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Evaluation of the Efficiency of Mechanized Technological Processes of Agricultural Production

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Abstract: The study presents generalized recommendations to choose technical facilities to perform main processing researcher in terms of large, medium and small-sized enterprises (according to the researcher's classification). When calculations were made impact of enterprise sizes and standard-setting factors of fields on target characteristics of machinery was taken into account. The resulted data can be used when farm enterprises develop their strategies for technical modernization and re-equipment. There is a comparative analysis of operating and production costs when using conventional and modern resource-saving technologies in conditions of different farms.

Key words: Plant growing, cultivation technology, agricultural machinery, economic evaluation, energy and resource saving, production costs, operating costs

INTRODUCTION

The special thing about farm production in the Russian Federation is that food products are produced by enterprises being very different in size, equipment capability, gross receipts and other characteristics. Thus, farm land size varies from several hundred hectares in small farm enterprises to hundred thousand hectares in large agricultural holding companies. They have different financial capacities and face the problem of choosing and introducing crop production technologies as well as machinery and equipment that meet their needs and correspond to modern technologies in agricultural production.

Solution of this problem is based on the multi-faceted research in effective use of existing machinery and equipment, the fullest employment of their technical and operational capacities as well as buying new machines and tools with account for specific production, enterprise size and its financial capacities. As matters stand, higher efficiency of agricultural production depends on introduced energy-saving technologies for crop growing and reduced expenditures on mechanized working operations.

Researchers claim that advanced technologies in crop production, effective use of existing machinery and equipment are the most productive means to increase farm production. However, innovative technologies are being introduced too slowly. There are several reasons of it; slow application of climatic cropping pattern, resource shortage and insufficient consideration of environmental conditions. To get the required returns from every field one must adapt this or that processing technology to the given conditions, take into account specifics of the cultivated crop. It is an engineering design of processing technologies with the proper concern for the all local conditions (Ariutov *et al*., 2010).

In present conditions being characterized with diverse crop production technologies, wide range of fertilizers and crop protection products, technical facilities for agricultural production being considerably different in characteristics and price there is a great chance to make a

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false decision. That's why, it's very vital for managers and experts to be able to make an objective comparison of the existing technologies and equipment in terms of their enterprise conditions.

There are plenty of Russian researches that investigate assessment of technical and economic indices of farm machinery and units, rational gathering of a machine and tractor fleet for a farm enterprise (Enikeev, 1981; Finn, 1985; Pronin and Prokopenko, 2008; Zangiev, 1991). Issues on improving production processes in agriculture are studied in researcher of foreign authors (Buckett, 1988; Kay and Edwards, 1994; Osteen *et al*., 2012).

There are different ways and methods to analyze and assess economic efficiency of crop production technologies.

Lieder (2014) developed and studied an assessment method to analyze resource efficiency in small and average-sized enterprises being the most common types of farm enterprises in Europe. Production facilities are valued from the dualistic point of view including indicators for decision making as well as observational evidence.

Rustamova (2016) following investigations of Bronzes (2014) shows that energy-saving technologies (Conservation Agriculture (CA) technologies) are less expensive and make it possible to save 45% of fuel 20% costs on workforce compared to conventional technologies. However, energy-saving technologies require additional expenses for herbicides that is not done in conventional technologies (Rustamova, 2016; Bronzes, 2014).

According to calculations of Rustamova (2016) conservative and zero soil tillage technologies have advantages according to their economic indicators. Profitability at conservative and zero technologies was 105.5 and 132.1%, correspondently (Rustamova, 2016).

By Nardin *et al*. (2015) says machinery and equipment as well as processing technologies in farm products production will be considerably different depending on farm specialization and natural environment and climatic conditions.

Terentiev and Menukhova (2015) offer a method to calculate operation expenditures on vehicles maintenance and repair that makes possible to compare rate of change in spending for different vehicles and has become a criterion for making scientifically based choice of cars and tractors.

The above mentioned works don't take into account impact of farm enterprise size, their location in a natural zone and standard characteristics of fields on technical and economic characteristics of machines and cars, the structure of the machine and car fleet and technology efficiency on the whole. The same farm machinery or unit can be a good buy for one enterprise and unreasonable money waste for another one. When a farm enterprise buys farm machinery they must consider the following things "price-quality-machine capacity and production costs in these particular conditions".

The aim of this investigation is to determine general recommended characteristics and design features for farm machinery and equipment that enable to reduce operation costs in crop production for different farm types.

MATERIALS AND METHODS

Based on a preliminary analysis of farm enterprises in the Republic of Bashkortostan three main types of farms-small, medium and large ones-are distinguished depending on their size, produced crops, equipment capability and financial capacity (Table 1).

Using expert, technical and economic assessment for different types of farms we identified recommended characteristics and design features for machinery and equipment to reduce operating costs in crop production for different types of farms, Table 2 presents some recommendations for conventional grain production technology.

It should be noted that, the most important condition for effective cost minimization is a high level of farming, clear technology performance, high-quality operation at the best time, proper use of efficient herbicides, use of sufficient doses of fertilizers and proper equipment at the disposal of farms.

A comparative analysis of technical and economic indicators of machine and tractor units was carried out on the basis of a methodology developed by the staff of the Volga Region's Vehicle Testing Laboratory and approved by the Scientific and Technical Council of the Russian Ministry of Agriculture (Pronin and Prokopenko, 2008). The methodology corresponds to the standards of the American Society of Association Executives and therefore is applicable for economic assessment of both domestic and foreign machines (American Agricultural Economics Association, 2000).

Table 1: Classification of farms in the system

	Types of farms		
Characteristics	Small	Medium	Large
Indication in the system	SML	MDM	LRG
Arable land (thous. ha)	<2	2, …, 5	5, …, 10 and more
Grain crop acreage (thous. ha)	<1	1, …, 3	3-6 and more

Table 2: Technical requirements for crop production machines and equipment

		Types of farms		
Working operation	Technical characteristics	SML	MDM	LRG
Fertilizer loading	Loader type	Front	Front	Telescopic
	Load capacity (ton)	Up to 0.85	Up to 3	More than 3
Mineral fertilizers transportation and application	Mineral fertilizer spreader type			
	Volume capacity (m^3)	Mounted up to 1	Tractor-drawn up to 3	Tractor-drawn more than 3
Plowing	Reversible plow Frame number	Up to 4	4-6	More than 8
Harrowing	Width (m)	8	Up to 16	Up to 24
Soil cultivation	Width (m)	4	8	More than 12
Seed treatment	Performance, at least (ton/h)	5	10	15
	Type of installation	Mobile	Mobile	Stationary
	Mixing principle	Continuous	Continuous	Continuous, batch fertilization
Seed planting	Seeder type	Seed-fertilizer seeder	Seed-fertilizer, sowing machine	
	Type of placement unit	Mechanical	Mechanical, pneumatic disk, tine, anchor	Pneumatic
	Coulter type Width (m)	3.6	3,6-8	Disk, tine, anchor more then 8
Crop spraying	Boom sprayer type	Mounted	Tractor-drawn	Tractor-drawn, self-mobile
	Volume capacity,	Up to 600	2000-3000	More than 3000
	Width (m)	Up to 18	Up to 28	Up to 40
Swath picking up and threshing	Combine harvesters Combine type	3	4,5	6
	Number of strawwalker sections	4	5	5,6
	Type of threshing device			
	Thresher width (mm)	120	1500	>1500
	Opeartion rate (kg/ses)	5-6	7-9	11-12

According to this methodology, hourly operating costs (rub./h) of an implement are defined as:

$$C_{impl} = C_{tr} + C_{fm} \quad (1)$$

where C_{tr} and C_{fm} stand for hourly operating costs of a tractor and a farm machinery being parts of the implement, rub./h. In turn:

$$C_{tr} = C_{DEPR} + C_{RM} + C_{IMPL} + C_{OTHDR} + C_{HFC} + C_{AHW} = \frac{B\mu_{RMTAR}}{100\mu LCC_{0.3B}} \quad (2)$$

$$\frac{B}{\mu LCC} + \frac{\mu LCC_{0.15B}}{\mu LCC} + 1000 Pr_{FU} q_{SP} N k_{exp} k_{LP} + \frac{2D}{7}$$

Where:

- C_{DEPR} = Denote depreciation costs (rub./h)
- C_{RM} = Costs on maintenance and repair (rub./h)
- C_{IMPL} = Stands for implicit costs on loan servicing or lost profit of the restricted equity (rub./h)
- C_{OTHDR} = Is are other direct expenditures dependent on machine price (rub./h)
- C_{HFC} = Means fuel and lubricants consumption rate at full load of the tractor (rub./h)
- C_{AHW} = Corresponds to an average hourly tractor driver's wage including all the accruals and tax payments (rub./h)
- B = Stands for a book value of the tractor (rub.)

μ is a coefficient to match hourly life-cycle costs of domestically produced tractors to the international standard (μ = 0.8 for tractors of Russian and Belorussian production; μ = 1 for imported tractors); LCC means tractor's life cycle costs (Table 3), h.

μ_{TAR} is a coefficient to match hourly costs on total accumulated repairs of domestically produced machines to the international standards (μ = 1, 2 for tractors of Russian and Belorussian production; μ = 1 for foreign tractors). TAR is total accumulated repairs costs according to the ASAE standards for the whole life cycle as a percentage of book value (Table 3) (%):

Where:

- Pr_{FU} = Is a fuel Price (rub./kg)
- q_{SP} = Is a specific fuel consumption rate (g/kWh)
- N = Is Nominal engine horsepower (kW)
- k_{EX} = Is a coefficient showing reduction in hourly fuel consumption at real load compared to rated operation

It is evaluated experimentally, for model calculations k_{EX} = 0.85; k_{LP} is a coefficient to account costs for lubricants (for machines produced in the CIS countries-1.1, for Foreign machines-1.25), D is a daily wage rate of a tractor driver (rub.), 2-a coefficient taking into account all the accruals and tax payments, 7-standard shift time (h).

Hourly operating costs of farm machinery C_{FM} are determined in the same way while hourly fuel

Table 3: Specified indicators for farm machinery (ASAE standards, USA)

Machines and implements	LCC (h)	Maintenance and repair costs for life cycle (%)	Shift time use coefficient (τ)
Tractors:			
Two driving wheels	12000	100	-
Four driving wheels	16000	80	-
Tillage machines:			
Mouldboard ploughs	2000	100	0.85
Huller	2000	60	0.80
Subsoil cultivators	2000	75	0.85
Full-length cultivators	2000	70	0.85
Spring harrows	2000	70	0.85
Disk harrows	2000	40	0.85
Rotary harrows	2000	60	0.80
Interrow cultivators	2000	80	0.80
Rotor cutters	1500	80	0.85
Seeding machinery:			
Row-crop planters	1500	75	0.70
Grain crop planters	1500	75	0.65
Harvesters:			
Tractor-drawn grain harvesters	2000	60	0.65
Self-propelled grain harvesters	3000	40	0.70
Field forage harvesters (tractor-drawn and mounted)	2500	65	0.70
Field forage harvesters (self-propelled)	4000	40	0.70
Beetroot harvesters	1500	70	0.60
Potato harvesters	2500	70	0.60
Cotton harvesters	3000	80	0.70
Grass harvesters			
Standard mowers	2000	150	0.80
Rotor mowers	2000	175	0.80
Mower-conditioners	2500	80	0.80
Rotor mower-conditioners	2500	100	0.80
Self-propelled mowers (cutters)	3000	55	0.80
Swath rakes	2500	60	0.80
Balers (rectangular bales)	2000	80	0.75
Balers (rectangular, large bales)	3000	75	0.80
Round balers	1500	90	0.65
Other machinery			
Mineral fertilizer spreaders	1200	80	0.70
Sprayers	1500	70	0.65
Garden sprayers	2000	60	0.60
Bean harvester (roll)	2000	60	0.80
Top harvesters	1200	35	0.80
Silage loader	1500	45	-
Fodder tractor trailers	2000	50	-
Grain tractor trailers	3000	80	-

Table 4: Estimate indicators for tractors of different drawbar category

	Value for tractors of drawbar category				
Indicator	1.4	2	3	4	5
Cost, thous. rub. (thous. $)	665 (11.2)	1300 (21.9)	2000 (33.7)	3100 (59.3)	5000 (84.3)
Engine capacity (kW)	59	96	130	156	205
Fuel consumption at rated load (kg/h)	15.2	21.7	28.6	39.0	48.0
Fuel consumption at real load (kg/h)	12.92	18.44	24.31	33.15	40.80

consumption is determined only for self-propelled machines and wage expenditures for implements that are operated by indirect workers for instance sowers.

Table 3 shows operational and technical parameters of farm machinery recommended for practical use after its technical and economic assessment (American Agricultural Economics Association, 2000; Pronin and Prokopenko, 2008).

To calculate hourly operating costs for tractors average data was used presented in Table 4. Shiftly performance of machinery is determined from Eq. 3:

$$W_{SH} = 0.1MWVT_{ST\tau} \quad (3)$$

Where:

- MW = Stands for operating plow width of the implement (m)
- V = Is a field speed (km/h)
- T_{ST} = Corresponds to standard operating time (6 h at work with toxic chemicals, 7 h in other cases)
- τ = Is a coefficient of using the shift time

Since, τ is greatly dependent on furrow length and other standard-setting factors, a number of farms in the Republic of Bashkortostan were analyzed to adopt field indicators presented in Table 5.

τ values for every working operation in farms were defined by statistical analysis of implement indicators given in standard specifications for fuel use and consumption.

It should be noted that, the values for variable operation rate given in the present System cannot be used as standard rates for W_{SH} is calculated according to predicted speed rates and average values of other standard-setting factors.

Direct operating costs C_{ha} per hectare of the cultivated area alongside with hourly costs are the most important economic characteristics of machine-tractor systems. They were defined by Eq. 4:

$$C_{ha} = \frac{T_{ST}C_{IMPL}}{W_{SH}} \quad (4)$$

Table 5: Estimated characteristics of fields

Indicators	Farm types: Large	Medium	Small
Arable land (thous. ha)	10	4	2
Grain crop acreage (thous. ha)	7	2.5	1
Middle furrow length (m)	>1000	600, ..., 1000	400, ..., 600
Standards for mechanized works			
Arable	3	4	5
Non-arable	2	3	4

RESULTS AND DISCUSSION

Table 6 presents a part of generalized technical and economic indicators of machine-tractor units according to farm types. According to these indicators, one can compare operating capacity and direct operating costs for particular machines in conditions of different farm types and based on this data take a decision on using or buying this or that equipment.

Higher efficiency of farm production can be ensured not only by reduced costs of separate working operations but by choosing the most effective ways for their integrated use in scientifically-based crop cultivation technology.

Criteria to assess economic efficiency of the plant growing technologies were production costs per unit of sown area and (or) unit of output and operating costs for separate machinery and implements. Calculation was based on technological maps to produce summer grain crops in different technologies. Average data for southern steppe zone of the Bashkortostan Republic in the Russian Federation was taken as initial values.

Comparative assessment of costs in production of spring grain crops according to currently used conventional technology with a traditional set of.

Table 6: Comparative analysis of technical and economic indicators of machine-tractor systems according to farm types

Name, brand, model	Operating width, m	Shiftly operatingperformance (ha) LRG	MDM	SML	Direct operating costs (rub./ha) LRG	MDM	SML
Primary tillage							
Chisel plow PCHN-4, 5P	4.5	29.5	28.0	26.5	767	797	826
Subsoiler GRP-2,3	2.3	12.3	11.7	11.1	888	920	948
Reversible plow Ibis L3+1	1.92	9.0	8.6	8.4	1037	1074	1092
Reversible plow ArcoAgro LM40 (6 frames)	2.82	16.8	15.9	15.1	1060	1105	1149
Cultivation							
Tiller KPS-4G	4	23.3	22.0	20.2	234	248	261
Tiller Versatile Ñ600	18.3	93.5	80.7	63.5	439	508	622
Tiller KPPSh-6	6	29.4	27.9	25.7	496	532	565
Disk headers, disk harrows							
Disk harrow Versatile TD500	12.3	102.5	97.3	92.2	312	334	350
Disk harrow BDM 6X4P	6	53.6	50.9	48.2	443	475	497
Sowing							
Mechanical grain seeders							
Seeder Ob'-4ZT	10	37.0	35.4	32.3	306	316	346
Seeder SZ-3,6A	3.6	19.8	18.9	17.6	422	445	393
Seeder Amazone D-9 40	4	19.9	19.1	17.8	448	470	498
Seeder Astra SZT-5,4	5.4	23.7	22.6	20.1	521	542	603
Sowing complexes							
Agrator-4800	4.8	19.6	19.0	17.3	667	688	741
PK-4, 8B Kuzbass	4.8	21.0	20.2	17.9	799	833	934
Flexi Coil ST 820	13.1	63.7	56.6	50.4	878	978	1088
Versatile DH730	12.2	59.1	52.9	47.0	947	1051	1173
John Deere 1890	12.7	69.5	59.4	52.5	1052	1219	1371
Amazone Primera DMC	6	24.2	23.4	21.3	1074	1114	1228
Bourgault 3310-40	12.2	59.1	52.9	47.0	1075	1192	1330
Mowing for bales							
Reaper ZhVN-6B	6	29.5	28.2	25.6	233	242	262
Reaper ZhVP-9,1	9.1	33.1	31.8	29.7	336	349	372
Reaper ZhVP-4,9	4.9	19.5	18.7	17.4	396	410	437
Reaper ZhVZ-10,7 "Polesie"	10.7	33.0	31.8	30.0	432	449	474

Table 6: Continue

Name, brand, model	Operating width, m	Shiftly operatingperformance (ha)			Direct operating costs (rub./ha)		
		LRG	MDM	SML	LRG	MDM	SML
Reaper ZhZB-4,2	4.2	14.8	14.2	13.3	475	493	521
Mower self-propelled MacDon M155	7.6	28.5	27.4	25.5	767	796	848
Harvesting, grain harvesters							
Grain harvester Vector-410	9	28.7	27.7	26.0	629	653	689
Enisei-12-HM	7	23.3	22.4	21.0	788	818	865
Grain harvester KZS-812 “Polesie”	9.2	29.3	28.2	26.5	796	826	873
Grain harvester SK-5-1 “Niva”	5	17.3	16.7	15.6	1135	1178	1251
Grain harvester ACROS-585	9	28.7	27.7	26.0	1148	1192	1261
Grain harvester “New Holland” CSX7080	9.15	29.1	28.0	26.4	1259	1306	1381
Grain harvester KZS-1218-29 “Polesie”	9	28.7	27.7	26.0	1260	1307	1382
Grain harvester John DeereW650	10.7	37.6	36.2	33.8	1296	1346	1433
Grain harvester CLAAS Tucano 320	9.12	33.1	31.9	29.7	1309	1360	1450

Table 7: Comparative assessment of costs in spring grain crop production according to different technologies

Characteristics	Conventional technology with plowing	Without soil tillage (No-till)		
	Medium farms	Large farms	Medium farms	Small farms
Operating costs (thous. rub./1 ha)				
Including technical maintenance	2.16	1.34	1.24	1.16
Technical maintenance and repair	3.17	3.39	2.29	1.50
Renumeration	1.27	0.80	1.03	1.15
Depreciation	3.07	3.55	2.64	1.70
Total operating costs				
per 1 ha, thous. rub.	9.67	9.08	7.20	5.51
per 1 ton, thous. rub.	4.03	3.78	2.99	2.29
Seeds (thous. rub./1 ha)	3.00	1.95	1.95	1.95
Mineral (phosphorus, potassium) and nitrogen Fertilizers (thous. rub./1 ha)	1.00	1.00	1.001.00	
Herbicides, fungicides, insecticides, treaters (thous. rub./1 ha)	1.1	3.12	3.123.12	
Total production costs				
per 1 ha, thous. rub. ($/per 1 ha)	14.77 (249.1)	15.15 (255.5)	13.27 (223.8)	11.58 (195.3)
per 1 ton, thous. rub. ($/per 1 ton of grain)	6.15 (103.7)	6.31(106.4)	5.53 (93.3)	4.84 (81.6)

Table 8: Direct operating costs of grain harvesters

Name, brand, model	Direct operating costs* (rub./ha)	
	According to the offered method (Table 6)	According to the car test center data (GID-14, 2013)
Enisei-12-HM	788…865 (7)	572, …, 925** (6)
John Deere W650	1296, …, 1433 (10,7)	1477 (9)
CLAAS Tucano 450	1309 ,…, 1450 (9,12)	1584 (9,12)

*Figures in brackets denote operating width of cutter (m), ** when yield is within 10, …, 35 c/ha

machines, conventional technology with a complex of implements recommended in the System, conservative and zero technologies is shown in Table 7.

Assessment of forecasted characteristics of machinery presented in Table 6 in terms of the results of test data in production conditions (GID-14, 2013) showed their comparability (Table 8).

Insignificant differences are due to different operating width of cutters, adopted prices for machinery and fuel and other factors. On the whole, data in Table 8 prove validity of our approach to predict machinery characteristics when they are compared to choose appropriate machines and equipment for crop production.

Calculations showed that operating costs for zero technology are lower compared to the existing conventional technology. It is quite natural due to the fact that most energy-consuming working operations in soil tillage aren’t used.

It is also, worth to be pointed out that effective introduction of No-Till technology is greatly dependent on farm size. Estimated data show (Table 1) that costs at No-Till directly depend on farm size. The more is a farm enterprise, the more are its total costs (costs rise at 12%, from 48% in small enterprises to 60% in large farms). Higher costs in large farm enterprises are related to the need to buy and operate productive, powerful and expensive equipment as well as to use foreign component parts that significantly increase their maintenance and repair.

As it was mentioned before, the given method is not intended just to choose machines and equipment but also,

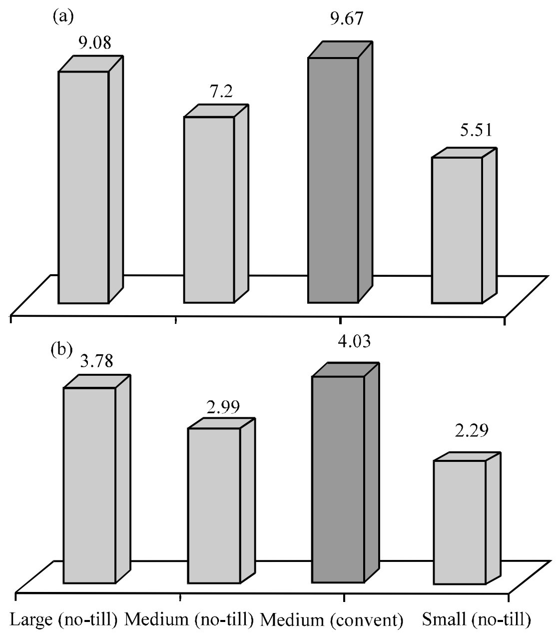

Fig. 1: Different operations: a) Operating costs of farm enterises per 1 ha, thous. rub. and b) Operating costs of farm enterises per 1 ton, thous. rub.

Table 9: Different tillage technologies

Zones	Conventional	Conservative	Zero
Northern forest-steppe	50	40	10
North-eastern forest-steppe	40	50	10
Southern forest-steppe	30	55	15
Cis-Ural steppe	30	45	25
Trans-Ural steppe	20	50	30
Mountain forest	30	70	-

to use scientifically-based requirements for all the working operations. In particular it is about standards to apply fertilizers, plant protection agents, adhere to agrotechnical terms, quality of working operations, etc. For example, it is recommended to increase fertilizer application standards in conventional technology from 50 kg/ha up to 130 kg/ha (Fig. 1).

When compare operating costs in medium farm enterprises you can see that farms using conventional technologies in grain production spend much more money on machinery purchase and maintenance (9.67 and 7,2 thousand rub./ha or more at 34%, Table 1), though when accounting total production costs differences between conventional and zero technologies level out and don't exceed 11% (total costs are 15,17 and 13,75 thousand rub./ha correspondently, Fig. 2).

Taking into account natural and climatic conditions and above given technical and economic assessment for the Bashkortostan Republic, we recommend different tillage technologies as it is given in Table 9.

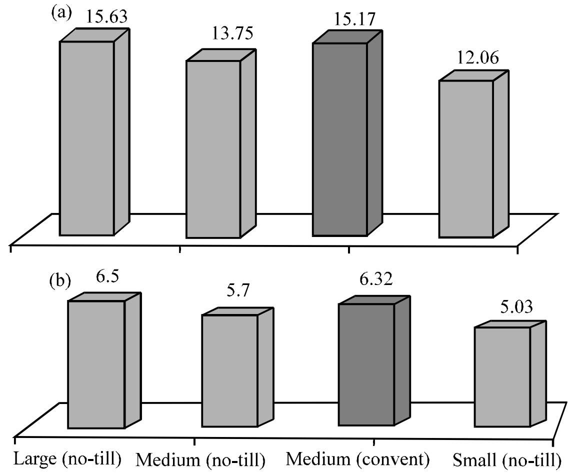

Fig. 2: Comparative assessment of production costs according to technology used: a) Operating costs of farm enterises per 1 ha, thous. rub. and b) Operating costs of farm enterises per 1 ton, thous. rub.

Table 9 Recommended proportion of soil tillage technologies according to zones in Bashkortostan for 2017-2022 (%).

CONCLUSION

In general, the proposed method is practically oriented to the specific conditions of the Republic of Bashkortostan entities and aims to achieve the following objectives, introduction of new scientifically-based technologies for crop cultivation in terms of natural and climatic conditions of the Republic of Bashkortostan. Higher labor productivity in agricultural production due to effective use of farm machinery and tractors, full realization of their technical and technological potential, reduced operating costs on machinery and equipment resulting in lower production cost of farm products.

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