Generalized indicator of adaptation of mobile units to zonal conditions

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Abstract. The article discusses the rationale for a generalized indicator of the net productivity of high-speed units in zonal natural and production conditions. Models and an optimization algorithm were compiled for a generalized indicator of the net performance of mobile units for various technological purposes. The optimal value of net productivity was found from the condition of its minimum per unit product of the square of the corresponding operational productivity and coefficient of utilization of the shift time equivalent to the lowest specific energy consumption. According to the results of modeling the influence of natural and production conditions on the optimal adaptation indicator of aggregates, the following was identified: an increase in the length of the head from 200 to 1000 m is accompanied by an increase in the optimal net productivity by 2.0-2.4 times and the corresponding operational productivity by 2.4-2.8 times; a decrease in the energy intensity of the technological operation, determined by the characteristic of the resistivity of the working machine, leads to an increase in the net productivity shown with a simultaneous decrease in the utilization factor of the shift time, regardless of the rut, which determines the nature of the change in operational productivity and the width of the machine at nominal speed. They substantiated the optimal values of the generalized adaptation indicator of mobile units for a set of natural and production conditions, which are the basis of the system for the formation of requirements standards and a qualitative update of the machine and tractor fleet of the agricultural zone, taking into account the achieved level of operational technologies development and the target program for technical support of crop production.

1. Introduction
The Krasnoyarsk Territory is located in the East Siberian agricultural zone 6.2 of the Siberian Federal District (SFD) by geographical location. More than half of the arable land consists of areas of at least 70 ha with a rut length of over 1000 m with a specific resistance of sod-podzolic soils of 65 kN/m². The region includes, differing in the main characteristics of natural conditions - the average rut length \( l_r \) - agrolandscape or natural zones: forest-steppe (\( l_r > 1000-53.4\% \)) and (600-1000 m - 25.4%); subtaiga (400-600 m - 13.2%); taiga (300-400 m - 6.1%) and (200-300 m - 1.9%) with different performance conditions, regardless of ownership, rural producers and achieved grain yield [1]. This makes it necessary at the initial (first) level of a system for the formation of differentiation of crop production requirements in tractors, taking into account the characteristic feature of natural zones – the headland class, which can be adapted to the conditions of specific producers.
The net productivity of the aggregate $W^*$, which is optimal by the criterion of minimum unit costs, is used as the main generalized parameter-adapter to natural and production conditions, which determines the corresponding operational productivity $P^*$ [2]. The values of $W^*$ depend mainly on the type of technological operation and the rut length and practically do not depend on the soil and climatic zones of operation in the intervals of change in the working speed accepted for agrotechnical requirements. The indicated generalized parameter $W^*$ characterizes the aggregate as a whole and serves as the basis for determining its indicators with justification at subsequent levels of the working machine working width $B_p^*$ and mass-energy parameters of the energy machine $m_{o}^{*}$, $N_{o}^{*}$ in the optimal speed range $(V_N \pm \Delta V)^*$. However, the results of studies [3-4] showed the need to correct the dependences $W^*$=$f(l_r)$ [2] for high-speed and units of various technological purposes based on energy-saturated 4x4 wheeled tractors.

2. Statement of the problem
This study was carried out in order to substantiate a generalized indicator of the net productivity of high-speed tillage units in zonal natural and production conditions.

Achieving this goal provided for the solution of the following tasks:
1) to form models and an optimization algorithm for a generalized indicator of the net performance of mobile units;
2) to determine the optimal values of the net capacity of the units for the zonal conditions of production operation.

3. Research methods
The technical shift output of the aggregate $P_{sh}$ (ha), for known values of the working width $B_p$ and the working speed $V$, is defined as [5]

$$P_{sh} = 0.36 \cdot B_p \cdot V \cdot T_p.$$  \(1\)

By $T_p$ is meant the actual running time during which the unit performs useful yield, with the standard duration of the shift $T_{sh}$. Denoting the coefficient of use of the change time $T_p/T_{sh}$=$\tau$ from equation (1) obtain the technical or operational hourly capacity of the unit (ha/h)

$$P = P_{sh}/T_{sh} = 0.36 \cdot B_p \cdot V \cdot \tau$$ \(2\)

The value of the aggregate performance $P$, when performing a specific operation, corresponds to a product of interrelated indicators

$$\begin{align*}
P &= 0.36 \cdot W \cdot \tau; \\
\tau &= (h_p - a_p \cdot W)/(1 + K_p \cdot W), \tag{3}
\end{align*}$$

where $h_p$, $a_p$, $K_p$ - coefficients taking into account the headland class and type of operation (type of unit).

The nature of dependences (3), with constant coefficients $h_p$, $a_p$ and $K_p$ [5] for specific natural-production conditions, shows that an increase in the net performance of $W$ increases $P$ but decreases $\tau$. Taking into account the opposing effects of $W$ on $P$ and $\tau$ the criterion was used to determine the optimal value of $W^*$: the minimum $W^*$, per unit product of the square of productivity $P$ and the coefficient $\tau$, equivalent to the specific energy consumption $K_{sp}(s/m^2)$

$$K_{sp} = \frac{W^*}{P^2 \cdot \tau} = \frac{1}{W^* \cdot \tau^3} = \min.$$ \(4\)

The optimization algorithm of the generalized adapter parameter in a cycle with a step of $W = 1 m^3/s$ includes the determination: $W$, $h_p$, $a_n$, $K_p$, $\tau(3)$, $P(3)$, $K_{sp}(4)$, $B_p(2)$. 

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4. Research results

Table 1 presents the functions $\tau(W)$, $P(W)$, $K_{sp}(W)$, $B_p(W)$ for dump plowing at $l_r=600-1000$ m and $>1000$ m, calculated according to the developed algorithm. Taking into account the results of timekeeping [6] and recommendations [5], the calculations used the equations $\tau(W)$ in the form:
\[
\begin{align*}
\tau_{600-1000} &= (0.990 - 0.0062 \cdot W)/(1 + 0.027 \cdot W); \\
\tau_{>1000} &= (0.995 - 0.0070 \cdot W)/(1 + 0.016 \cdot W).
\end{align*}
\]

| $l_r$=600-1000 m | $l_r$ >1000 m |
|------------------|-----------------|
| $W$, m$^3$/s  | $\tau$  | $P$, m$^3$/s | $K_{sp}$, s/m$^2$ | $B_p$, m | $W$, m$^3$/s | $\tau$  | $P$, m$^3$/s | $K_{sp}$, s/m$^2$ | $B_p$, m |
| 9               | 0.752 | 6.768 | 0.261 | 3.60 | 11 | 0.781 | 8.591 | 0.191 | 4.40 |
| 10              | 0.731 | 7.310 | 0.256 | 4.00 | 12 | 0.764 | 9.168 | 0.187 | 4.80 |
| 11              | 0.711 | 7.821 | 0.2529 | 4.40 | 13 | 0.748 | 9.724 | 0.184 | 5.20 |
| 11.92*          | 0.693 | 8.261 | 0.2521 | 4.77 | 14 | 0.733 | 10.262 | 0.181 | 5.60 |
| 12              | 0.691 | 8.292 | 0.2525 | 4.80 | 14.90* | 0.719 | 10.713 | 0.1806 | 5.96 |
| 13              | 0.672 | 8.735 | 0.2535 | 5.20 | 15 | 0.717 | 10.755 | 0.1808 | 6.00 |
| 14              | 0.655 | 9.170 | 0.2540 | 5.60 | 16 | 0.702 | 11.233 | 0.1809 | 6.40 |
| 15              | 0.638 | 9.570 | 0.2577 | 6.00 | 17 | 0.687 | 11.676 | 0.1814 | 6.80 |
| 16              | 0.622 | 9.953 | 0.2600 | 6.40 | 18 | 0.673 | 12.114 | 0.1823 | 7.20 |

An increase in $W$ in the realizable range leads to a decrease in $\tau$, which determines the nature of the increase in the operational productivity of the unit $P$. With an increase in $W$ the increase in productivity $P$, corresponding to the same increase in $W$, significantly decreases due to a decrease in $\tau$. The optimality criterion also decreases, reaching the minimum value $K_{sp\text{ min}}$ at the optimal productivity $W^*$. A further increase in $W$ is impractical due to an increase in $K_{sp}$. Therefore, the value of $W^*$ determines the upper limit of the net productivity $W^* \leq W_{max}$ for specific environmental conditions and the achieved level of technical support for tillage technologies.

The definition of $W^*$ is made by minimizing the function $K_{sp}(W)$ according to the developed algorithm by the dichotomy method. For an example of real operating conditions of high-speed arable units with a nominal speed $V^*_h$=2.50 m/s at $l_r=600-1000$ m optimal productivity $W^* = 11.92$ m$^3$/s, according to the optimization criterion $K_{sp\text{ min}}=0.2521$ correspond to $\tau^*=0.693$, $P^*=2.97$ ha/h and $B_p=4.77$ m. Increasing the length of the headland to $l_r>1000$ m provides an increase in optimal productivity by 25% to $W^*=14.90$ m$^3$/s by $K_{sp\text{ min}}=0.1806$ and $\tau^*$ by 3.75% to 0.719. Increase in $P^*$ is determined from the condition $\lambda P^* = \lambda W^* \cdot \lambda \tau^*$ and is 30% by $\lambda B_p^* = \lambda W^*$.

The above regularities are also valid for other tillage and sowing operations. To assess the effect of the headland on the optimal performance of other types of aggregates, and taking into account the correction according to the results of timing of the speed mode and components of the shift time, the values of the coefficients $h_i^T$, $a_i^T$ and $K_i^T$ are used determined according to the normative data for the most used operating technologies [5] and typical conditions.

The simulation results (table 2) of the headland and type of operation effect on the optimal adaptation indicator of aggregates made it possible to establish the general laws of its change:
- an increase in the length of the headland is accompanied by an increase in the generalized optimization indicator $W^*$ and, accordingly, the coefficient of use of the shift time $\tau^*$, which determine
the value of the operational productivity $P^*$ and the working width $B_p^*$ at the set nominal speed of the unit $V_N$:
- reducing the energy intensity of the operation, determined by the characteristic of the resistivity $K_d(V)$ of the unit, leads to an increase in the optimal productivity $W^*$ with a simultaneous decrease in $r^*$, regardless of the headland, which determines the nature of the change in $P^*$ and $B_p^*$;
- the optimum implement width $B_p^* = W^*/V_N$ at $W^*$ is determined for the nominal operating speed established by the conditions of agricultural requirements and resource saving.

The obtained numerical values of the optimal net productivity of $W^*$ aggregates for different natural and production conditions should be taken as the basis for the general system for the formation of the machine and tractor fleet of individual producers, natural zones, the region and the agricultural zone.

| Table 2. The effect of headland and type of operation on the optimal performance of mobile units. |
|---------------------------------------------------------------|
| Operation (group of operations) | Indicator | 200-300 | 300-400 | 400-600 | 600-1000 | >1000 |
|---------------------------------|----------|--------|--------|--------|---------|-------|
| 1. Moldboard tillage with high-speed plows ($V_N=2.50 \text{ m/s}$) | $W, \text{ m}^2/\text{s}$ | 6.28   | 8.16   | 9.41   | 11.92   | 14.90 |
|                                  | $\tau, \text{ h/ha}$ | 0.606  | 0.665  | 0.690  | 0.693   | 0.719 |
|                                  | $B_p, \text{ m}$      | 2.51   | 3.26   | 3.76   | 4.77    | 5.96  |
| 2. Non-moldboard mixed cultivation ($V_N=2.80 \text{ m/s}$) | $W, \text{ m}^2/\text{s}$ | 10.41  | 12.92  | 15.82  | 20.83   | 22.91 |
|                                  | $P, \text{ h/ha}$     | 0.563  | 0.610  | 0.630  | 0.650   | 0.715 |
|                                  | $B_p, \text{ m}$      | 2.03   | 2.70   | 3.39   | 4.60    | 5.89  |
|                                  | $W, \text{ m}^2/\text{s}$ | 15.83  | 19.11  | 22.97  | 25.81   | 32.92 |
| 3. Surface mixed cultivation ($V_N=3.33 \text{ m/s}$) | $P, \text{ h/ha}$     | 0.540  | 0.595  | 0.620  | 0.642   | 0.695 |
|                                  | $B_p, \text{ m}$      | 3.08   | 4.09   | 5.13   | 5.97    | 8.23  |
|                                  | $W, \text{ m}^2/\text{s}$ | 4.75   | 5.74   | 6.90   | 7.75    | 9.89  |
| 4. Pressowing and sowing ($V_N=2.80 \text{ m/s}$) | $\tau$ | 0.464  | 0.503  | 0.521  | 0.532   | 0.554 |
|                                  | $P, \text{ h/ha}$     | 2.38   | 3.10   | 3.69   | 4.63    | 5.75  |
| 5. Early-spring harrowing (moisture closure) ($V_N=3.33 \text{ m/s}$) | $B_p, \text{ m}$ | 5.09   | 6.11   | 7.03   | 8.64    | 10.30 |
|                                  | $W, \text{ m}^2/\text{s}$ | 38.71  | 42.97  | 46.00  | 58.66   | 71.30 |
|                                  | $\tau$ | 0.444  | 0.512  | 0.610  | 0.628   | 0.664 |
|                                  | $P, \text{ h/ha}$     | 6.19   | 7.92   | 9.95   | 13.26   | 17.04 |

5. Conclusions

Models and an optimization algorithm have been formed according to the criterion of the minimum energy consumption of net performance, as a generalized adapter parameter of mobile units to natural and production operating conditions;

The optimal values of net productivity and the corresponding performance indicators of aggregates for a set of natural and production conditions are established, which are the basis for the formation of requirements standards and a qualitative update of the machine and tractor fleet of the agricultural zone, taking into account the improvement of operational technologies and technical support for crop production.

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