Determination of indicators affecting the cross-country capacity of machine-tractor units

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Abstract. This study provides an assessment of the traction-coupling qualities of the machine-tractor unit consisting of the Belarus 1221 tractor and the Unia MX1600 mineral fertilizer dispenser. The quantitative evaluation is carried out through the cross-country coefficient. The characteristic of cross-country capacity with different soil conditions on the horizontal section is shown, and it is established that during operation on feeding along seedlings the machine has a sufficient cross-country capacity. At operation on rough relief the passability at speeds up to 8 m/s decreases by 25%. The cross-country ratio depends on the internal tyre pressure. With a drop in pressure from 1.8 to 0.8 kg/cm², there is an increase in cross-country capacity on any kind of soil. In general, it has been found that the machine-tractor unit has a sufficient reserve of cross-country capacity.

1. Introduction

In modern agricultural production, fertilization is seen as a process of enriching soil and plants with nutrients. For this purpose there is a complex array of machines all with different methods of connection, load capacity and working tools. The most common are the hinged dispensers of hard mineral fertilizers.

Among the advantages of such machines are compactness and excellent economic efficiency. But on wet, loose and snowy soils, traction-coupling qualities (cross-country capacity) of machine-tractor units decreases [1, 2]. Improvement of traction-coupling qualities is possible with an increase in tractor-coupling weight and an increase in the traction of propulsors on the soil (four-wheel drive, low-pressure tires, twin wheels, etc.) [3, 4]. In the case of surface application machines, passability is generally limited to tractive properties and gauge formation [5].

2. Materials and methods

To quantify the passability of tractors, one must determine the passability factor [6]

\[ \eta = \frac{P_k - P_f - P_{sp}}{P_k}, \]

where \( P_k \) - tractor tangential traction force; \( P_f \) - tractor self-transfer resistance force; and
The nominal pull force on the hook (tractor traction class) is:

\[ P_{sp}^{H} \]

Experimental studies and the practice of operating machines for applying mineral fertilizers have shown that the improvement of traction-coupling qualities is more evident with an increase in the adhesion of propellers to the soil compared to an increase in coupling weight. At the same time, the cross-country capacity of machines which do not have technological working tools interacting with soil – for example, on wetted meadow-black-earth soils – is limited by the formation of gauge and bearing capacity of a “propulsor-soil” system. A feature of machines on double low-pressure tyres is that the maximum traction force is realized at an unusually high towing value (up to 80%).

Thus, as a coupling indicator of cross-country capacity of machines for surface application of mineral fertilizers, it is advisable to adopt a cross-country reserve factor determined by the formula

\[ \eta = 1 - \frac{P_{v}}{P_{kw}} \]

where \( P_{kw} \) - maximum tangential force of engines, realized during engine operation according to external characteristics (taking into account power take-off to the actuator of operating elements);
\( P_{v} \) - total force of resistance to movement of the machine.

When moving along the horizontal area of arable land:

\[ \eta = 1 - \frac{P_{f}}{P_{kw}} \]

The proposed cross-country capacity criterion shows that one of the best ways to increase cross-country capacity of various machine-tractor units on deformable soils is to reduce the value of resistance to movement.

Resistance to movement of machine-tractor units at various soil states depends on speed, load (total mass and axis distribution) and tyre pressure. Experimental studies were carried out on a machine-tractor unit for application of mineral fertilizers from the Belarus 1221+Unia MX1600 (www.belustractor.com, www.uniamachines.com) in the production conditions of the Amur region [7, 8]. As the analysis of experimental data showed, considering the positions and dependencies established in the theories of automobiles and tractors to describe the functional dependence of the power of the resistance of movement in the expression [9]:

\[ N_{f} = f mgv \]

where \( f \) - coefficient of resistance to the movement;
\( m \) - mass of the unit;
\( v \) - speed of the movement; and
\( g \) - acceleration of gravity.

Coefficient of resistance to swing:

\[ f = f_{0}(\rho_{w}) + k_{1}v + k_{2}m, \]

where \( f_{0}(\rho_{w}) = k_{0} + k_{3}\rho_{w}, \)

where \( \rho_{w} \) - pressure in tires.

**3. Results of probes**

Considering the accepted assumptions, the motion resistance power determined by the results of the multifactor experiment is described by the expression:

\[ N_{f} = 10^{3} \cdot gmv \cdot (P_{1} + P_{2} \cdot v + P_{3} \cdot m + P_{4}\rho_{w}), \]

where

\[ P_{sp}^{H} \] - nominal pull force on the hook (tractor traction class).
where $P_1$-$P_4$ is determined by using the least squares application algorithm to calculate nonlinear regression equations, given in Table 1. Quantitative assessment of adequacy of equations and regression is also given. Estimates meet 95% confidence interval requirements.

**Table 1.** Values of coefficients of regression equation and estimation of adequacy of regression equations.

| Condition of the soil | Regression coefficients | Assessing the adequacy of regression equations |
|-----------------------|-------------------------|-----------------------------------------------|
|                       | $P_1$                   | $P_2$                          | $P_3$                              | $P_4$                          | Residual variance | Fischer’s criterion | Coefficient of a multiple correlation |
| After tillage (before sowing) | 0.128                   | $0.613\times10^{-2}$          | $0.222\times10^{-5}$             | $-0.486\times10^{-4}$          | 51.29             | 7.9                 | 0.93                                   |
| Fertilizing on shoots | 0.0415                  | $0.149\times10^{-2}$          | $0.39\times10^{-5}$              | $0.173\times10^{-3}$           | 12.56             | 17.05               | 0.97                                   |
| Before early spring soil treatment | 0.0409                 | $0.227\times10^{-2}$          | $0.227\times10^{-5}$             | $-0.348\times10^{-5}$          | 21.25             | 25.2                | 0.98                                   |

Figure 1 shows the graphical relationships of the cross-country reserve factors of Belarus 1221+Unia MX1600 on different soil states.

![Graph showing cross-country reserve factors](image)

**Figure 1.** Cross-country characteristics of the machine for application of mineral fertilizers from the Belarus 1221 Unia MX1600 on the horizontal section. Weight of machine-tractor unit with full hopper: 6500 kg. Pressure in tyres of driving wheels: 1.8 kg/cm$^2$. 1 - feeding by sprouts 2 - before early spring soil treatment 3 - after soil treatment (before sowing).

The higher the cross-country capacity index, the more cross-country capacity the machine has under these conditions. As can be seen from Figure 1, the Belarus 1221+Unia MX1600 machine-tractor unit has a sufficient margin of cross-country capacity at maximum speeds when operating on horizontal sections and feeding on sprouts. With regard to the application of fertilizers before the early
spring treatment and after the soil treatment (before sowing), the maximum speed at which the machine can move does not exceed 4.5 to 5.3 m/s (16.2 to 19.1 km/h).

If the field’s terrain is crossed rather than even, then the passability index is determined by the formula:

\[ \eta = 1 - \frac{P_i + P_l}{P_{km}} \]  \hspace{1cm} (8)

where \( P_i \) - component of force of resistance to movement to overcome lifting.

Figure 2 shows graphs of the cross-country capacity dependence factor for the Belarus 1221+Unia MX1600 with a full hopper when moving the machine to the lift.

![Graph showing cross-country capacity dependence factor](image)

**Figure 2.** The cross-country ratio depends on the slope\(^{a,b}\). Speed in m/s.

\(^a\) - After tillage (before sowing)  \hspace{1cm} \(^b\) - Before early spring tillage

Considering the actual distribution of agricultural land slopes, the machine-tractor unit provides cross-country capacity on the field before early spring soil treatment on 100% of the area while moving at a speed of not less than 4 m/s. Cross-country capacity after soil treatment (before sowing) is done at a speed of up to 8 m/s under various conditions on 100% of the area and up to 25% on the area with a slope.

As shown in formula (1), the resistance force of the machine-tractor unit is more dependent on the tyre pressure. At the same time, as the air pressure in the tyres decreases due to the reduction of the dynamic radius of the wheel, the traction force of the driving wheels increases (at constant power of the transmission). The impact of tyre pressure on the cross-country margin factor is shown in figure 3.

When comparing the dependencies of the three backgrounds, the tendency is clearly visible: the increase in the tyres’ air pressure on the deformed base significantly reduces the cross-country capacity. The quantitative estimation of the intratyre pressure’s degree of influence \( P_w \) is expressed by the value of the coefficient of the regression equation \( P_\alpha \).

**4. Conclusions**

Mounted machines for application of mineral fertilizers have a sufficient reserve of cross-country capacity on the main agricultural backgrounds. Estimated indicators of resistance to movement and
cross-country capacity of the MTA Belarus 1221+Unia MX1600 have been determined, as have the character of influence of speed and pressure of air in the tyres.

![Figure 3](image)

**Figure 3.** Dependence of the cross-country capacity factor of the fertilizer application machine on the tyre pressure on the horizontal section. The weight of the machine is 6500 kg. Speed is -4 m/s. 1 - feeding by sprouts 2 - before early spring soil treatment 3 - after soil treatment (before sowing).

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