Res. on Crops **19** (3) : 560-567 (2018) DOI : 10.31830/2348-7542.2018.0001.30
With one figure
Printed in India

A review of assessment of the machinery tillage tools' performance for higher crop production efficiencies

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(Received : July 18, 2018/Accepted : August 30, 2018)

ABSTRACT

The efficiency of crop production technologies to a great extent depends on the selected tillage tools and their performance. The aim of this study was to assess general quantitative performance of various machinery tillage tools. At first stage of study, the general assessment of soil tillage tools with regard to crop yielding capacity was assessed. The task of the second stage of study was to assess the performance of modern tillage tools from the perspective capacity of tractors. The study showed that the most rational practice was alternation of soil tillage tools for different crops grown under various crop rotations. At the same time, the energy-saturated aggregates, on an average, showed the same indicators of specific fuel consumption, running speed and switch-over time utilization coefficient as that of the aggregates with tillage tools of less operating width. The primary advantage of the wide-cut aggregates was narrowed to reduction of labour input, the value of which was reciprocally proportional to the operating width of the given tool. The gain in specific materials consumption of the tillage tools outruned the intensity of their operating width, which had a non-linear increase in the machinery cost, the level of its negative impact on the territory, and it's more complicated exploitation. These drawbacks were compensated with a series of advantages with the decrease in the labour input. In case of introducing driverless tractors, the profit from the diligence of the aggregates with an increased operating width was to a great extent smoothed over. Thus, hypothetically the development of site-specific crop growing and automation of the agricultural processes will lead to the limitation of tractor capacity and operating width of the tools aggregated with them.

Key words : Driverless tractor, operating width, soil tillage system, specific materials consumption, tillage tools, yielding capacity

INTRODUCTION

Crop science is the most important sub-branch of the farming sector, which not merely provides people with plant-produced food and animals with fodder, but also dishes out the source of unique raw materials for several industrial sectors. The efficiency of crop production technologies to a great extent depends on the selected soil tillage systems and specific indicators of its implementation (Esfahani *et al.,* 2016; Azizi *et al.,* 2017). However, among the agricultural production specialists, there is still no single opinion on the necessity of tillage and preference of some or other kind of tools. With some generalization, the existing opinions about tillage tools may be narrowed through following five basic approaches :

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1. Compulsory introduction of moldboard ploughing into the technological cycle, which allows efficient weed control, causal organisms and pests without pesticides (or with their particular application). Likewise, the ploughing ensures deeper aeration of soil, increases the water holding capacity of soil, allows burying organic and mineral fertilizers into the root zone soil and facilitates the conditions for execution of other aggregates, first of all, for seeding.
2. Application of intensive non-moldboard tillage ensures decomposition of organic matter and deeper aeration of soil in combination with conservation of the straw in the top soil surface. It allows significantly less possibility of soil erosion, increasing efficiency of soil moisture retention and accumulation, creating favourable conditions for preservation of humus layer in soil and ensuring biological equilibrium of the soil.
3. Replacement of heavy tillage operations from the technological cycle with minimum and surface tillage. Such an approach is rather efficient technology for controlling weeds thereby significant decrease in labour input and material consumption of the processes. The conditions for burying the fertilizers are preserved, and the performance of the seeding machinery is optimized.
4. Adoption of no-till technology allows significant decrease in total material consumption with higher energy output of the technologies. Moreover, higher preservation of humus layer in soil, thereby control of soil erosion and higher efficiency of soil moisture accumulation and regulation of heat balance of the soil.
5. Alternation of various soil tillage systems/tools for different crops under various crop rotations.

At the same time, each of the above listed approaches regarding necessity and preferences for tillage tools also has some drawbacks, leading to lower crop yields and their quality. Unfortunately, despite the thousand years of crop farming history, there is still no single quantitative assessment of soil tillage systems' which influences potential yield capacity of crops. It might be due to the fact that the crop yields obtained at farmers and experimental fields significantly differ depending on the geographical area, morphological characteristics of specific crop variety or hybrids, climatic conditions during the crop period, landscape of the fields, agrotechnical indicators of separate operations, etc. Besides, many companies and dealers who are seeking to increase their sales of the machinery, pesticides, weedicides or other kinds of products often distribute partially unreliable or untested information, which makes the analysis of the crop production experience more complicated.

The tillage operations are the most energy and labour consuming part of crop growing, therefore, it is important to clearly define the need and use of modern tillage tools in agriculture (Lipkovich, 1983). In crop cultivation, the proper amount of tillage operations with suitable tillage tools requiring less possible labour input contributed to the manufacturing of tractor driven efficient tillage tools of various operating width. Hence, the aim of this study was to conduct generalized quantitative assessment of various tillage tools' performance in agricultural output.

MATERIALS AND METHODS

There were two stages of the study. The undertaking of the first stage was to broadly evaluate the soil tillage systems' influence on giving capacity of crops. The groundwork of the analysis was formed by the experimental data, presented in public sources after 2008 (Alabushev *et al.,* 2009; Ivenin *et al.,* 2010; Ulanov *et al.,* 2010; Kerimov, 2011; Pridvorev *et al.,* 2011; Samykin *et al.,* 2011; Vasyukov *et al.,* 2011; Kuzychenko, 2012; Beltyukov *et al.,* 2013; Ryzhikh *et al.,* 2014; Vlasenko *et al.,* 2014; Nesmiyan and Galayan, 2015; Nesmiyan *et al.,* 2016).

Follow-up of the literature demonstrated that nearly all the observational studies regarding this issue take the moldboard tillage technologies as basic. Thus, if at analysis of the terminations of such subjects in each considered experiment the value of tillage yielding capacity is equal to one, then yielding capacity of the same variety (hybrids) of the current crops at other tillage systems will be expressed by dimensionless indicator. At the same time, the obtained indicator of relative yielding capacity (IRYC) did characterize the efficiency of the analyzed technology already considering the distinctive features of the study conditions (variety, weather conditions, set of technological operations, level of mineral nutrition, acidity of the soil, content of humus in soil, etc.). Due to it, joint assessment of soil tillage systems' influence on giving capacity of the crops by segmental experiments without consideration of any additional conditions becomes possible. On the basis of the total obtained data the mathematical expectations of the indicator of relative yielding capacity ?IRYC were calculated for several crops, according to different tillage systems and their mean-square deviations (σ).

The project of the second level of the studies was to study the operation of the modern tillage tools, foremost of all, from the perspective of capacity of the tractor, which they are aggregated with. At the same time, the test protocols of 216 tillage tools were broken down, having been endorsed at the machinery testing stations of the Russian Federation since 2000 (Nungezer *et al.,* 2011; Rosinformagrotekh, 2014). The main statistical characteristics by the following indicators were determined for various groups of tools : specific fuel consumption (q, kg/ha); operating speed (VP, km/h); and the shift-over time utilization coefficient (τ). The authors have found the dependence of operating width and weight of tillage tools on the capability of the tractor engine (hereinafter – tractor capacity), which they are aggregated with.

RESULTS AND DISCUSSION

Table 1 represents the generalized information on assessment of various tillage technologies' influence on the mean value of an indicator of the relative yielding capacity of crops. The outcomes of the generalized calculations represented in Table 1 allow making the following determinations :

1. Both for close-growing and for cultivating crops, decrease in the intensity of tillage leads to the reduction in the yielding capacity.
2. The generating capacity at intensive sub-surface tillage insignificantly differs from the yielding capacity obtained in the furrowed fields. On an average, it decreases by 1 to 3%. Specific crops (pea, grain corn) in non-moldboard backgrounds showed the highest yielding capacity. Presence of stubble along the air spaces of the field influenced the seeded crops, for which the decrement in the indicator of relative yielding capacity in non-moldboard backgrounds was equal to 9 to 11% compared to the other tillage systems.
3. Cultivated crops are more responsive to tillage. However, nearly all the cultivated crops except for Indian corn, are relatively tolerant to decrease in the

Table 1. Indicators of relative yielding capacity (IRYC) of crops under various types of tillage systems

Crop		Moldboard		Non-moldboard		Superficial		No-till	
		IRYC	σ	IRYC	σ	IRYC	σ	IRYC	σ
Close-growing crops	Winter wheat	1.00	-	0.96	0.07	0.93	0.10	0.91	0.14
	Summer wheat	1.00	-	0.97	0.05	0.97	0.08	0.92	0.12
	Barley	1.00	-	0.98	0.06	0.95	0.10	0.93	0.13
	Autumn-sown rye	1.00	-	0.97	0.04	0.98	0.01	-	-
	Pea	1.00	-	1.03	0.02	0.79	0.11	0.66	0.10
	Rape	1.00	-	0.98	0.06	0.96	0.11	0.95	0.05
	Herbs	1.00	-	0.89	0.09	0.91	0.06	-	-
	Average	1.00	-	0.97	-	0.93	-	0.87	-
Cultivated crops	Sugar-beet	1.00	-	0.99	0.03	0.98	0.03	-	-
	Maize for silage	1.00	-	0.98	0.03	0.91	0.04	-	-
	Grain maize	1.00	-	1.01	0.08	0.88	0.07	0.58	0.17
	Sunflower	1.00	-	1.00	0.04	0.94	0.04	0.92	0.16
	Soybean[a]	1.00	-	0.97	0.05	0.94	0.05	0.83	0.15
	Average	1.00	-	0.99	-	0.93	-	0.78	-

[a]May be considered as both close-growing and cultivated crops.

depth of tillage, even sugar-beet. Thus, for instance, at the transition from moldboard tillage to minimum tillage the decrease in average yielding capacity of crops was equal to only 2 to 6% but, for maize it was 9 to 12%.

4. No-till technologies are not rational for growing all cultivated crops, because for such crops the averaged reduction of yielding capacity is more than 20%. Nevertheless, one of the most popular cultivated crops, sunflower, showed rather high yielding capacity at direct seeding. Compared with the technologies based on moldboard tillage, a decrease in its bearing capacity was only equal to 8%.
5. The majority of close-growing crops are tolerant to decrease in the intensity of tillage and even with "no-tillage" backgrounds ensure 0.91 to 0.95% of yielding capacity compared to the same indicator at moldboard tillage. However, for specific crops, for example, pea, decrease in intensity of tillage and further no-tillage approach caused a steep decline in yielding capacity (by 11 to 34%).

Overall, the generalized analysis allowed indicating a positive influence of tillage intensity on yielding capacity of the crops. At the same time, there were no evident reasons revealed for refusal from some kinds of cultivated soil in favour of others.

The research conducted on the second stage allowed indicating that on rational aggregating speed and specific energy characteristics of tillage aggregates did not depend on the operating width of the tools, but was influenced by the variety of performing operations and operating conditions (Nungezer *et al.,* 2011; Rosinformagrotekh, 2014; Nesmiyan, 2017). Table 2 shows average values (M) and mean-square deviations (σ) of a series of such indicators viz., operating speed, energy output and switch-over time utilization coefficient (where, *n* is the number of the relevant tools, considered at analysis, pcs). These tables may be used in conducting theoretical substantiation of machine-tractor aggregates and technological complexes of the machinery.

Data in Table 2 allow for conducting averaged quantitative assessment of implementation of the following operations :

1. Chiseling at a set depth of processing is the most energy consuming operation.
2. Specific fuel consumption at implementation of which is about 10% more than at moldboard plowing.

The highest operating speed (V_p σ 10,2 km/h) is peculiar to the tools with disk-shaped operating devices (disk headers, rotovators) and spring-tooth harrows, while the lowest one (V_p ≈ 7,2 km/h) to chisel ploughs. Switch-over time utilization coefficient for the majority of the aggregates with simple tools varies in the range 0.73 to 0.75, whereas for the aggregates with a more complicated design of the tools (rotovators, spring-tooth harrows, combined tools) the switch over time utilization coefficient varies from 0.65 to 0.70, etc. At the same time, it is necessary to take into account that in specific conditions the value of the considered parameter may significantly differ from the average one, for example, by specific fuel consumption the values varied from 16 to 40% for different types of tools.

The set characteristics of the aggregates significantly depend on the adequacy of their arrangement, correspondence of tractor capacity to the operating width of the tool considering the scheduled conditions of work. The data fitting conducted by Rosinformagrotekh (2014) set aside to reveal the dependencies of the rational operating width of the tillage tools on tractor capacity (expressed in kW), which they were aggregated (Table 3) within the accuracy 0.93 to 0.99. Application of the obtained dependencies and the data of the Machinery Testing Stations' protocols (Rosinformagrotekh, 2014) on the weight of the tools also allowed obtaining the dependences characterizing specific materials consumption of the tools (Table 3).

Dependencies represented in Table 3 allowed to conclude that increase in capacity of tractors led to the linear growth of the operating width of the tools exploited, thus, relative increase in operation and decrease in labour costs. At the same time, the increase in specific materials consumption is also of linear nature. Table 4 presents the estimated indicators of specific use of goods and services

Table 2. Performance indicators of MTA operation

Basic MTA tools A	Average depth a, cm	Statistical characteristics of indicator	Indicators		
			Specific fuel consumption (kg/ha)	Operating speed (km/h)	Switch-over time utilization coefficient
Single-furrow plows	24	M	15.9	8.1	0.74
		σ	3.2	0.9	0.05
		n	53		
Chisel plows, sub-surface cultivators	22	M	12.2	8.6	0.73
		σ	3.7	1.1	0.04
		n	18		
Chisel ploughs	37	M	17.4	7.2	0.75
		σ	2.8	0.9	0.05
		n	16		
Disk headers and harrows	11	M	7.8	10.2	0.74
		σ	2.8	1.9	0.05
		n	40		
Combined tools	12	M	8.0	9.0	0.70
		σ	2.3	1.2	0.07
		n	18		
Stubble and chisel cultivators	12	M	7.1	8.7	0.74
		σ	1.2	1.4	0.04
		n	26		
Field cultivators	9	M	4.1	9.0	0.73
		σ	1.0	1.1	0.04
		N	34		
Rotovators	9	M	3.7	10.3	0.65
		σ	0.6	1.3	0.04
		n	3		
Tooth harrows (spring-tooth)	5	M	1.7	10.2	0.69
		σ	0.7	2.2	0.07
		n	8		

MTA : Machine Tools Associates (name of USA company).

Table 3. Dependence of operating width and specific consumption of tillage tools' materials on capacity of the aggregating tractors

Basic MTA tools	Dependence	
	Operating width (m)	Specific materials consumption (kg/m)
Single-furrow plows	$B_p(N)$=0.011 N+0.397	m_n (N)=0.756 N+606.3
Chisel plows, sub-surface cultivators	$B_p(N)$=0.015 N+0.462	m_n (N)=1.049 N+253.6
Chisel ploughs	$B_p(N)$=0.018 N-0.067	m_n (N)=0.492 N+377.7
Disk headers and harrows	$B_p(N)$=0.022 N+0.725	m_n (N)=1.415 N+571.5
Combined tools	$B_p(N)$=0.024 N+0.987	m_n (N)=2.866 N+132.2
Stubble and chisel cultivators	$B_p(N)$=0.028 N+0.659	m_n (N)=0.844 N+309.3
Field cultivators	$B_p(N)$=0.042 N+1.337	m_n (N)=1.261 N+159.2
Rotovators	$B_p(N)$=0.072 N+1.055	m_n (N)=2.919 N+173.1
Tooth harrows (spring-tooth)	$B_p(N)$=0.191 N-1.627	m_n (N)=1.233 N+26.1

MTA : Machine Tools Associates (name of USA company).

of the tools' materials to the tractors, the engine capacity values of which are peculiar to the wheel tractors of the standard drawbar categories (from 1.4 to 8), accepted as the classification attribute in the Russian Federation.

The data presented in Table 4 show that the increase in tractor capacity leads to the growth in specific consumption of the tools' materials. It is explained by the fact that wide-cut tools require more massive frame in section with swivel mechanisms for its folding, reinforced carrier of the core section, more complicated and branched hydraulics, etc. At the same time, the lower specific energy yield of the process carried out by means of the tool is quicker its operating width grows with the gain in the tractor's capacity. Therefore, higher

Table 4. Estimated specific materials consumption for the tools (kg, m), aggregated with tractors of standard capacity

Basic MTA tools	Mean power of tractor engine, kW (h. p.)						
	62 (84)	94 (128)	135 (184)	190 (258)	200 (272)	290 (394)	330 (449)
Single-furrow ploughs	653	677	708	750	758	826	856
Chisel plows, sub-surface cultivators	319	352	395	453	463	558	600
Chisel ploughs	408	424	444	471	476	520	540
Disk headers and harrows	659	705	763	840	855	982	1038
Combined tools	310	402	519	677	705	963	1078
Stubble and chisel cultivators	362	389	423	470	478	554	588
Field cultivators	237	278	329	399	411	525	575
Rotavators	354	447	567	728	757	1020	1136
Tooth harrows (spring-tooth)	103	142	193	260	273	384	433

MTA : Machine Tools Associates (name of USA company).

the intensity of increase in specific materials consumption (Fig. 1). For chisel and single-furrow ploughs, the growth of specific materials consumption in transition from tools to tractors with the capacity of approximately 60 kW, then the tools for tractors with the capacity of approximately 330 kW amount to just over 30%, and for Rotovators and spring-tooth harrows the same transition leads to the growth in specific materials consumption by 3 to 4 times and more.

By and large, one may conclude that the trend towards an increase in the operating width of the tillage tools and the capacity of the tractors aggregating them has a series of apparent following disadvantages :

1. Development of the tools' materials consumption outruns the intensity of the aggregates' performance increase, which leads to the non-linear growth of the machinery costs and its more complicated exploitation. At the same time, for example, at less total weight two six-meter aggregates ensure the same performance as one aggregate with the tool of the twenty-meter operating machinery.
2. For the same reason, one observes the deep compacting influence of the

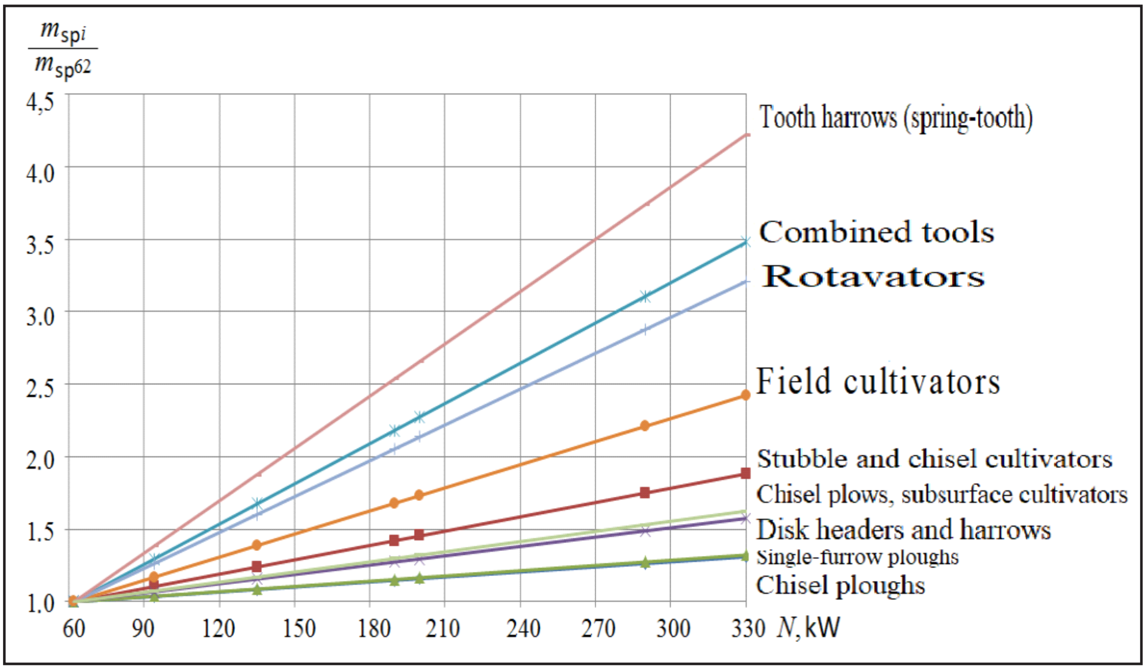

Fig. 1. Change in specific consumption of the tools' materials for boosting the aggregation tractor capacity.

tractors' carrier and of the tools on the soil. Also, the influence of "milling" effect increases, which not just leads to dusting of the surface soil, but also decreases the propulsive coefficient of the tractor's performance.

3. In case of a defect of a big tractor or a wide-cut tool, the performance of the operation is completely stopped. At the same time, the breakdown of operation of a complex of aggregates with less operating width has only a partial decrease in the daily turnout of the composite.

During modern stage of technological development, the above mentioned drawbacks are compensated with important advantages of the wide-cut aggregates viz., decrease in the labour input for performance of an operation and the facilitation of labour management. However, even today series of large tractor companies have taken to produce testing samples of driverless tractors, which make possible, that they will be used in farming in rather short-run. Introduction of driverless technological vehicles will significantly decrease the effect of the application of energy-saturated tractors and wide-cut tools if their drawbacks are not corrected. So, one may suppose that there is a potential trend opposed to the existing one, towards the limitation of tractor capacity and of their aggregated tools' operating width.

CONCLUSIONS

1. Different crops have different responses to the change in tillage intensity, the most rational is alternation of soil tillage systems for different crops in crop rotation, including stabling-in. The survey has not disclosed a need of refusal from any tillage kind in favour of another.
2. Energy-saturated aggregates, on an average, show the same indicators of specific fuel consumption, running speed and switch-over time utilization coefficient as that of the aggregates with tillage tools of less operating width. The primary advantage of wide-cut aggregates is narrowed to decrease in the labour input of the operations, the value of which is reciprocally proportional to the applied tool's operating width.
3. Development of the specific materials consumption of the tools outruns the growing volume of their operating width. In the majority of cases, the estimated tools' specific materials consumption to the tractors with the engine capacity of 330 kW is from 31-88% higher compared to the tools aggregated with the tractors having engine capacity of 62 kW, which causes a non-linear increase in the cost of the machinery, the degree of its negative impact on the soil and its more complicated exploitation. In some cases, the tools' specific materials consumption increases by three-four times.
4. At the modern stage of technological development, the drawbacks of energy-saturated aggregates' application are paid with a series of advantages, first of all, with a decrease in production labour input. In case of introducing driverless tractors, the advantages of the application of the aggregates with an increased operating width are almost completely smoothed over (except for the components of the aggregates and their technical maintenance). Thus, hypothetically further development of site-specific crop farming and automation of the processes in agriculture will contribute to the limitation of tractor capacity and operating width of the tools aggregated with them.

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