the technological requirements of agricultural activities are called the agro-technical properties. The technico-economic properties are divided up into two sub-groups: those mainly concerning the work capacity of the tractor, and those concerning its economy of operation.

The remaining properties which do not have a direct influence on the agro-technical performance, the work capacity and the economy of the tractor are the general technical properties.

The agro-technical properties of the tractor are those which directly influence its working capability. Such properties are, for example, its ability to operate between the rows of plants and its manoeuvrability. These properties are relevant not only to tractors but also to other similar agricultural machinery and equipment.

The technico-economic properties, such as the work capacity and the economy in fuel consumption, as well as the general technical properties such as safety and comfort of operation, are relevant not only for tractors and agricultural machines, but also for other machines of the most varied purpose and construction.

In analysing the properties and performance figures of different tractors the approach should always be a comprehensive one and the interconnexion between the various properties and figures should always be borne in mind.

Wheeled tractors are more versatile, lighter per unit of engine power, and easier to couple to tractor-mounted machines than tracklaying tractors. Wheeled tractors can also be used more effectively for high-speed operation. The use of tracklaying tractors for certain types of operations may give higher productivity, however. Because of the ability of tracklaying tractors to work on difficult ground, certain operations, especially in spring, can be carried out by such tractors at times which are more advantageous from an agro-technical point of view. The tractive efficiency of tracklaying tractors is also higher than the continuous tractive efficiency of wheeled tractors, especially on loose soil.

For practical purposes, the most suitable tractors are those whose performance figures fit in with each other in a balanced manner and satisfy the entire set of requirements. The development of designs of modern tractors is proceeding along two directions: universalization and specialization. Thus, while the range of operations that can be carried out by tractors of a given type is continually being widened, an increasing number of special types of tractors, such as those intended for use in marshy areas, gardens and in hilly areas, is being developed.

It can readily be appreciated from the above that new types of tractors and agricultural machines must be developed side by side, and this is a complex task which calls for deep study.

The machine-and-tractor unit, consisting of a tractor and an agricultural machine, is the basic unit in the mechanization of agriculture. The execution of a given operation, such as ploughing, mowing, etc., can be carried out by machine-and-tractor units with various parameters, although possibly of the same basic design. Thus, for example, the unit may use machines of different working width and different operating speeds, coupled to a tractor of a given weight and power, or the units may consist of different tractors coupled to an agricultural machine of a given working width.

The question of the selection of the best parameters for machine-and-tractor units is therefore one of the most important questions to be solved in establishing standard types of tractors and agricultural machines.

The first steps towards the scientific study of the question of selecting the best parameters for machine-and-tractor units was made by the father of the theory of agricultural machinery and the creator of "agricultural mechanics", Academician of the Academy of Sciences of the USSR, Vasilii Prokhorovich Goryachkin, who worked out the main problem arising under the "theory of mass and speeds" laid down by him, namely, the determination of the adequate and necessary size of the working parts of equipment and engines so as to be able to accommodate the largest possible amount of mechanical power per unit of mass.

Taking the example of the relationship between mass and speed in nature, Academician V. P. Goryachkin wrote: "Similarly, there must be certain maximum values of mass and speed for agricultural machinery and equipment also; excessive weight is useless or even harmful, while on the other hand insufficient weight is also inadmissible". Excessive weight is harmful because it increases the amount of power required for the propulsion of the unit and thus reduces the amount of power available for the execution of the actual technological process: that is, it reduces the work capacity and the economic efficiency. On the other hand, insufficient weight reduces the adhesion of the unit and reduces its tractive capacity.

In the opinion of V. P. Goryachkin, the question of the right weight is the most important question in agricultural mechanics.

In showing the way to study the problems of the theory of mass and speed, V. P. Goryachkin warned against the useless complication of the question under consideration with incidental factors of minor importance.

"The work capacity of agricultural machines for use in the field, for example, depends on many elements (the particular features of the soil, the engine, the weather, etc.). Basically, however, it is necessary to take into account only the working width of the machine and its speed of movement, and the answer to the question of the work capacity of field machinery is to be found in the area covered per unit of time."

Academician Goryachkin stressed the need to consider the execution of a given technological process as a whole, and not piecemeal, when studying the parameters of machine and tractor units. He pointed out that the engine, the machinery and the material being processed are the main elements in any working process and must be considered as a whole. The general purpose of the investigation is to shed light on the links between these elements.

Evaluation of the process is possible only when all three of the elements in question are taken into account.

Considering the resistance of the working parts in various technological processes and also the motor characteristics, V. P. Goryachkin showed that the resistance and energy consumption of the working parts can be expressed generally by the following equation:

$$P = c + dv^2 \quad ; \quad N = (c + dv^2)v$$

while the tractive capacity and power capacity of the tractor can be expressed by:

$$P = a - bv^2 \quad ; \quad N = (a - bv^2)v$$

and can be expressed graphically by parabola of different kinds (see figure 1).

"These formulae" - writes V. P. Gorytchkin - "form a basic system covering the main essentials of the process, although they are not always completely accurate."

The graphs which are given in this paper are constructed for the case where the speed of movement of the tractor varies in a stepless manner and the tractor engine develops the same power regardless of changes in speed.

Further investigations have enabled the curves for the tractor to be plotted more accurately, but their basic form remains the same (see dotted lines).

The point of intersection of the curves for the resistance to traction $P_{op} = f(v)$ and the power consumption of the machine $N_{op} = f(v)$ with the curves for the tractive capacity $P_{kp} = f(v)$ and the power capacity of the tractor $N_{kp} = f(v)$ defines the maximum speed of movement of a unit consisting of a given tractor and a given agricultural machine.

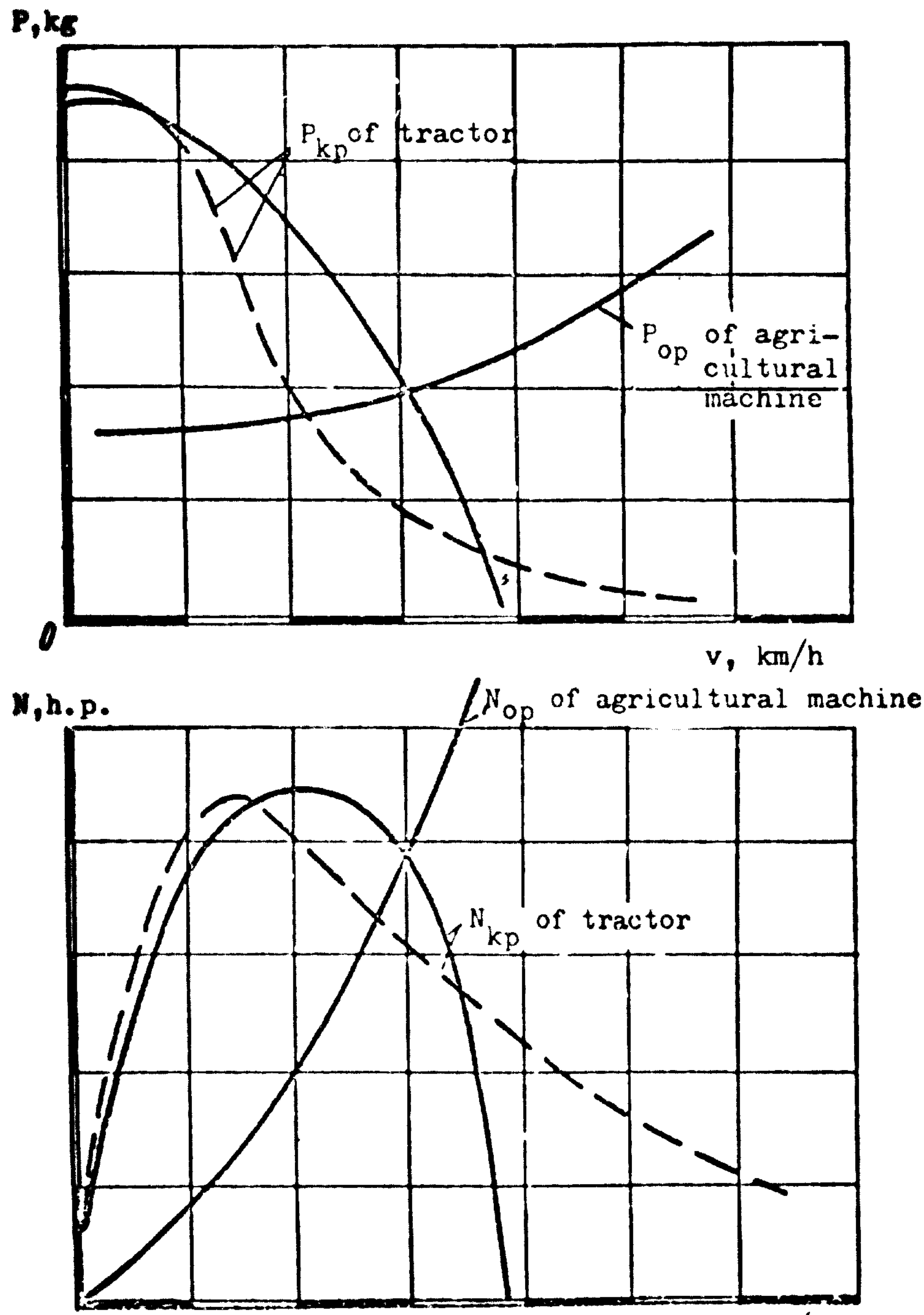
Here the tractive capacity and the power capacity of the tractor are limited by the curves $P_{kp} = f(v)$ and $N_{kp} = f(v)$ which determine the amount of power that can be used by the agricultural machine.

In the graphs given in this paper, the value $P_{kp\ max}$ is determined by the adhesion characteristics - the weight and design of the tractor - while the speed at which $P_{kp} = 0$ is determined by the power of the tractor engine.

The variation of the power capacity shown in figure 1 is characteristic for all types of tractors - tracklaying and wheeled.

These capacities cover the engine, the agricultural machine, and the material being worked. The power consumption of the agricultural machine depends both on the parameters of the machine itself and on the nature of the material being worked. The possible power made available by the engine driving the unit depends, in its turn, both on the properties of the engine itself and on the design parameters of the tractor in which it is installed, as well as on the nature of the soil over which the unit is moving.

Figure 1


P,kg
P_{kp} of tractor
P_{op} of agricultural machine
0
v, km/h
N,h.p.
N_{op} of agricultural machine
N_{kp} of tractor
0
v, km/h

The various engine power capacities and working element requirements shown in figure 1 form the basis for the selection of the best possible economic parameters for the unit.

We will consider below the methodological questions regarding the determination and basic data required for the determination of the best economic weight and power of tractors, the working width of agricultural machines, and the speed of movement of machine-and-tractor units.

Optimum economic parameters for machine-and-tractor units

The optimum economic parameters for machine-and-tractor units are those parameters which make possible the execution of given agricultural operations with minimum expenditure of labour and materials.

Out of the large number of parameters for the mobile unit, the tractor and the agricultural machine, we will select those which, while fully characterizing the unit and providing the basic parameters for the tractors and machines, at the same time do not restrict the design possibilities for these units. Such parameters are the following:

(a) Type and design of tractor - T (tracklaying, wheeled tractors with two driving wheels, four-wheel-drive tractors, etc.);

(b) Power of tractor engine - N;

(c) Weight of tractor - G_T, its tractive capacity and its class;

(d) Type and design of the agricultural machine - M_M (knife coulter plough, disc coulter plough, rotary plough, etc.);

(e) Working width of agricultural machine - B;

(f) Speed of movement of the unit - V.

A machine-and-tractor unit is not just a tractor mechanically linked to an agricultural machine, but a unitary whole with new properties. The parameters of tractors and machines must therefore be determined simultaneously, in a single process, and the methods of determining them must be such as to make possible the simultaneous determination of the above-mentioned optimum parameters of the units.

The optimum parameters of units must be determined in conformity with the actual natural and technical conditions of the given area, region, zone or country as a whole.

Within a given area (region, zone, etc.), the calculations are based on typical farms.

The determination and establishment of the optimum economic parameters of units is carried out by finding the conditions which give the minimum expenditures for the execution of operations of a given extent and nature which are characteristic for the units in question.

Criteria for the determination and establishment of the optimum economic parameters for machine-and-tractor units

In solving the problem under consideration, it is extremely important to establish criteria for comparing machine-and-tractor units or complexes with each other and determining the parameters of units which comply with the principle of optimality.

Such characteristics of the units as their power consumption, metal content, number of operating personnel required, and so forth may be used as criteria for the establishment of the parameters of the units. The most important of all the possible criteria, however, are the economic efficiency and the work capacity of the units.

It was stated above that the optimum economic parameters are those which enable the unit to work with minimum expenditure of labour and materials at a high rate of productivity. This statement requires some further definition, however. The fact is that the criterion which is most widely accepted at present, and which will also be accepted by us as the basic criterion for the optimality of units, is the criterion of minimum specific expenditure per unit of work carried out. This value represents the ratio of the expenditures of human and mechanical work connected with the operation of the units for a given period of time to the volume of work carried out in that period of time. The operating expenditure is made up of the expenditure of fuel and lubricants, the cost of repairs, technical servicing and maintenance, renewal of parts, and the wages of the operating personnel. Apart from this, the use of new technology must make possible a given return on the capital investment.

The investigations carried out on the dependence between the productivity of units and their associated costs on the one hand, and the parameters of the units and their conditions of operation on the other, show that the parameters corresponding to minimum costs and maximum productivity of units do not coincide. Therefore, when speaking of the optimum economic parameters of units, we mean the parameters of units which correspond to minimum operating costs.

At the same time, cases are possible where the work capacity of units is of more practical significance than their economic efficiency. In selecting the parameters of units, therefore, their work capacity must be calculated and the conditions in which this capacity reaches its maximum must be determined. This is all the easier because the determination of the work capacity of units is an essential stage in calculating their economic effectiveness.

Determination of expenditures involved

Depending on the problem to be solved, the expenditures are calculated either per unit of work carried out or for the total volume of work.

In the first case, the expenditures are determined according to the formula:

$$E = Z + A + R + C_G + X + K_B \qquad (1)$$

where Z is the wages of the operating personnel;

A is the depreciation costs;

R is the expenditure on servicing and major and routine maintenance;

C is the expenditure on fuel and lubricants;

X is the expenditure on the storage of tractors and agricultural machines; and

K_B is the standard rate of return on capital investments.

The components of the formula for calculating the expenditures are expressed in their turn in the following manner:

- expenditure on the wages of the operating personnel:

$$Z = \frac{L_M \cdot Z_{HM} + L_C \cdot Z_{HC} + L_T \cdot Z_{HT}}{W} \qquad (2)$$

where $L_{M,C,T}$ is the number of operators working on the agricultural machine, the coupling and the tractor, respectively, during operation of the unit.

$Z_{M,C,T}$ is the hourly wage of the operators working on the agricultural machine, the coupling and the tractor, according to their specialities and their qualifications; and

W is the productivity of the unit per hour of shift work.

The amount of the depreciation deductions per unit of work carried out is:

$$A = \left(\frac{C_m \cdot a_M^1}{t_{yM}} + \frac{C_c \cdot a_c^1}{t_{yc}} + \frac{C_T \cdot a_T^1}{t_{yT}}\right) \cdot \frac{1}{100W} \qquad (3)$$

where $C_{M,C,T}$ is the cost of the agricultural machine, coupling and tractor in question

$a^1_{M,C,T}$ is the annual percentage of depreciation for each machine, coupling and tractor; and

$t_{yM,C,T}$ is the annual loading of the agricultural machines, couplings and tractors

The expenditure on major and routine maintenance and servicing per unit of work carried out is expressed by the formula:

$$R = \left(\frac{C_M \cdot Q_M}{t_{yM}} + \frac{C_c \cdot Q_c}{t_{yC}} + \frac{C_T \cdot Q_T}{t_{yT}}\right) \cdot \frac{1}{100W} \qquad (4)$$

where $Q_{M,C,T}$ is the percentage of annual deductions for major and routine maintenance and servicing for the agricultural machines, couplings and tractors.

The total expenditure on storage of the unit per unit of work carried out is determined by the formula:

$$X = \frac{X_M + X_C + X_T}{W} \qquad (5)$$

where $X_{M,C,T}$ is the expenditure on storage of the machines, couplings and tractors per hour of operation of the unit.

The expenditure on fuel and lubricants per unit of work carried out is calculated according to the formula:

$$C_G = \frac{g.F.N}{W} \qquad (6)$$

where g is the specific consumption of fuel;

F is the price of fuel and lubricants; and

N is the power utilized.

The rate of profitability of capital investments, relative to each unit of work carried out, is calculated according to the formula:

$$K_B = \frac{J}{W}\left(\frac{C_M}{t_{yM}} + \frac{C_c}{t_{yc}} + \frac{C_T}{t_{yT}}\right) \qquad (7)$$

where J is the standard coefficient for the profitability of the capital investments.

The expenditure for a given volume of work is determined in the following manner:

$$E_H = E.H \qquad (8)$$

where H is the given volume of work.

It was stated above that although the expenditure is the basic criterion for establishing the optimum parameters of units, it is advantageous to determine at the same time such figures as the work capacity, the expenditure of human labour, the fuel consumption and the metal content, which characterize individual aspects of the effectiveness of units. These figures, which are supplementary criteria to the expenditure, can in certain circumstances play an important role and act as criteria for the determination of the optimum parameters of units. The analysis of these figures in combination with the analysis of the expenditure enables a more qualitative approach to be made to the determination of the advisability of introducing specific kinds of units into farm operations.

The work capacity of the unit is determined according to the formula:

$$W = W_T . \tau \qquad (9)$$

where W_T is the work capacity of the unit per clear hour of work;

τ is the coefficient of utilization of the shift time.

The expenditure of human labour on the execution of a given amount of work is determined according to the formula:

$$Z_T = \frac{H(L_M + L_c + L_T)}{W} \qquad (10)$$

and is expressed in man/hours.

The hourly fuel consumption(s) is determined in the following manner:

$$S = g.N \qquad (11)$$

The fuel consumption for the execution of a given amount of work is determined as follows:

$$S_H = S.H.\frac{1}{W} \qquad (12)$$

The metal content D of operations when they are carried out by a given unit is determined according to the formula:

$$D = \frac{1}{W}\left(\frac{G_M}{t_{yM}} + \frac{G_c}{t_{yc}} + \frac{G_T}{t_{yT}}\right) \qquad (13)$$

and is expressed in kilogrammes per unit of worked area.

In formula 13, G_M, G_c and G_T are the design weight of the agricultural machine, coupling and tractor, respectively.

The metal content D_H of the entire complex of work carried out by given units is determined in the following manner:

$$D_H = D.H \qquad (14)$$

As may be seen from the formulae for the various expenditures (1-8) and the supplementary indexes (10-14), the determination of the expenditure does not present any unusual features, and the expression of the expenditures and the expressions for the supplementary indexes is quite straightforward. The problem of determining and establishing the optimum parameters for machine and tractor units really lies in finding the relationship between the expenditures, the parameters of the units, and the conditions of operation of the units.

<u>Procedure for determining the optimum economic weight and power of tractors, optimum working width of agricultural machines, and optimum speed of movement of machine-and-tractor units. Finding the relationship between the corrected expenditures and supplementary indexes and the parameters of the units</u>

1. First of all take farms (x) which are typical of the area of the country in question from the point of view of layout of cultivated areas, range of crops cultivated, list of operations carried out (0), soils, and operating conditions for machine-and-tractor units (length of working run of tractor in the fields, dimensions of fields, etc.).

For each agricultural undertaking it is then necessary to determine the volume of work involved in respect of each operation and the values of such operating indexes as the specific resistance of the soil, the length of the uninterrupted working runs in the fields, the dimensions of the individual fields to be worked, the different depths to which the soil must be worked, etc., as well as the inter-relationship between all these factors at the farms in question.

Depending on the actual conditions of the developing country, this stage can be solved either by selecting typical farms or by taking the country as a whole. This stage is essential for the correct determination and choice of the types of tractors and agricultural machines to be used to carry out given operations in the cultivation of agricultural crops which are typical of the developing country in question.

It is recommended that the results of this stage should be set out in a table or in a form similar to that shown below (figure 2).

2. Depending on the range of operations to be carried out in the cultivation of agricultural crops, the present state of agricultural technology, and its development prospects, alternative variants can be established for the units from the point of view of the type and design of the tractors (T), the weight of the tractors (G_T), the tractor engine power (N) and the working width of the agricultural machines (W) for each type or design (M_M).

At this stage, the various possibilities of carrying out the operations are considered: for example, with wheeled or crawler tractors of different classes and capabilities coupled to ploughs of mouldboard or non-mouldboard type, and so forth.

All the possible variants of machine/tractor units are tabulated in figure 3. The power, operating, economic and other parameters must be established for each machine/tractor unit or group of units. The correlation between these parameters and the weight and power of the tractor, the working width of the agricultural machine and the speed of advance of the unit is calculated. Similarly, calculations are made of the relationship between the formula for determining the expenditures and the sought-for parameters of machine/tractor units. In carrying out this stage of the work, it is necessary to determine the twoing coefficient and the resistance to motion of tractors

Table of agricultural work (operations), their volume and distribution, under headings of specific resistance, depth of working, length of run, etc., on a typical farm

Figure 2

Length of run (dimensions of field)	Type of work (operation)	Specific resistance of soil (kg/cm²)	Percentage ratio of soils with different specific resistances	Depth of working of soil, cm.	Percentage ratio of fields where soil must be worked to different depths	Volume of agricultural work, hectares
A_1	O_1	K_1	%	a_1 a_2 ⋮ an	% % ⋮ %	F_1 F_2 ⋮ Fj
		K_2 ⋮	%	a_1 a_2 ⋮ an	% % ⋮ %	F_1 F_2 Fj
		Kc	%	a_1 a_2 ⋮ an	% % ⋮ %	Fj F_2 Fj
	D_2 ⋮	K_1	%	a_1 a_2 ⋮ an	⋮ %	F_1 F_2 Fj
		K_2 ⋮	%	a_1 a_2 ⋮ an	% % %	F_1 F_2 Fj
⋮		Kc	%	a_1 a_2 ⋮ an	% % ⋮ %	F_1 F_2 Fj
⋮ Ai	Ok	Kc	%	an	%	Fj

Figure 3

List of variants of machine/tractor units from which optimum is selected

Type of work (operation)	Type of tractor	Weight of tractor	Engine power of tractor, h.p.									
			N_1					...	N_n			
			Type of agricultural machine	Working width, m					Type of agricultural machine	Working width, m		
			M_{cl}	B_1	B_2	...	B_n	M_{cl}	B_1	B_2	...	B_n
		G_1	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
			M_{cw}	B_1	B_2	...	B_n	M_{cw}	B_1	B_2	...	B_n
		⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
O_1	T_1		M_{cl}	B_1	B_2	...	B_n	M_{cl}	B_1	B_2	...	B_n
		G_y	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
			M_{cw}	B_1	B_2	...	B_n	M_{cw}	B_1	B_2	...	B_n
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	T_t											
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
O_k	T_t	G_y	M_{cw}	B_1	B_2	...	B_n –	–	–	–	–	–

of the types under consideration, the correlation between the resistance to traction and the power required to operate agricultural machines, the values of the coefficients of efficiency of machine/tractor units, the influence of changes in specific soil resistance on the execution of agricultural operations, the utilization factor of units, the cost of tractors of various engine capacities and of agricultural machines of various working widths, the standard rates of various deductions, and other indexes.

It is recommended that the following formulae giving the relation between a number of the above indexes and the desired unit parameters be used.

Thus, for example:

The planning price of agricultural machines depends basically on their working width and can be determined to a sufficient degree of accuracy by the expression:

$$C_M = C_{unitM} \cdot B$$

where C_{unitM} = the unit price of a machine.

This expression is also valid for the planning price of couplings, i.e.:

$$C_c = C_{unit_C} \cdot B$$

where C_{unit_C} = the unit price of a coupling.

The analysis of the indexes for tractors shows that the planning price of a tractor chassis can be expressed as a function of the weight of the tractor by the formula:

$$C_{ch} = C_{unit\ ch} \cdot G_T$$

where $C_{unit\ ch.}$ = the unit price of a tractor chassis, which differs for different types and designs of tractors,
while the planning price of a tractor engine essentially depends on its rated power and can be expressed by the formula:

$$C_{eng} = C_{unit\ eng.} \cdot N$$

where $C_{unit\ eng.}$ = the unit price of a tractor engine.

Before considering the expenditure on fuel and lubricants, the following points must first be made:

In calculating operating costs by the method described below, the parameters of units will vary with the speed of advance and the working width. The required engine power is a function of these two parameters. Thus a given unit of any given working width will develop different engine power at different speeds of advance. In actual units, the engine power is limited to a definite figure and cannot exceed it - that is to say, the unit cannot exceed a certain speed owing to insufficient power.

It is assumed that the specific fuel consumption of the unit's engine does not vary with changes in the power required to operate the unit. This is based on the fact that, having determined the optimum engine power for the machine/tractor unit, it is always possible to build an engine having the specific fuel consumption assumed in the calculations.

The rates that it is reasonable to assume for depreciation and repairs in cost calculations will differ for each type of design of machine, but, within a single type, they will be the same for different working widths, capacities, speeds, etc.

The working time utilization factor, τ, can be determined from the relation between the time, τ_w, during which the unit is carrying out a technical operation, and the total time in the field, τ_{tot}.

The latter, i.e., the total time spent in the field, is composed of the working time plus the time spent in turning the unit round at the end of a fun, τ_{turn}.

$$\tau_{tot} = \tau_w + \tau_{turn}$$

Thus $$\tau = \frac{\tau_w}{\tau_w + \tau_{turn}}$$

In this way we can establish the relation between the working time utilization factor and the speed of advance and working width of the unit.

It is known that:

$$\tau_w = \frac{\Lambda}{v}, \text{ and}$$

$$t_{turn} = \frac{\Delta_{turn}}{v_{turn}}$$

where Λ = the length of run,

Λ_{turn} = the length of turn, and

v_{turn} = the turning speed of the unit.

Then:

$$\tau = \frac{1}{1 + \frac{\Delta_{turn} \cdot v}{\Lambda \cdot v_{turn}}}$$

There are two basic ways in which units can move when carrying out agricultural work in the field: the up-and-down method and the round-and-round method. The round-and-round method of movement is not used by soil-working units, so in considering the variations in the working time utilization factor, we shall use only the up-and-down method as an example.

In the up-and-down method of movement, the unit works in straight lines up and down the length of the field or at an angle to it, with idle turns or passes at opposite ends of the field. Depending on the form of the idle turns, the up-and-down method of movement can, in its turn, be divided into looped and non-looped.

In calculating optimum parameters, one type of turn may be taken as typical for plough units and the other for the remaining types of soil-working units (seed drills, cultivators, etc.).

Thus plough units using the up-and-down method can make wide or tight turns. In this case, the average length of turn is:

$$\Delta_{turn} = 0.5(\Sigma - B) + 2.14\,\theta + 2$$

where Σ = the width of the field or strip,

θ = the turning radius of the unit, and

e = the distance the unit moves out before turning.

For plough units, then,

$$\mathcal{T} = \frac{1}{1 + \frac{[0.5(\Sigma - B) + 2.14\,\theta + 2e]v}{v_{turn}\ \Lambda\ units}}$$

It is assumed that seed drills, cultivators and other units comprising similar machines make simple, pear-shaped loop turns, for which the length of turn is:

$$\Lambda_{turn} = 6\,\theta + 2e$$

The turning radius can be taken as being equal to the working width of the unit:

$\theta = B$

Hence, the working time utilization factor for this type of unit is:

$$\mathcal{T} = \frac{1}{1 + \frac{(6B + 2e)v}{v_{turn}}}$$

The power required for the work of the machine/tractor unit (in the case of ploughs and other machines, the actual force applied through the tractor drawbar) is given by the formula:

$$N = \frac{N_f + N_{or}}{(1 - \gamma)\,\eta_{mg}}$$

where $N_f = f_t . G_t . V$ = the power of the tractor available for self-propulsion,

f_t = the coefficient of rolling resistance of the tractor,

$N_{or} = R_{or} . V$ = the power required to overcome the tractive resistance of the agricultural machine,

R_{or} = the tractive resistance of the agricultural machine,

γ = the towage coefficient of the tractor engine, and

η_{mg} = the efficiency of the transmission and engine of the tractor.

Academician V. P. Goryachkin's formula provides a rational method for determining the tractive resistance of ploughs:

$$R_{or} = f_{or} \cdot G_{or} + k a B + \Sigma a B v^2$$

where f_{or} = the coefficient of friction of the plough in the furrow,

G_{or} = the weight of the plough,

k = a proportional coefficient expressing the resistance to deformation of the cross-section of a layer of soil,

a = the depth to which the soil is worked, and

Σ = a proportional coefficient expressing the resistance arising out of the kinetic energy communicated to the particles of the soil layer when they are pushed aside.

Here: $G_{or} = \gamma B$

where γ = the specific metal content of the machine.

Hence: $R_{or} = B(f_{or} \cdot \gamma + ka + \Sigma a v^2)$

For other types of soil-working machines (cultivators, seed drills, harrows, stubble ploughs, etc.) the tractive resistance is taken as being determined by the formula:

$$R_{or} = K_{ud} \cdot B$$

where K_{ud} = the tractive resistance of an agricultural machine per metre of working width.

In this case, for determining the specific resistance of agricultural machines as a function of their speed of advance, it is best to use the compound percentages formula, which reflects quite accurately the variations in K_{ud} and is comparatively easy to calculate:

$$K_{ud} = K_o\left(1 + \frac{\Sigma 1}{100}\right)^v$$

where K_o = the specific resistance to movement of an agricultural machine when the speed of movement is nearly zero,

$\Sigma 1$ = the percentage increase in the tractive resistance for each increase of speed by one unit of value.

The definitive form of the formula, from which expenditures are calculated, is found by substituting the calculated variations of the unit indices as a function of the sought-for parameters for the values assumed for the various coefficients in the original formula for finding the expenditures.

4. First, the speed of advance of the unit corresponding to the required load/power ratio on the tractor is calculated for each variant of the machine/tractor unit for a given tractor weight and power and working width of the agricultural machine, by means of the formula for the energy balance corresponding to these parameters, then the expenditures are calculated.

Diagrams for determining the speed of advance and a type of graph showing the variation of expenditures for variation of the speed of movement and working width of the unit with given types of tractor are given in figure 4 below; it will be seen that they fully correspond to Academician Goryachkin's diagram.

The minimum value of the expenditures determines the optimum combination of speed of advance of the unit and working width of the agricultural machine for every variant of unit and for every operation.

The appearance of the economically optimum combination of working width of the agricultural machine and speed of advance of the unit, for constant given tractor weight and power, can be explained as follows. The basic index with the greatest influence on changes in expenditure is the productivity of the machine/tractor unit. It appears in the denominator of each term of the formulae (2-7) for determining the expenditures, so that these expenditures are in inverse ratio to productivity.

Let us consider the variations of the productivity of different types of unit coupled to a given tractor. By comparing the tractor power with the requirements of the agricultural machine (figure 4), the theoretical productivity of the unit ($W_{theoret}$) can be found.

The point where the curve of the power requirements of an agricultural machine of given working width intersects with the tractor power curve determines the speed of advance of the assembly.

Figure 4

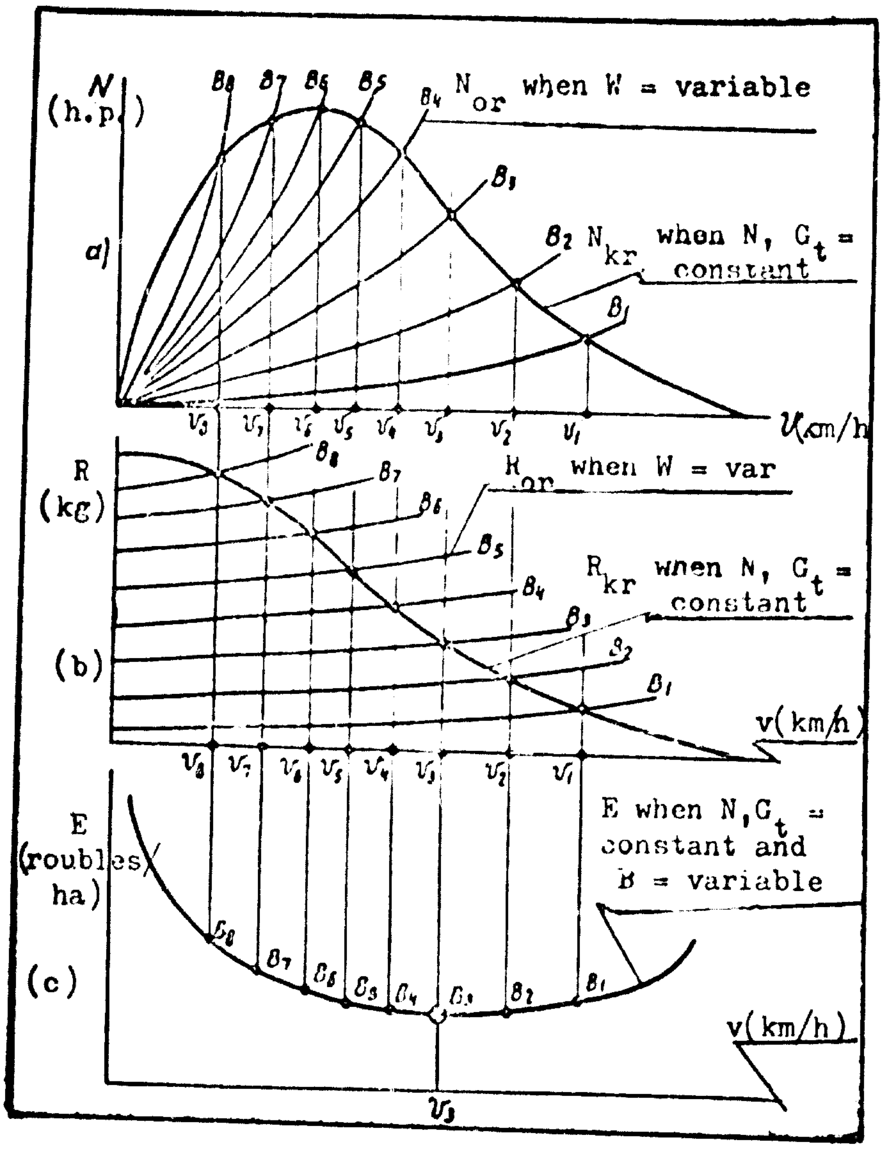


Diagram for determining the speed of advance (v_i) of agricultural **machines** and equipment of varying working width (B = variable) and **the** optimum combination of speed and width for units with tractors **of** given weight and power (G_t and N = constant) for a given steady load/power ratio on the tractor.

(The combination B_3v_3 is the optimum one).

The curve thus plotted for the theoretical productivity of the unit under consideration is determined by the formula:

$$W_{theoret} = Bv$$

and is shown in figure 5. On this curve $W_{theoret} = f(B,v)$ are superimposed radiating lines indicating the variations in the theoretical productivity of the unit for constant working width; in this way the working width of the agricultural machine corresponding to the maximum productivity can be determined by graphic methods.

From figure 5 it can be seen that the productivity of a unit with constant engine power reaches a maximum value at a particular speed of advance. This is due to the fact that, for a given tractor power, as the speed of advance increases the working width of the assembly declines from its initial value to zero - when all the power will be used for the propulsion of the unit.

To begin with, for low speeds of advance, the fall in the working width is small in comparison with the increase in the speed of advance, and productivity rises. Later, with higher speeds of advance, the working width falls more rapidly than the speed of advance increases, and the productivity, after attaining a maximum value, begins to decline.

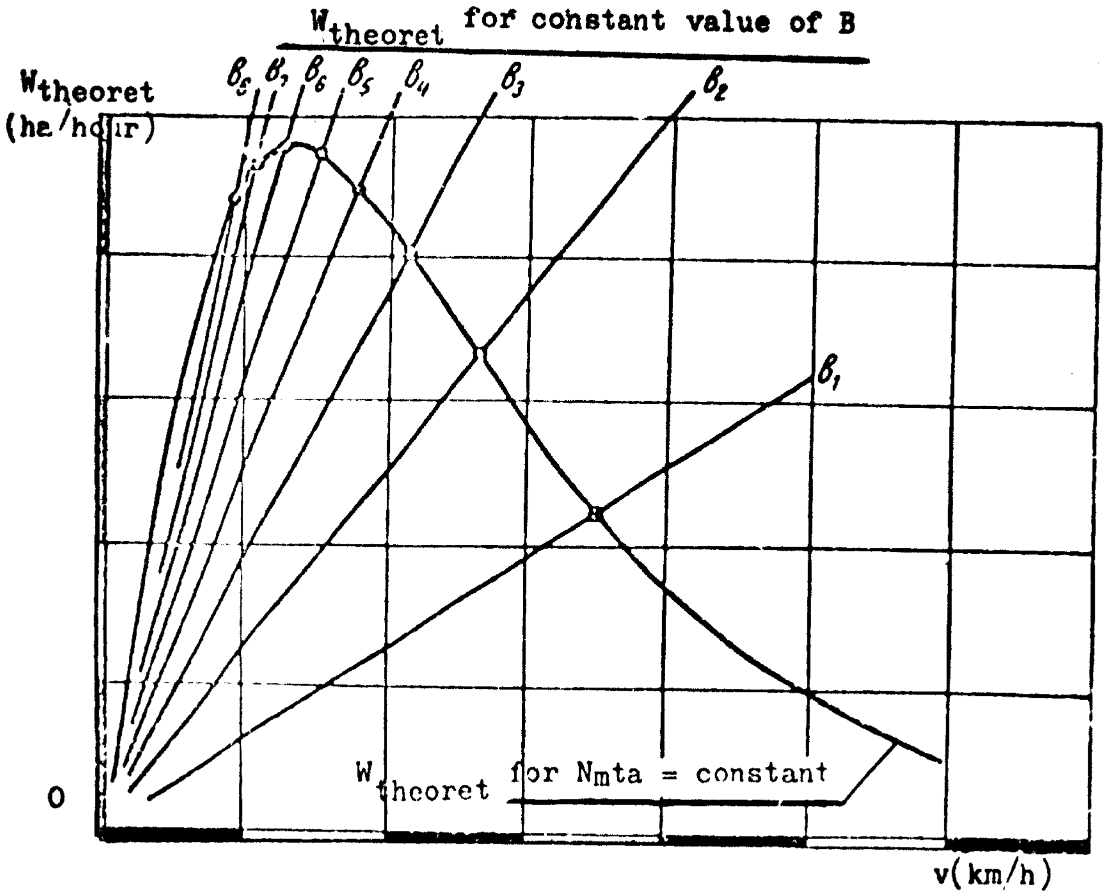
This is the way the theoretical productivity varies, and, taking into account the working time utilization factor and the actual productivity, it determines the form of variation of the operating costs of the unit for constant tractor weight and power, once these exceed some minimum value.

5. The operating cost for given volumes of work is now calculated for each variant of a unit with a given tractor weight and engine power and a given optimum ratio of working width to speed of advance.

The data concerning operating costs obtained in this way are assembled in a table (figure 6) and totalled for the various operations carried out by units having tractors of a given weight and power.

It is of the highest importance, and indeed indispensable, to determine the expenditures involved in carrying out a given volume of work, operation by operation, for units having tractors of a given weight but varying power.

Figure 5


W theoret for constant value of B
W theoret (ha/hour)
B8 B7 B6 B5 B4 B3 B2
B1
0
W theoret for Nmta = constant
v(km/h)

The expenditure per unit area worked depends mainly on the energy consumed during the process.

The most expensive operation is ploughing, in which the resistance of the plough is great and the productivity small. When the tractive resistance of the agricultural machine is lower, it is possible, with the same tractor parameters, to increase the working width and, consequently, the productivity of the unit.

When this is done, the expenditure falls. This is why the cost of ploughing is considerably higher than the cost of operations like cultivating, stubble ploughing, sowing, harrowing and so on.

If the volume of work involved in carrying out these operations is not taken into account, then, when the expenditures for carrying out all these operations with units comprising tractors of given weight but variable power are added together, it appears that the minimum expenditure, and, hence, the economically optimum power, is determined by one single operation - ploughing.

The volume of work on a farm accounted for by cultivating (two passes) or sowing (cross-sowing) and so on may be substantially greater than the volume of ploughing, however. In this case, the expenditure in respect of the whole volume of these operations is comparable with the cost of ploughing and thus exerts a greater influence on the relation between minimum costs and engine power.

In these circumstances, the economically optimum power of a tractor of a given weight is different from that required for ploughing and yet has a considerable overall economic effect on the farm.

6. The optimum engine power of a tractor of given weight is determined by the minimum value of total expenditure recorded with respect to the whole volume of work on the farm for units comprising tractors of given weight and varying power.

The analysis of expenditure when selecting the optimum tractor engine power can be carried out either by means of tables of calculated results or by means of a graph. A specimen graph showing the variation of expenditure as a function of the power of a tractor of given weight is shown in figure 7.

Figure 6

Expenditure (in roubles) for different variants of units, broken down by operations

Length of run	Type of work (operation)	Specific resistance of soil (kg/cm2)	G_1											...	G_l				
			N_1					...						...			N_i		
			V Speed of advance, m/sec	B Working width	W Hourly productivity	E_h Expenditure per hour (roubles)	E_w Expenditure (roubles) per unit of work		V	B	W	E_h	E_w		V	B	W	E_h	E_w
	O_1	a_1	v	b	w	e_h	e_w	...	v	b	w	e_h	e_w	...	v	b	w	e_h	e_w
		a_2	v	b	w	e_h	e_w	...	v	b	w	e_h	e_w	...	v	b	w	e_h	e_w
		⋮	⋮	⋮	⋮	⋮	⋮	...	⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮	⋮	⋮
		a_n	v	b	w	e_h	e_w	...	v	b	w	e_h	e_w	...	v	b	w	e_h	e_w
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	...	⋮	⋮	⋮	⋮	⋮	...	⋮	⋮	⋮	⋮	⋮
Δ_l	O_k	K_e a_n	v	b	w	e_h	e_w	...	v	b	w	e_h	e_w	...	v	b	w	e_h	e_w

Figure 7

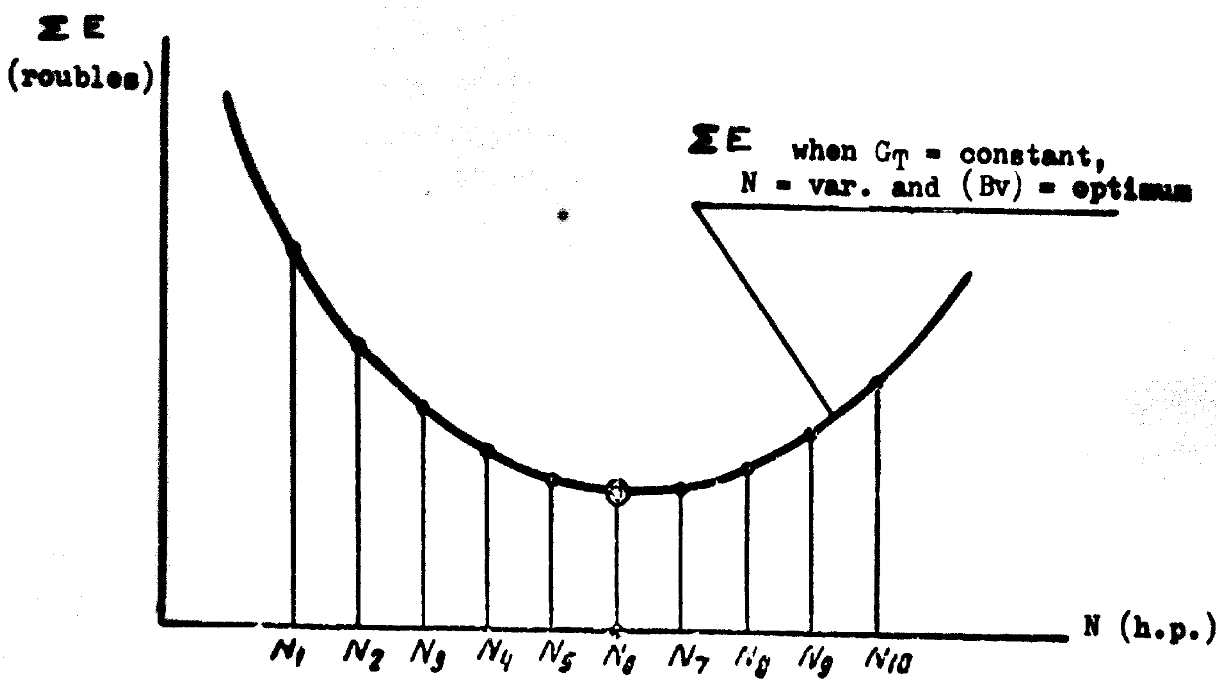


Diagram for determining optimum power for a tractor of given weight for units carrying out a given set of agricultural operations on a given farm (Power N_6 is the optimum)

It should be pointed out that the search for the optimum engine power of a tractor of given weight used for a number of different operations is useful primarily when it is intended to employ only one type of tractor. If, for each operation, a tractor having the optimum power for the agricultural operation in question is used, the resulting savings may be considerable - if the consequent diversification of the tractor stock and the resulting operational and repair difficulties are left out of account.

Such questions have not been taken into account in the method of selecting optimum parameters described above, but it has been assumed that it would be more efficient to use tractors of a single weight and power on a farm than to use tractors with different parameters.

This assumption has also been made in selecting the economically optimum tractor weight.

7. Optimum tractor weight for the given conditions is determined by the minimum value of total expenditure for units comprising tractors of optimum power but varying weights.

This stage of the calculations concludes the determination of the economically optimum tractor weight and power, the working width of machines, and the speed of advance of machine/tractor units.

A graph showing variation of total expenditure for tractors of different weight and optimum power is given in figure 8.

8. The same sequence is followed in the calculation and analysis of other indices used when it is necessary to elucidate particular aspects of the efficiency of various machine/tractor units.

All the data obtained, whether for expenditures or for other indices (labour costs, fuel consumption and metal content) can be conveniently plotted together on one or more graphs, like those shown in figure 9.

Such graphs assemble all the indices of units involved in the determination of optimum tractor weight and power. They can conveniently be plotted as a function of tractor weight, and all the indicators reduced to an equal level of energy saturation (relation of the tractor power to its weight).

Figure 8

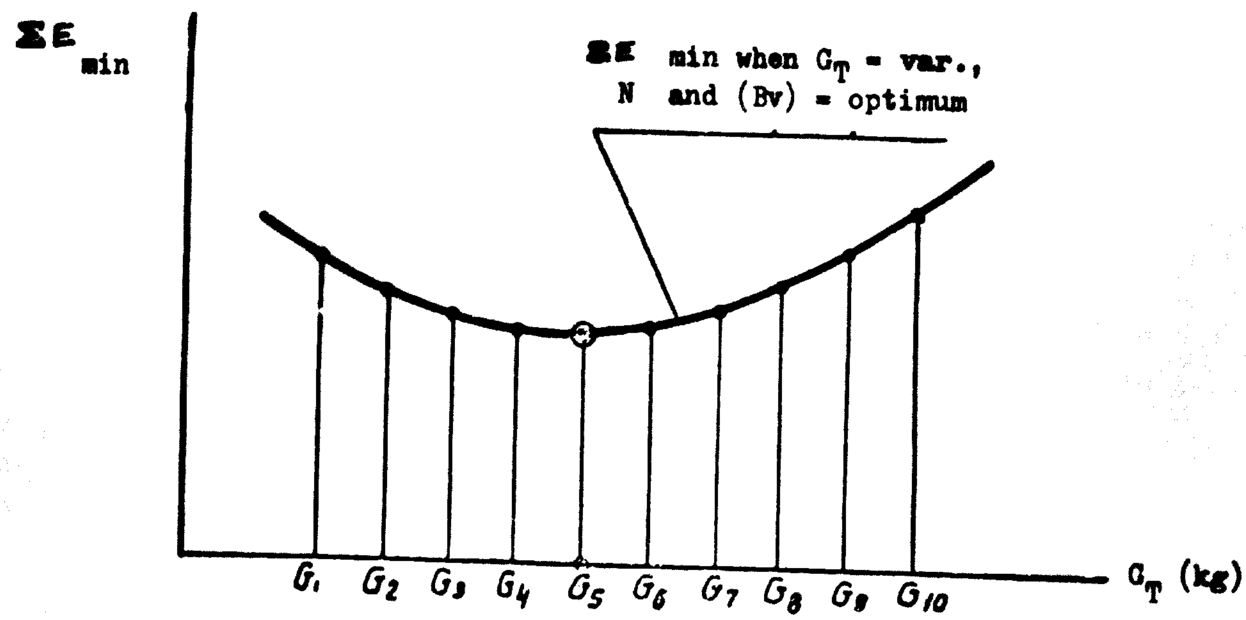


Diagram for determining optimum tractor weight for tractors of a single type carrying out, as components of units, a given set of agricultural operations on a given farm. (Weight G_5 is the optimum).

9. The analysis of the results obtained is carried out in reverse order. First of all, it is necessary to determine the economically optimum weight and power of the tractors (separately for each type of farm or region of the country) which ensure minimum expenditure for carrying out a given volume of work (agricultural operations carried out on a given area).

If equal minimum costs are found with tractors of different weight and power (different levels of energy saturation), additional indices must be analysed for these tractors.

The graph (figure 9) shows that expenditures are practically the same for a whole range of sizes and types of tractors. Analysis of the additional indices, however, shows that labour costs, fuel consumption and metal content are different in the case of units comprising these tractors. Depending on the actual conditions on farms in developing countries, the tractors selected in this case will be those ensuring optimum efficiency with the lowest labour costs, fuel consumption and metal content.

Next, optimum combinations of the working width of agricultural machines and speed of advance of units are determined for the optimum tractors, taking into account each type of operation involved, as well as the previously determined working conditions of the unit.

The optimum parameters of tractors and agricultural machines thus obtained are used in the calculation and justification of type selection.

Figure 9

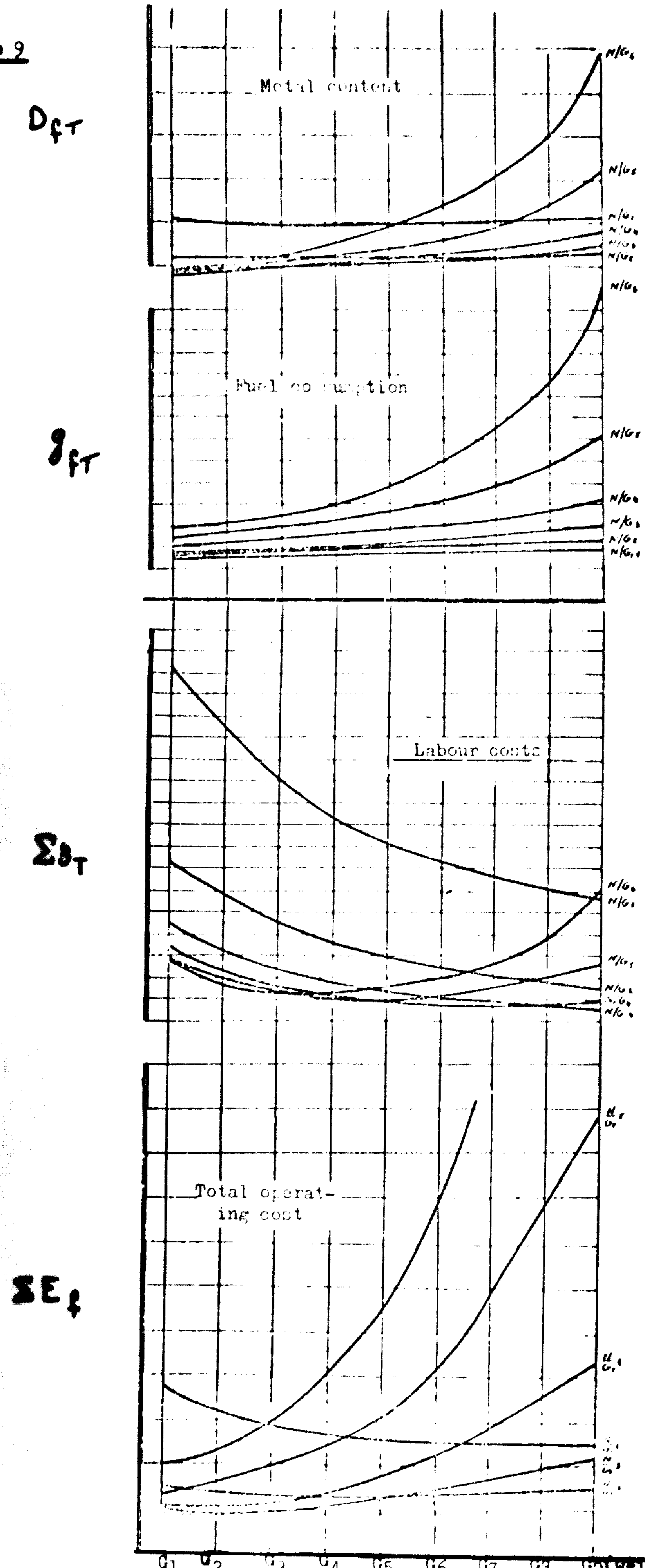


Diagram showing variation of expenditure and other indices of machine/tractor **as a function** of the weight and energy saturation of tractors, for **the total volume of work.**

CONCLUSIONS

The calculation and justification of the type range of tractors and agricultural machines is a complex task involving a whole series of problems connected with the manufacture and operating conditions of tractors and the agricultural machines to which they are coupled.

The determination of tractor weight and power, the working width of agricultural machines and the speed of advance of the machine/tractor unit is an essential element in the selection of type ranges.

The method set out above for determining and justifying the optimum parameters for machine/tractor units makes it possible to identify the economically optimum weight and power of tractors, working width of agricultural machines and speed of advance of units so as to ensure maximum efficiency in carrying out a given volume of work.

The criterion for determining and justifying the optimum parameters of assemblies is the achievement of minimum expenditure, expressed as the money cost per unit area worked. At the same time, additional indices such as labour costs, fuel consumption and metal content should be determined so that a more qualitative approach can be made to the selection of machine/tractor units and the determination of the appropriateness of using them in the national economy.

The collection of data on natural and agricultural conditions and on specific features of the cultivation of agricultural crops, together with the determination of the relation between expenditures and the parameters of machine/tractor units are fundamental tasks in determining the economically optimum parameters of machine/tractor units.

The variants of machine/tractor units for which expenditures are calculated and from which the optimum is selected should if possible take into account differences in working conditions, as well as in design and economic factors.

The method we have described may be used in the assessment and selection of alternative lines of development of agricultural technology.

As labour costs, fuel consumption and metal content are also determined when estimating the expenditures, analysis can if necessary be carried out on the basis of any of these factors and the unit parameters which ensure maximum efficiency of the unit for given values of these factors can be determined.

The method set forth may be used in other branches of the national economy.

BIBLIOGRAPHY

1. Goryachkin, V.P. - Collected papers, Vols. I-III, Moscow, 1965.
2. Kirtbaya, Yu.K. - Fundamental theory of the use of machines in agriculture. Kiev-Moscow, 1957.
3. Kolotushkina, A.P. - Basic methods of determining the economic efficiency of new agricultural machines in the national economy. Moscow, 1961.
4. Lintvarev, B.A. - Scientific bases for raising the productivity of agricultural units. Moscow, 1962.
5. Orlov, N.M. - Determination of optimum speeds of advance and working width of units. Journal of Agricultural Science, No. 4, 1961.
6. Orlov, N.M. - Determination of optimum parameters of machine/tractor units. Collection "Power engineering and unit parameters". Moscow, 1967.
7. Svirshchevsky, B.S. - Operation of the machine/tractor fleet. Moscow, 1958.
8. Trepenenkov, N.N. - Operational indices of agricultural tractors. Moscow, 1959.

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