Efficiency of tractor track scarifiers used for sowing grain crops

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Abstract. The paper explores the efficiency of tractor track scarifiers that, once mounted, are constantly used with tractors for performing various technological operations, including layout of seedbed and sowing. The efficiency of tractor track scarifiers is calculated using a mathematical model of agricultural implements. A performance indicator is total energy consumption that include the energy of the crop lost due to soil compaction by tractor wheels. The computational experiments show the efficiency of tractor track scarifiers for sowing. A power effect for a sowing machine used with a John Deere-9430 tractor is in the range of 8000-10000 MJ/ha.

1. Introduction

An ongoing population growth calls for continuous brainstorming to boost labor productivity in the agrarian sector. It is possible to raise labor productivity of agricultural workers not only by increasing the availability of energy consumed by production [1-3], associated with the use of more powerful, heavier machinery negatively affecting the soil, and later the growth and development of crops, but also by reducing losses of a potential crop [4-6]. One of the types of potential yield losses is caused by soil compaction by the wheels of high traction powerful tractors [7-10]. Soil compaction is highest in spring, when soil moisture is high to perform such technological operations as disc harrowing, cultivation and seeding.

One of the ways to address the challenge is to use tractor track scarifiers to perform technological operations, especially during early spring activities [11-13].

2. Materials and Methods

To study the efficiency of tractor track scarifiers, a tractor-implement mathematical model is used that performs a technological operation during spring field activities. The model was constructed for a tractor-operator-implement-field-soil-crop (TOIFSC) system, i.e. it involves the measurements of the tractor and agricultural machine to have an impact on the crop being planted. Here is an energy indicator (performance criterion) that serves as a basis for the mathematical model.

The performance indicator to assess the efficiency of the tractor track scarifier is as follows [4]:

\[ E = E_{m.tr} + E_{m.imp} + E_{m} + E_{c.c} + E_{c} + E_{d} + \frac{E_{agr} + E_{com}}{min}, \]  

(1)
where $E$ is total energy consumption per 1 hectare, MJ/ha;

$E_{m.tr}$, $E_{m.imp}$ is energy spent, respectively, for the manufacture of a tractor and agricultural implement, MJ/ha;

$E_{r.m}$ is energy spent on all types of repair and maintenance practices of a tractor and agricultural implement, MJ/ha;

$E_{s.c.}$ is specific energy costs for a system to travel from field to field, MJ/ha;

$E_i$ is energy spent by a machine operator to control the system, MJ/ha;

$E_{fl}$ is energy spent for fuel, MJ/ha;

$E_{agr}$ is energy of the crop lost due to violated deadlines, MJ/ha;

$E_{com}$ is energy of the crop lost due to wheel compaction, MJ/ha.

Overcompaction of the soil by the wheels of the tractor deteriorates its physical and mechanical properties, resulting in losses of some potential yield. It can be defined by the formula [4]:

$$E = A \cdot Y \cdot Q \cdot \frac{B \cdot \rho_w \cdot b \cdot q_{max} \cdot U}{2B} \cdot \left[ 1 - \frac{n B}{2B} \cdot \frac{U}{B} \right] \times 100,$$

where $A$ is the percentage of the yield lost per unit of a compacting effect produced by the tractor wheels, \%\cdot m/kN;

$Y$ is potential yield, kg/ha;

$Q$ is the specific energy consumption of the lost grain, MJ/kg;

$B_i$ is the impact of wheel compaction on the yield, m;

$B_r$ is the coverage provided by the tractor, m;

$n$ is the number of wheel tracks after one run of the tractor across the field;

$w$ is coefficient related to the parameters of the wheels;

$b_w$ is tractor wheel tire width, m;

$q_{max}$ is maximum possible pressure of the tractor wheel on the soil, kPa;

$[U]$ is permissible value of the compacting effect of the tractor wheel on the soil, kN/m.

An empirical formula (3) was derived to calculate $q_{max}$ based on experimental studies, which adequately reflects the findings of other researchers [15-25]:

$$q_{max} = 3.46 \rho_w + 0.075552H - 0.23353(\rho_dD^3)/M - 7.4493\rho_w/D;$$

where $q_{max}$ is the ultimate pressure of the tractor wheel on the soil, N/m$^2$;

$\rho_w$ is pressure in tires, N/m$^2$;

$H$ is soil hardness, Pa;

$\rho_d$ is soil density, kg/m$^3$;

$D$ is the tire outer diameter, m;

$M$ is the tractor weight per wheel, kg;

$B$ is the tire width, m.

The calculations were made for a no till seeder coupled with a John Deere-9430 tractor, operating without and with a track scarifier.

3. Results

The economic efficiency from the use of tractor track scarifiers is evaluated by calculating total energy consumption. Let us compare the total energy consumption of the John Deere-9430 tractor performing direct seeding with and without track scarifier.

The calculations are based on the conditions listed below.

**Basic data for calculation:**

- The area of the field is =100 ha;
- Length of run is =1 km;
- Distance of moving of =3 km;
- Density of seeds is =800 kg/m$^3$;
- Coefficient of durability of bearing surface =0.9
- The volume of work is =500 ha;
- Number of business hours in a day =16 h;
The planned productivity of crops = 4000 kg/ha; 
Pressure in tires = 0.16 MPa; 
Number of tractors on operation =1 units; 
Number of wheels per axle (separately left and right) =1 (i.e. no double wheels); 
Wheel adhesion coefficient on sowing =0.5; 
Wheel rolling resistance coefficient of the tractor on sowing=0.17; 
Seeding unit specific resistance is =4.2 kN/m;

Figure 1 shows the dependence of the total energy consumption on the field area for John Deere-9430 tractors used for direct sowing with and without track scarifier. It is evident that track scarifier significantly reduces the total energy consumption, which is attributed to decreased crop energy lost due to negative wheel compaction and takes up about 80% in the structure of total costs (Table 1). A growing field area leads to a sharp decrease in the total energy consumption in fields up to 20 hectares. Therefore, it is not profitable to have fields less than 20 hectares.

Figure 1. Performance indicator (energy consumption) vs the field area during direct sowing with John Deere-9430 tractor with and without track scarifier

Figures 2 and 3 are 3D graphs that show how the performance indicator changes when the speed of the seeder and its working width change with and without track scarifier. Based on the figures, the total energy consumption required for sowing with the track scarifier is much lower, while the optimal working width of the $B_{\text{opt}}$ seeder decreases by 2 m. Thus, the use of the track scarifier with the John Deere-9430 tractor for sowing alone saves up to 11,335 MJ/ha of total energy costs. In terms of wheat grain, it will be 0.59 kg/ha, in terms of diesel fuel it will be 218 kg / ha. And, ultimately, in terms of rubles, at the cost of diesel fuel, the savings will amount to 7,411.4 rubles/ha.

Today, the Republic of Tatarstan is launching energy-saving technologies, including the no till technology. The technology is specific due to the cumulative overcompaction of the soil at a depth of 10-30 cm. In this regard, there is a need for mechanical decompaction of the soil with subsoilers to a depth of 30-35 cm at least once every 2-4 years, depending on crop rotations, planted crops, type of soil, etc. Let us calculate, using a mathematical model of tractor systems, the basic measurements of a
multi-purpose tractor (weight and engine power) which will be used for direct sowing (in spring) and for deep loosening of the soil (in autumn).

Table 1. Effect of using track scarifiers for sowing

| Index                                                                 | TIS without track scarifier | TIS with track scarifier | Difference |
|-----------------------------------------------------------------------|----------------------------|--------------------------|------------|
| 1. Productivity, ha/h                                                  | 7.95                       | 7.24                     | -0.71      |
| 2. Fuel consumption per hectare, kg/ha                                 | 4.44                       | 4.60                     | +0.16      |
| 3. Specific energy consumption for the repair of a tractor and agricultural machinery, MJ/ha | 460                        | 456                      | -4         |
| 4. Energy of the crop lost due to violated sowing deadlines, MJ/ha     | 1802                       | 2022                     | +220       |
| 5. Energy to turn the system from operating to transport state, MJ/ha  | 0.11                       | 0.09                     | -0.02      |
| 6. Energy of the crop lost due to wheel compaction, MJ/ha              | 11560                      | –                        | -11560     |
| 7. Fuel energy consumption, MJ/ha                                      | 221                        | 231                      | +10        |
| 8. Energy to control the system, MJ/ha                                 | 16                         | 15                       | -1.0       |
| 9. Overall energy consumption, taking into account the energy of the lost crop, MJ/ha | 14.059                     | 2724                     | -11335     |

Figure 2. Performance indicator (energy consumption) of sowing machine with John Deere-9430 tractor vs the width of system and its speed without track scarifier ($B_{opt}=16$ m; $V_{opt}=9$ km/h; $E_{min}=14.058$ MJ/ha)

The calculations to determine the optimal basic measurements of a multi-purpose tractor (weight and power), designed for both direct sowing and a highly energy-intensive operation – deep loosening
of the soil, showed that they largely depend on the specific resistance of the agricultural machine (Fig. 4).

Figure 4 shows that as the resistance to the agricultural machine increases, both in $K_{dx}$ sowing and in $K_{dl}$ plowing, the optimal tractor weight $M$ continuously increases as well. The average weight of a multi-purpose tractor should be in the range of $M = 150$ kN, engine power $N = 380$ kW. The width of the seeding machine is $B_{pds} = 16$ m, the subsoiler $B_{pdl} = 6$ m, respectively, the speed of the seeding machine is $V_{pds} = 12$ km/h, the subsoiler is $V_{pdl} = 11$ km/h. The sum of energy costs for the two operations will amount to 17,500 MJ/ha. It is advisable to use the Kirovets K-744R2 Standard K-744R4 Premium tractor.

Figure 3. Performance indicator (energy consumption) of sowing machine with John Deere-9430 tractor vs the width of system and its speed with track scarifier ($B_{opt} = 14$ m; $V_{opt} = 9$ km/h; $E_{min} = 2,722.9$ MJ/ha)

Figure 4. Graph for optimal measurements of system with multi-purpose tractor for direct sowing with Agromaster seeder and subsoiler
Let us calculate the same measurements for the case when a multi-purpose tractor will be used for sowing with a track scarifier to neutralize the negative impact of the tractor wheels on the soil. The calculation results are shown in Fig. 5.

Figure 5 shows that the sum of energy consumption over the entire traction resistance to the seeder and the subsoiler has decreased. The greater the specific traction resistance of agricultural machines – sowing implement and subsoiler, the lower the amount of energy consumption. With a specific resistance of 3 kN/m, the saving in the amount of energy consumption is 7,700 MJ/ha, and with a specific resistance of 5.4 kN/m, it is sometime around 18,500 MJ/ha.

**Figure 5.** Graph of changes in the optimal measurements of system with multi-purpose tractor for direct sowing with Agromaster seeder with track scarifier and for subsoiling

Figure 5 shows that the average weight of the tractor when used for sowing with a track scarifier increased to 170 kN, and the required power increased to 420 kW. Besides, the sum of energy costs for two operations amounted to 5,670 MJ/ha, which is 11,830 MJ/ha less than when using a sowing machine without a track scarifier.

Versatile 4WD 570-620 tractors with a base weight of 158 kN and the possibility of weight transfer up to 260 kN are preferred.

**4. Conclusion**

In early spring, when moisture content is high, the soil tends to be overcompacted by tractor wheels during technological operations. One of the most suitable means of loosening the soil is the tractor track scarifier. The use of the John Deere-9430 track scarifier for direct sowing leads to savings in total energy consumption, including the energy of the crop lost from soil compaction, in the amount of up to 11,000 MJ/ha.

Track scarifier used with multi-purpose tractor performing a series of technological operations – direct sowing (in spring) and subsoiling (in autumn), allows farmers to choose a heavier tractor with more powerful engine, which leads to a significant reduction in the amount of energy costs for two operations. Energy savings vary from 7,700 to 18,500 MJ/ha, depending on the type of soil, its density, hardness and resistance to agricultural machines. The most acceptable tractors can be tractors of the Versatile 4WD 570-620 series with a base weight of 158 kN and the ability to transfer weight up to 260 kN, manufactured in Rostselmash.
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