OPTIMISATION OF AGRICULTURAL PROCESSES: MULTI-CRITERIA DECISION-MAKING IN SELECTION OF MACHINE–TRACTOR AGGREGATES FOR PLOWING

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Abstract. *Efficient configuration of machine-tractor aggregates (MTAs) for plowing is critical for reducing operational costs, conserving soil moisture, and meeting agronomic standards under seasonal time constraints. In this study, we developed a multi-criterion decision-making (MCDM) model integrating integer programming and simplex methods to select optimal tractor–plow combinations. The model accounts for field geometry, soil properties, operational speeds, and power compatibility, aiming to minimize costs while ensuring technical feasibility. The approach was tested using the "Kahramon-Lochin" farm in Uzbekistan as a practical example, where 80 tractor–plow configurations across four fields were evaluated. Results indicate that a 180 hp tractor with a 4-body plow (0.44 m working width) operating at 12 km/h provides the most cost-effective and high-performance solution for cotton field plowing, reducing service costs and achieving field performance above 95%.*

Keywords: *management science, operational research, optimization, linear programming, selection of machine-tractor aggregates, agriculture process mechanisation.*

Introduction. Soil tillage is the most resource-intensive stage in cotton cultivation, accounting for 57.6% of pre-sowing costs, with plowing alone contributing 46.7%. The configuration of MTAs—comprising a tractor and its matched plow—plays a decisive role in operational efficiency, cost control, and soil moisture preservation, especially during narrow seasonal plowing windows.

In Uzbekistan, plowing is typically conducted in late autumn or early summer. Each period presents specific challenges: autumn rains and early snowfall can delay or degrade tillage quality, while summer heat accelerates soil moisture loss, leading to clod formation and reduced compliance with agronomic standards. These constraints demand timely, well-coordinated operations using MTAs that are optimally matched to field conditions.

The choice of MTA is influenced by multiple factors: soil structure, moisture content, topography, field geometry, cropping system, and the type of agricultural enterprise—ranging from large agro-clusters to smallholder farms. Additionally, climate variability and the need for sustainable resource use underscore the importance of technical and economic optimization.

This research applies a structured MCDM approach to identify tractor–plow configurations that balance technical compatibility, field-specific requirements, and cost efficiency. By integrating kinematic, dynamic, and economic parameters into a unified decision-making model, the study provides practical recommendations for enhancing plowing performance and supporting sustainable agricultural practices.

Literature Review. Research on optimizing machine-tractor aggregates (MTAs) can be broadly classified into five main areas:

Tractor selection – Studies focus on identifying the most suitable tractor for specific agricultural operations. For example, Ayşegül Tüş İşık and Adalı (2016) applied multi-criteria decision-making using six parameters—purchase cost, nominal power, cylinder count, tire replacement ease, maneuvering safety, and after-sales service—to enhance tractor selection accuracy.

Tractor–implement pairing – Çanakçı et al. (2011) investigated optimal matching of tractor power with agricultural implements to reduce operational costs, applying computational programming to identify efficient combinations based on crop type, soil conditions, and climate.

Route optimization – Jense (2012) developed models for minimizing travel time from machine depots to fields, between fields, and within fields, improving MTA operational efficiency.

Fleet composition – Henning et al. (2004) and Artemev (2012) created decision-support tools for forming cost-efficient tractor–machinery fleets. These tools allow comparison of new and used equipment, integrating multi-criteria analysis through systems such as GAMS and database-driven decision-making platforms.

Operational management – Luzak et al. (2020) addressed inefficiencies caused by fragmented coordination, proposing the AF-VRP routing algorithm with centralized, decentralized, and distributed control modules to optimize real-time MTA use, particularly in shared machinery systems.

The reviewed literature demonstrates that while significant advances have been made in individual aspects—tractor selection, implement matching, route planning, fleet management, and coordination—there remains a need for integrated approaches. Few studies simultaneously consider tractor–implement compatibility, field-specific constraints, and cost minimization within a unified optimization framework. This research addresses this gap by developing and testing a multi-criteria decision-making model that combines technical, operational, and economic factors in selecting MTAs.

Theoretical Framework. The selection of an optimal machine-tractor aggregate (MTA) for plowing requires the integration of technical, operational, and economic parameters into a unified decision-making framework. In this study, we developed a multi-criteria decision-making (MCDM) model that systematically evaluates tractor–plow combinations against field-specific constraints to minimize operational costs while ensuring technical feasibility. The framework consists of three main stages:

Selection of agricultural machine type – Choosing the plow configuration based on working width, number of bodies, and compatibility with crop and soil conditions.

Identification of tractor type – Matching the plow to a tractor with sufficient engine power, traction force, and fuel efficiency.

Formation of the MTA – Integrating the selected plow and tractor, accounting for field geometry, kinematic parameters, and time constraints.

The general logic of the MCDM framework is shown in **Figure 1**

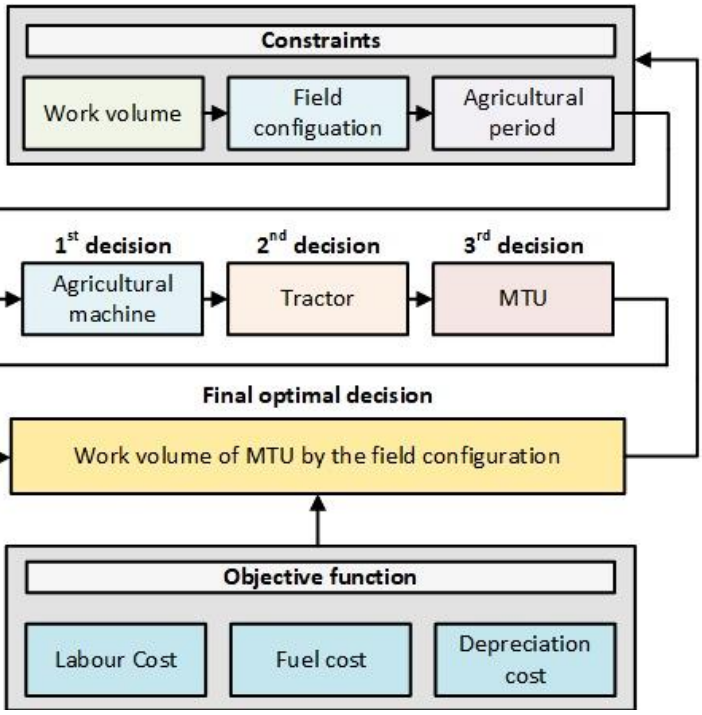

Figure 1. Conceptual scheme of the multi-criteria decision-making framework for selecting MTAs (developed by authors).

Plow Draft Resistance. The plow draft resistance is calculated as:

where:

— specific soil resistance (kN/m)
— number of plow bodies
— working width of one plow body (m)
— plowing depth (m)
— slope of the field (degrees)
— plow weight (kN)

Required Tractor Power. The operating power requirement is calculated as:

where:

— required tractor power (kW)
— operating speed (m/s).

Safety Margin Adjustment. To ensure reliable operation and prevent engine overloading, the calculated tractor power is increased by a 28% safety margin:

where is the adjusted tractor power (kW).

Modeling. The optimization model determines the most cost-effective MTA configuration by combining technical constraints, field parameters, and service costs into a single decision-making framework. The model is formulated as a linear programming problem.

Field Coverage Constraint. Each field j must be fully covered by the selected MTAs:

where:

- work volume completed by MTU on field (ha),

- total area of field (ha),
- number of possible MTU configurations.

Time and Capacity Constraints. The working time must not exceed the maximum allowable period :

where:

— working width of MTU (m),

— operating speed of MTU (m/s).

Additionally, the adjusted tractor power from Equation (3) must not exceed the available tractor power.

Binary Selection Variable. A binary decision variable ensures that only MTUs meeting all technical and operational requirements are selected:

Objective Function. The optimization seeks to minimize the total service cost:

where:

— service cost per hectare for (UZS/ha),

— number of fields.

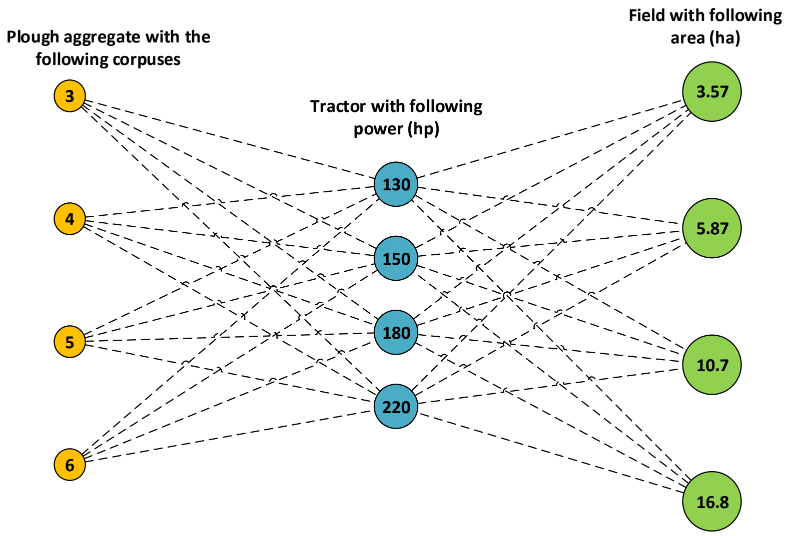

Figure 2. illustrates the simplified flow of the optimization logic, from field parameter input to MTU selection (developed by authors).

Solution. The developed model was applied to the *"Kahramon-Lochin"* farm in the Yakkabag district, Kashkadarya region, Uzbekistan. The farm's total land area is 91.6 ha, of which 37 ha are allocated for cotton cultivation. Four fields with different geometries, slopes, and soil compositions were considered.

Available tractors included 130 hp, 150 hp, 180 hp, and 220 hp models. Plows ranged from 3- to 6-body configurations, with working widths from 0.33 m to 0.50 m. The operational speed range was 8–12 km/h, resulting in 80 possible tractor–plow combinations for evaluation.

The model filtered these combinations by:

- Meeting the **technical constraints** (power requirement, traction capability, compatibility with slope and soil type),
- Satisfying the **time constraints** for seasonal plowing,

- Minimizing **service cost per hectare**.

Following the multi-criteria evaluation, 35 feasible MTAs remained. The model then applied the linear programming formulation (Equations (4) – (7)) to allocate MTAs to each field.

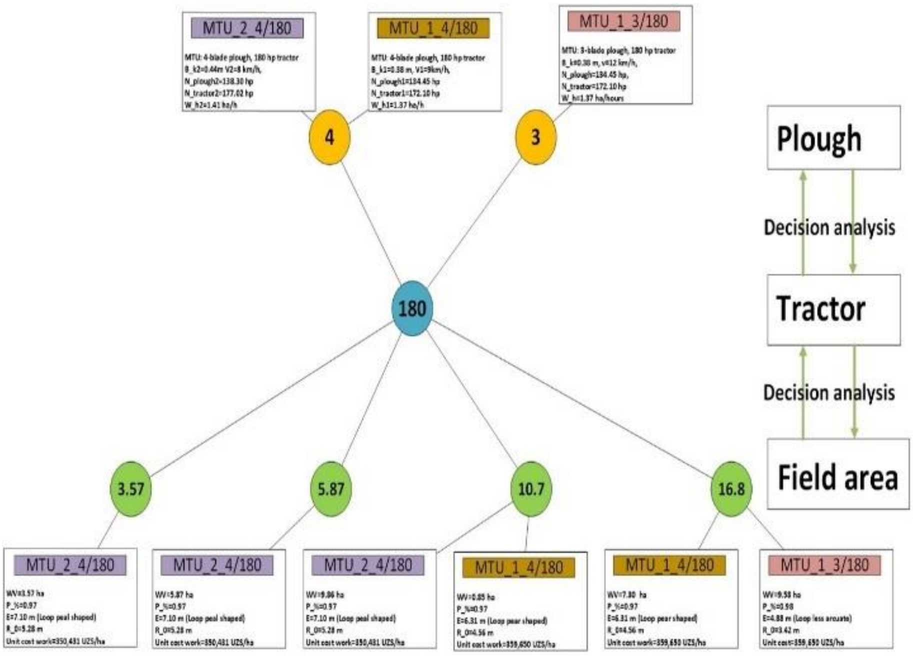

Figure 3. presents the allocation results, showing the optimal MTU selection for each field contour (developed by authors).

The analysis identified the **optimal configuration** for the studied farm as **180 hp tractor** with **4-body plow** (0.44 m working width) operating at **12 km/h**.

This configuration delivered:

- Field performance above **95%**,
- Service cost reduction to **350,000 UZS/hour**,
- Balanced utilization of available machinery resources.

Alternative viable options included:

- 180 hp tractor + 3-body plow (0.38 m),
- 180 hp tractor + 4-body plow (0.38 m).

These alternatives are recommended where field geometry or temporary operational constraints prevent using the primary optimal configuration.

Outcomes. The model's application demonstrated its capability to select MTAs that minimize operational costs while meeting field-specific technical requirements.

The primary **optimal MTA** identified was:

- **180 hp tractor** + **4-body plow** (0.44 m working width) at **12 km/h**, achieving:
- Field performance: >**95%**,
- Service cost: **350,000 UZS/hour**,
- Full compliance with seasonal time constraints.

Alternative configurations provided slightly lower performance but remained within acceptable operational parameters:

- 180 hp tractor + 3-body plow (0.38 m),
- 180 hp tractor + 4-body plow (0.38 m).

The model also revealed **excluded configurations -** 5 and 6-body plows at higher speeds exceeded the power capacity of available tractors, making them unsuitable for the given farm conditions.

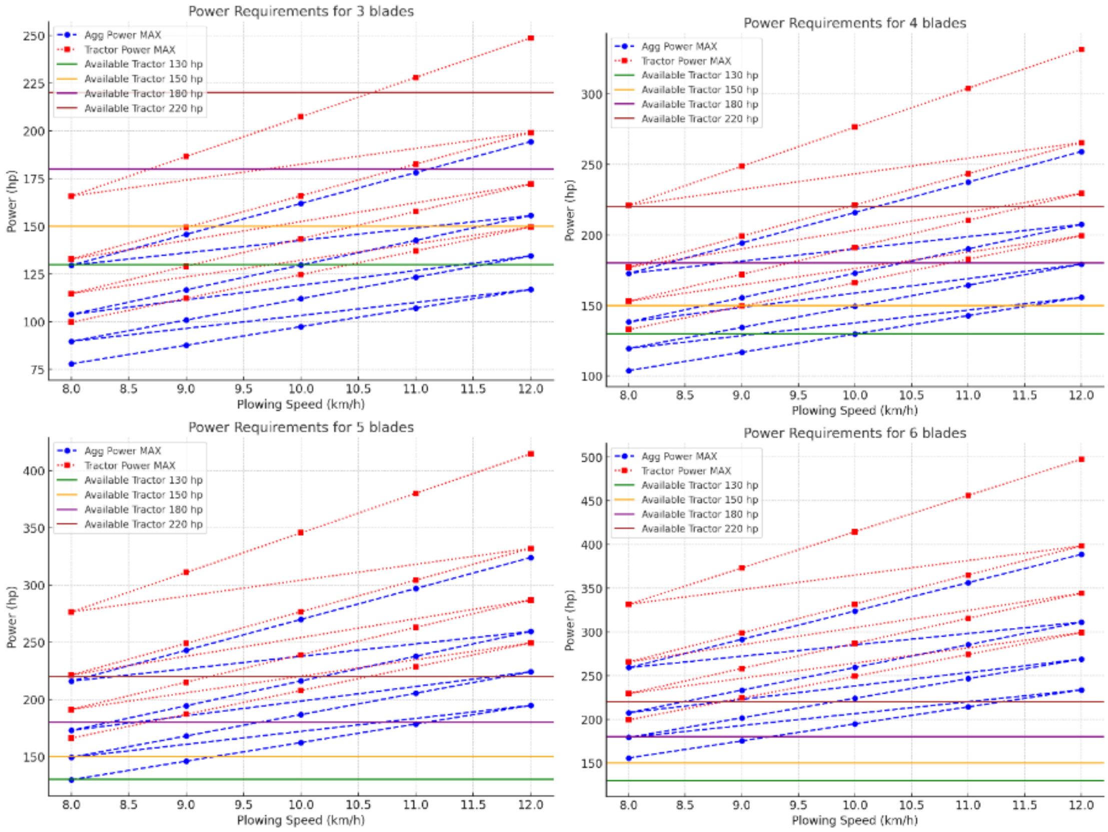

Figure 4. Relationship between plow body number, working width, and tractor power requirements, highlighting the technical feasibility boundaries (developed by authors).

By integrating technical performance data, operational constraints, and cost parameters, the model ensures that MTA selection is both economically justified and operationally viable for farms with varied field conditions.

Conclusion. This study developed and tested a linear programmimng model with sensitivity analyis (LPMSA) integrating integer programming and simplex methods to optimize the selection of machine-tractor aggregates (MTAs) for plowing operations. The model accounts for field geometry, soil properties, operational constraints, and machinery specifications, enabling objective and data-driven decision-making.

Application of the model to the *"Kahramon-Lochin"* farm in Uzbekistan demonstrated its ability to identify tractor–plow configurations that balance technical feasibility and economic efficiency. Among 80 evaluated combinations, the optimal solution was a 180 hp tractor paired with a 4-body plow (0.44 m working width) operating at 12 km/h, achieving over 95% field performance and reducing service costs to 350,000 UZS/hour.

The results confirm that integrating technical, kinematic, and economic parameters into a single optimization framework supports more efficient resource allocation, reduces operational costs, and ensures timely completion of plowing within seasonal windows. The model's adaptability makes it applicable to farms with varying sizes, machinery availability, and field conditions, providing a valuable tool for agricultural machinery planning and management.

Recommendations. Based on the study results and the tested optimization model, the following recommendations are proposed:

1. **Adopt LPMSA-based selection for plowing operations**

Farms should integrate multi-criteria decision-making tools into machinery planning to ensure technical compatibility and cost efficiency.

2. **Prioritize mid-power tractors with adjustable plows**

For medium-sized farms, 180 hp tractors equipped with 4-body plows (0.44 m working width) offer the best balance between operational efficiency and cost.

3. **Implement machinery-sharing systems**

Smallholders should form cooperatives or use service providers to access optimal MTAs, reducing capital investment burdens.

4. **Align machinery selection with field geometry and soil conditions**

Field-specific parameters must guide MTA choice to avoid power mismatches and operational inefficiencies.

5. **Develop national guidelines for MTA optimization**

Policymakers should incorporate technical and economic selection criteria into official agricultural machinery recommendations to improve sector-wide efficiency.

REFERENCES

1. Bochtis, D. D., & Vougioukas, S. G. (2007). Agricultural machine allocation based on simulation. In *Proceedings of the Second IFAC International Conference on Modeling and Design of Control Systems in Agriculture* (pp. 147–152). Osijek, Croatia.
2. Çanakcı, M., Ünal, İ., & Topakçı, M. (2011). Development of computer software for determination of optimum tractor power and machinery sizes. *Tarım Makinaları Bilimi Dergisi*, 7(4), 415–420.
3. Cline, W. R. (2007). *Global warming and agriculture: Impact estimates by country*. Peterson Institute.
4. Cupiał, M., & Kowalczyk, Z. (2020). Optimization of selection of the machinery park in sustainable agriculture. *Sustainability*, 12(4), 1380. https://doi.org/10.3390/su12041380
5. Dzuganov, V. B. (2011). K otsenke effektivnosti proizvodstvenno-tekhnologicheskogo servisa sel’skikh tovaroproizvoditeley [On assessing the efficiency of production-technological service of rural producers]. *Mezhdunarodnyy Tekhniko-Ekonomicheskiy Zhurnal*, (5), 6–11.
6. Edwards, G., Sørensen, C. G., Bochtis, D. D., & Munkholm, L. J. (2015). Optimised schedules for sequential agricultural operations using a Tabu Search method. *Computers and Electronics in Agriculture*, 117, 102–113.
7. Hillier, F. S., & Lieberman, G. J. (2001). *Introduction to operations research* (7th ed.). McGraw-Hill.
8. Işık, A., & Adalı, E. (2016). A comparative study for the agricultural tractor selection problem. *Decision Science Letters*, 5(4), 569–580. https://doi.org/10.5267/j.dsl.2016.3.003
9. Jensen, M. A. F., Bochtis, D., Sørensen, C. G., Blas, M. R., & Lykkegaard, K. L. (2012). In-field and inter-field path planning for agricultural transport units. *Computers & Industrial Engineering*, 63(4), 1054–1061. https://doi.org/10.1016/j.cie.2012.06.017

10. Khafizov, C., Khafizov, R., Nurmiev, A., & Galiev, I. (2020, May). Optimization of main parameters of tractor and unit for plowing soil, taking into account their influence on yield of grain crops. In *19th International Scientific Conference Engineering for Rural Development Proceedings* (Vol. 18, pp. 585–590).
11. Kurochkin, I. M., & Dorovskikh, D. V. (2012). *Proizvodstvenno-tekhnicheskaya ekspluatatsiya MTP* [Production-technical operation of MTA].
12. Lu, H., Zhao, Y., Zhou, X., & Wei, Z. (2022). Selection of agricultural machinery based on improved CRITIC–Entropy weight and GRA–TOPSIS method. *Processes*, 10(2), 266. https://doi.org/10.3390/pr10020266
13. Lujak, M., Sklar, E., & Semet, F. (2021). Agriculture fleet vehicle routing: A decentralised and dynamic problem. *AI Communications*, 34(1), 55–71. https://doi.org/10.3233/AIC-200635
14. Odu, G. O. (2019). Weighting methods for multi-criteria decision-making technique. *Journal of Applied Sciences and Environmental Management*, 23(8), 1449–1457. https://doi.org/10.4314/jasem.v23i8.7
15. Palmer, R. J., Wild, D., & Runtz, K. (2003). Improving the efficiency of field operations. *Biosystems Engineering*, 84(3), 283–288. https://doi.org/10.1016/S1537-5110(02)00272-1
16. Søgaard, H. T., & Sørensen, C. G. (2004). A model for optimal selection of machinery sizes within the farm machinery system. *Biosystems Engineering*, 89(1), 13–28. https://doi.org/10.1016/j.biosystemseng.2004.05.003
17. Tkach, R. J., & Simonovic, S. P. (1997). A new approach to multi-criteria decision making in water resources. *Journal of Geographic Information and Decision Analysis*, 1(1), 25–43.
18. Zaynagabdinov, R., Gabitov, I., Bakiev, I., Gafurov, I., & Kostarev, K. (2020). Optimum planning use of equipment in agriculture. *Journal of Industrial Engineering and Management*, 13(3), 514–528. https://doi.org/10.3926/jiem.3093
19. Артемьев, Ю. Г. (2010). Обоснование алгоритма оптимизации состава машинно-тракторного парка сельскохозяйственного предприятия [Justification of the algorithm for optimizing the composition of the machine-tractor fleet of an agricultural enterprise]. *АгроЭкоИнженерия*, (82), 81–87.
20. Артемьев, Ю. Г. (2012). Алгоритмические основы выбора состава машинно-тракторного парка на основе теории множеств [Algorithmic foundations for selecting the composition of the machine-tractor fleet based on set theory]. *АгроЭкоИнженерия*, (83), 60–69.