Minimum required power capacity of tractors depending on grain cultivation methods

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Abstract. The paper identifies aggregate power capacity produced by tractor engines on a farm engaged in spring grain cultivation alternating methods for primary and secondary tillage by years and crop rotations. The required power capacity is calculated based on an energy tractor-implement model in primary, secondary tillage and sowing operations. Power capacity is enhanced with due account of measurements and quantity of equipment to have an impact on spring grain harvest. The minimum power capacity is required for no till methods (0.93-1.42 kW/ha). The maximum power capacity is required for deep autumn plowing, spring harrowing and, after 5-8 days, simultaneous cultivation, sowing and rolling with single-operation implements (3.3 kW/ha). The optimal weight of a universal tractor for performing all technological operations is 13 tons, its engine power is 366 kW. The number of tractors required to cultivate 1000 hectares of arable land for spring crops is 9. With these measurements, the total energy consumption for the above methods, being alternated by years, will be minimal.

1. Introduction
At present, the structure of grain areas in the Republic of Tatarstan mostly includes spring wheat and barley. They account for approximately 450-500 thousand hectares each, which is 70-75% of the area under crops in the entire grain, cereal and leguminous group [1]. In the Russian Federation, this figure is 48-50% of the total sown area of crops, amounting to 79629.7 thousand hectares [2]. Let us determine power capacity to ensure cultivation of spring cereals through various techniques.

By the degree of intensity (crop productivity), agricultural techniques for spring grain cultivation are subdivided into extensive, conventional, intensive and high [3-9]. Due to the fact that these techniques rest on various types of primary and secondary tillage, let us define the agricultural options applied by this indicator.

The types of primary and secondary tillage for spring crops and the conditions for their effective use are shown partially in Table 1. Due to the fact that we need to determine power capacity produced by tractor engines for agricultural production, we need to identify techniques involving minimum and maximum numbers of tractors. The minimum number of tractors and capacity of tractor engines can be assumed for no till resource-saving option. The maximum number of tractors, presumably, is needed for conventional (basic, ordinary) techniques, including mechanical weed control, both before the primary tillage (stubble plowing) and after it, especially in the period of bedding and after sowing (moisture closure, cultivation, sowing, rolling, before and after germination harrowing).
In most of the above types of primary and secondary tillage (1, 2, 3, 4, 7) for spring crops, technological operations are performed sequentially with lag time.

A number of technological operations in the 5th and 6th techniques are performed overlapping in time, for example, cultivation, seed drilling with disk working components and seed rolling, which can increase the minimum required power capacity of agricultural production through these techniques.

The optimal tractor measurements for each technique will be calculated together with the minimum power capacity of tractors required to ensure the production process.

2. Materials and Methods
The rationale for optimal measurements of tractors, the number of tractors for performing a given amount of work during a separate technological operation or a complex of technological operations and, ultimately, the minimum required power capacity for the production of spring grain crops will be provided based on an energy tractor-implement mathematical model by carrying out computational experiments. The model was verified and adequately reflects the operation of real machines [10-15].

For a clear presentation of the developed method for calculating the required power capacity for an enterprise involved in the cultivation of spring grain crops, the paper presents an energy criterion for identifying the required power capacity, taking into account the influence of the measurements of tractors and implements on the produced grain crop. It looks like [9]:

\[ E = E_{m.tr} + E_{m.imp} + E_{rts} + E_{u.c.} + E_{drv} + E_{fo} + E_{ag} + E_{exp} - \min, \]

where:
- \( E \) – specific total energy consumption, MJ·ha\(^{-1}\);
- \( E_{m.tr}, E_{m.imp} \) – energy spent, respectively, for the manufacture of a tractor and agricultural implement, per 1 hectare, MJ·ha\(^{-1}\);
- \( E_{rts} \) – energy spent on all types of repair and technical service of a tractor and agricultural implement, MJ·ha\(^{-1}\);
- \( E_{u.c.} \) – energy spent on assembling and disassembling the seeding unit, MJ·ha\(^{-1}\);
- \( E_{drv} \) – energy spent by the machine operator on the control of the unit (turning, stopping and starting and shifting gears), MJ·ha\(^{-1}\);
- \( E_{fo} \) – energy spent for fuel, MJ·ha\(^{-1}\);
- \( E_{ag} \) – energy of the crop lost due to a violation of the technological terms of the technological operation, MJ·ha\(^{-1}\);
- \( E_{exp} \) – energy of the crop lost due to soil compaction by the tractor wheels, MJ·ha\(^{-1}\).

3. Results
For the first, second and third techniques (Table 1), the need for tractors is determined by the sowing technological operation, as the most energy-intensive having a limited timing. The specific resistance to a sowing machine ranges from 3 to 6 kN/m, subject to the type, texture, moisture content of the soil and design features of the sowing components. For conserving moisture, spike-tooth and spring-tine harrows are used that give much lower resistance compared to sowing machines and ranges from 0.8 to 3.0 kN/m. After harrowing, before sowing, there is lag time provided to provoke weed growth for 6-10 days, which means that these two technological operations are carried out sequentially without overlapping in time. In this regard, the required number of tractors and their annual workload consider direct spring grain planting as the most energy-intensive technological operation.

The calculation results are shown in Table 2. It can be seen that the optimal power input to provide the first three techniques in Table 1 is from 1.3 to 2.5 HP per 1 hectare. A higher figure corresponds to heavier soils having higher resistance to plowing.

The primary tillage applied for the fourth technique is a technological operation that determines the production power capacity (Table 1) – sub soiling to a depth of 20 cm by cultivators such as KTP, KPE, KSP, APK giving a resistance of 6-10 kN/m, as the most energy-intensive in a series of successive operations. The required power capacity for this technological operation, as can be seen from Table 2 ranges from 1.9 to 2.2 HP per 1 hectare of arable land, which covers the need for energy during spring tillage activities associated with conserving moisture and sowing with sowing machines.
The optimal weight of the tractor for this technological operation is within the range of the optimal weight of the tractor used for direct sowing – 12-14 tons.

The primary tillage applied for the fifth technique of spring grain cultivation is the most energy-intensive operation – plowing to a depth of 20 cm. The required power capacity for this technological operation ranges from 2 to 2.8 HP per 1 hectare, which is the maximum among the previously mentioned technological operations.

The optimal weight of the tractor increases to 14-16 tons. However, it is necessary to find out whether such power capacity covers the need for energy during spring tillage activities because such operations as secondary tillage, layout of seedbed/sowing and rolling of crops must be carried out in parallel, without lag time.

The demand of tractor energy is greater for the sixth technique (Table 1), as it involves moldboard ploughing to a depth of 30 cm. The required minimum energy is in the range from 2.79 to 2.98 HP per hectare of arable land.

Let us estimate the required power capacity for the fifth and sixth techniques during the spring tillage operations. To do this, let us calculate the required power capacity for three operations (secondary tillage, sowing and rolling of crops) performed separately, then in parallel. The calculation results are shown in Table 3.

**Table 1.** Types of primary and secondary tillage for spring crops and conditions for their effective use

| Primary tillage | Secondary tillage, sowing | Conditions for effective use |
|-----------------|---------------------------|------------------------------|
|                 |                           | Primary tillage for forecrops | Soil profile | Weeds | Planned pesticides |
| 1. No till       | Moisture conservation with BMR-15 (K=0.8-3 kN/m), sowing with cultivator or anchor tines (K = 3-6 kN/m) | Plowing | Sandy/sandy loam | Low |
| 2. Surface (8-10 cm) K=3-4 kN/m | Moisture conservation with BMR-15 (K=0.8-3 kN/m), sowing with cultivator or anchor tines (K=3-6 kN/m) | Medium |
| 3. Shallow disc harrowing (up to 15 cm) K=4-6 kN/m | Moisture conservation (BMR-15, spring harrows), sowing with a cultivator or anchor tine |                          | |
| 4. Subsoil tillage (up to 20 cm) K=6-10 kN/m | Moisture conservation (BMR-15, spring harrows), sowing with a cultivator or anchor tine |                          | |
| 5. Moldboard plowing (up to 20 cm) K=40-50 kN/m² | Moisture conservation (BZTS, BMR-15, spring harrows), seeding depth tillage (K=2.4-3.2 kN/m), sowing with any seeder, possible rolling of crops after SZ-3.6 seeders (0.8-1.6 kN/m) | No till, shallow or shallow no till | Sandy loam | High | Not recommended |
| 6. Deep moldboard plowing (up to 30 cm) K = 50-70 kN/m² | Moisture conservation (BZTS, BMR-15, spring harrows), seeding depth tillage, sowing with any seeder, rolling of crops after SZ-3.6 seeders |                                | |
| 7. Deep disc harrowing (30-45 cm) K=12-16 kN/m | Moisture conservation (BMR-15, spring harrows), sowing with cultivator or anchor tines and rolling crops | Medium |
Table 2. Optimal measurements of tractor and implement involved in technological operations per 1000 hectares of area and the required power input for production

| Technological operation / Brand of agricultural machine | Specific resistance, kN/m | Tractor weight, t | Engine power, kW | Machine working width, m | Machine working speed, km/h | Total energy input, MJ/ha | Required number of tractors, psc | Power availability, kWh/ha (hp/ha) |
|--------------------------------------------------------|----------------------------|------------------|-----------------|--------------------------|---------------------------|--------------------------|-------------------------------|---------------------------------|
| Sowing / Agromaster (cultivator coulter)               | 3.2-5.2                    | 8-12             | 255-385         | 14-13                    | 10                        | 2742.1-4075.7             | 5                             | 0.93-1.42 (1.27-1.93)             |
| Sowing / Agrator anker (anchor coulter)                | 3.2-5.2                    | 9-14             | 260-494         | 16-15                    | 9-11                      | 4792.1-6804.0             | 5                             | 0.96-1.82 (1.30-2.47)             |
| Primary disc harrowing                                | 6-10                       | 12-14            | 486-539         | 9-6                      | 13-13                     | 1403.8-2324.9             | 4                             | 1.43-1.62 (1.9-2.2)              |
| Primary moldboard plowing                             | 8-12                       | 10-14            | 398-557         | 5.25-4.9                 | 12-12                     | 2451.3-2965.8             | 5                             | 1.46-2.05 (2.0-2.8)              |
| Primary moldboard plowing                             | 15-20                      | 14-16            | 557-595         | 4.9-3.5                  | 12-12                     | 2965.8-3977.8             | 5                             | 2.05-2.19 (2.79-2.98)            |
| Deep disc harrowing                                   | 14-19                      | 20               | 554-546         | 5.5-4.0                  | 11-11                     | 3216.2-4070.1             | 3                             | 1.22-1.20 (1.66-1.64)            |

Table 3. Required power input for spring tillage operations based on the 5th and 6th options per 1000 hectares of area

| Technological operation / Brand of agricultural machine | Specific resistance, kN/m | Tractor weight, t | Engine power, kW | Machine working width, m | Machine working speed, km/h | Total energy input, MJ/ha | Required number of tractors, psc | Power availability, kWh/ha (hp/ha) |
|--------------------------------------------------------|----------------------------|------------------|-----------------|--------------------------|---------------------------|--------------------------|-------------------------------|---------------------------------|
| Secondary tillage / KPS, KBM, TurboCombinator L        | 2.4-3.2                    | 4-4              | 88-98           | 7-5                      | 10-11                     | 1796.1-2385.8             | 8-10                          | 0.71-0.98 (0.96-1.33)             |
| Layout of Seedbed and Sowing / SZ-3.6                  | 0.8-1.8                    | 4-4              | 50-100          | 18-7.2                   | 7-15                      | 1232.0-1737.3             | 4-7                           | 0.2-0.7 (0.27-0.85)              |
| Rolling / KKSh-15-23                                   | 0.7-1.1                    | 4-4              | 58-82           | 23-13                    | 7-10                      | 1062.1-1151.4             | 4-6                           | 0.23-0.49 (0.32-0.67)             |

Required power input for three operations performed simultaneously

| Plowing+sowing / PLN+SZ-3.6                           | 12-21/0.8-1.8              | 5-9              | 126-267          | 1.75-2.1/18-18           | 10-11/15-15               | 7916.5-10366.8             | 6-6                           | 0.75-1.6 (1.03-2.18)              |
| Plowing+tillage / PLN+CBM                             | 12-21/2.4-3.2              | 10-11            | 288-320         | 3.85-2.45/18-16         | 12-12/9-9                | 7858-10604                 | 6-6                           | 1.73-1.92 (2.35-2.61)            |
| Plowing+rolling / PLN+KKSh                             | 12-21/0.7-1.1              | 7-8              | 210-229         | 2.8-1.75/23-23           | 12-12/10-10              | 5780-7841                  | 6-6                           | 1.26-1.37 (1.71-1.87)            |
| Plowing+tillage+sowing+rolling                        | 21/3                       | 13               | 366             | 2.8/18                  | 12/9                     | 13339                      | 9                             | 3.3 (4.48)                      |

Power capacity required by a farm 3.3 (4.48)
As can be seen, the required total energy for three operations performed simultaneously is less than for deep plowing up to 30 cm and is in the range – 1.14-2.17 kW/ha. However, Tables 2 and 3 indicate that the optimal weight and power of a plow tractor and tractors for spring tillage operations are very different. Therefore, we will calculate compromise tractor measurements acceptable both for plowing and for spring tillage operations, in which the sum of the combined energy costs for several technological operations will be minimal.

A universal tractor for plowing and sowing should have a weight from 5 to 9 tons, depending on the resistance to agricultural implements, for plowing and secondary tillage from 10 to 11 tons, and for plowing and rolling from 7 to 8 tons. Given that all three spring technological operations are performed simultaneously, the tractor should weigh 13 tons, engine power should be 366 kW, the required number of such tractors for performing all technological operations with minimum total energy costs is 9. The demand of tractor energy for the farm to perform the sixth technique is the most advanced and amounts to 3.3 kW/ha (4.48 HP/ha).

The seventh technique involving deep autumn loosening of the soil (Table 1) requires the maximum power capacity to ensure direct sowing in spring with sowing machines and the demand of energy is 1.82 kW/ha (2.47 HP/ha).

The current practice of organizing crop rotations rests on all 7 techniques being alternated over years. Therefore, the required power capacity of tractor engines is determined by the technique where the need for tractors is maximum – this is the sixth option with deep autumn plowing at 0.3 m, spring harrowing and after 6-10 days – simultaneous cultivation, sowing and rolling of crops. Thus, the demand of tractor energy when cultivating grain crops through the techniques listed in Table 1 is 3.3 kW/ha (4.48 HP/ha). The number of required tractors with a mass of 13 tons and an engine power of 366 kW per 1000 hectares of arable land is 9.

Nine tractors with the specified measurements allow all types of techniques for spring grain cultivation with minimal crop losses.

4. Conclusion
Various technological operations of primary and secondary tillage are used in the cultivation of spring grain crops, which alternate depending on the forecrop and the type of soil cultivation for the forecrop.

The minimum power capacity of tractors is required for direct no till sowing with cultivator or anchor coulters. It is equal to 1.82 kW/ha (2.47 HP/ha).

The maximum power capacity of tractors is required for deep autumn plowing to a depth of 0.3 m and a list of spring operations performed simultaneously (secondary tillage, sowing with disc coulters and rolling). The required energy is 3.3 kW/ha (4.48 HP/ha). The number of tractors with a mass of 13 tons and an engine power of 366 kW per 1000 hectares of arable land is 9.

Agricultural machines that combine secondary tillage, sowing and rolling of crops will significantly reduce the demand of energy consumed by the farm.

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