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MODELING AND EVALUATION OF A NO-TILLAGE SOIL PREPARATION MACHINE FOR TOMATO CULTIVATION UNDER TUNNEL FILM CONDITIONS

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Abstract: The present research focuses on the design, modelling, and agronomic assessment of a no-tillage soil preparation machine intended for open-field tomato (Solanum lycopersicum L.) cultivation under mulch-film (tonelli-film) conditions. The purpose of the study is to determine the most efficient operational parameters of the proposed implement, to evaluate its effects on soil physical properties, energy consumption, and yield performance, and to integrate the technology into sustainable crop-production systems relevant to semi-arid regions such as southern Uzbekistan. Theoretical modelling was applied to establish relationships between draft resistance, working depth, tool width, and operational speed, while field experiments were conducted during the 2025 growing season at the experimental site of Karshi State Technical University. The results revealed that a working depth of 0.15–0.20 m, tool width of 0.25–0.30 m, and forward velocity of 1.0–1.4 m s^{-1} ensured the best combination of energy efficiency and soil loosening quality. Compared with conventional tillage, the no-tillage mulch-film system reduced energy consumption by approximately 22 %, increased soil-moisture retention by 18 %, and enhanced tomato yield by 25–30 %. The outcomes suggest that no-tillage soil preparation beneath mulch film can be successfully implemented in open-field vegetable systems to reduce carbon emissions, conserve water resources, and maintain soil fertility. This innovation contributes directly to the Sustainable Development Goals (SDG 2 – Zero Hunger, SDG 12 – Responsible Production and Consumption, and SDG 13 – Climate Action).

Keywords: No-tillage, mulch film, tomato cultivation, soil conservation, energy efficiency, mechanisation, sustainable agriculture.

Аннотация:Настоящее исследование посвящено проектированию, моделированию и агрономической оценке машины для безотвальной подготовки почвы, предназначенной для возделывания томата (Solanum lycopersicum L.) в открытом грунте под мульчирующей плёнкой (тонелли-плёнкой). Цель работы заключается в определении наиболее эффективных эксплуатационных параметров предлагаемого агрегата, оценке его влияния на физические свойства почвы, энергопотребление и урожайность, а также в интеграции данной технологии в устойчивые системы земледелия, характерные для полузасушливых регионов, таких как южный Узбекистан.

Теоретическое моделирование позволило установить взаимосвязь между тягловым сопротивлением, глубиной обработки, шириной рабочего органа и скоростью движения. Полевые испытания были проведены в 2025 году на экспериментальном участке Каршинского государственного технического университета. Результаты показали, что глубина обработки 0,15–0,20 м, ширина рабочего органа 0,25–0,30 м и скорость 1,0–1,4 м/с обеспечивают наилучшее сочетание энергетической эффективности и качества рыхления почвы.

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По сравнению с традиционной обработкой, безотвальная система под мульчирующей плёнкой снизила энергозатраты примерно на 22 %, повысила сохранение влаги в почве на 18 % и увеличила урожай томатов на 25–30 %. Полученные результаты свидетельствуют о возможности успешного внедрения технологии безотвальной обработки под плёнкой в системах открытого овощеводства для сокращения выбросов углерода, экономии водных ресурсов и сохранения плодородия почв. Данное новшество напрямую способствует достижению Целей устойчивого развития: **ЦУР 2 – «Ликвидация голода», ЦУР 12 – «Ответственное потребление и производство», ЦУР 13 – «Борьба с изменением климата»**.

Ключевые слова: безотвальная обработка, мульчирующая плёнка, выращивание томатов, сохранение почвы, энергоэффективность, механизация, устойчивое сельское хозяйство.

Annotatsiya: Ushbu tadqiqot ochiq dalalarda tonelli plyonka ostida pomidor yetishtirish uchun mo‘ljallangan tuproqqa ag‘dargichsiz ishlov beruvchi mashinaning loyihalanishi, modellashtirilishi va agronomik baholanishiga qaratilgan. Tadqiqotning maqsadi taklif etilgan agregatning eng samarali ish parametrlarini aniqlash, uning tuproqning fizik xususiyatlariga, energiya sarfiga va hosildorlik ko‘rsatkichlariga ta’sirini baholash, hamda texnologiyani Janubiy O‘zbekiston kabi yarim qurg‘oqchil hududlarga xos barqaror dehqonchilik tizimlariga integratsiya qilishdan iborat.

Nazariy modellashtirish yordamida tortilish qarshiligi, ishlash chuqurligi, ishchi qism kengligi va harakat tezligi o‘rtasidagi bog‘liqliklar aniqlangan. Dalaviy tajribalar 2025-yilgi vegetatsiya davrida Qarshi davlat texnika universitetining tajriba maydonida o‘tkazildi. Natijalar shuni ko‘rsatdiki, 0,15–0,20 m ishlash chuqurligi, 0,25–0,30 m ishchi kengligi va 1,0–1,4 m/s harakat tezligi energiya samaradorligi va tuproqni yumshatish sifati bo‘yicha eng optimal natijalarni ta’minlaydi.

An’anaviy ishlov berish tizimi bilan solishtirganda, ag‘dargichsiz tonelli plyonka ostida ishlov berish energiya sarfini qariyb 22 % ga kamaytirgan, tuproq namligini 18 % ga oshirgan va pomidor hosildorligini 25–30 % ga ko‘paytirgan. Tadqiqot natijalari tonelli plyonka ostida tuproqqa ag‘dargichsiz ishlov berish texnologiyasi ochiq dala sabzavotchilik tizimlarida muvaffaqiyatli qo‘llanilishi mumkinligini ko‘rsatdi. Bu yondashuv uglerod chiqindilarini kamaytirish, suv resurslarini tejash va tuproq unumdorligini saqlashga xizmat qiladi. Ushbu innovatsiya bevosita quyidagi Barqaror Rivojlanish Maqsadlariga hissa qo‘shadi: **SDG 2 – “Ochlikka barham berish”, SDG 12 – “Mas’uliyatli ishlab chiqarish va iste’mol”, SDG 13 – “Iqlim bo‘yicha chora-tadbirlar”**.

Kalit so‘zlar: ag‘dargichsiz ishlov berish, tonelli plyonka, pomidor yetishtirish, tuproqni muhofaza qilish, energiya samaradorligi, mexanizatsiya, barqaror qishloq xo‘jaligi.

Introduction

Background and Relevance

Tomato (Solanum lycopersicum L.) is one of the most economically significant vegetable crops worldwide and plays a vital role in the food-supply chain of arid and semi-arid regions. In Uzbekistan, tomatoes constitute a core component of both domestic food security and export revenue, being grown predominantly in open-field conditions under irrigation. However, traditional deep-tillage methods—based on repeated soil inversion and mechanical pulverisation—have led to structural degradation of soils, accelerated water loss, and a marked decline in organic-matter content.

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Global climatic changes and the depletion of soil resources demand technological innovations that reduce the environmental impact of crop production while maintaining or improving yields. Among various conservation-agriculture approaches, no-tillage cultivation combined with mulch-film coverage has gained increasing attention. The system preserves soil structure, minimises evaporation, suppresses weeds, and improves micro-climatic stability around plant roots.

Problem Statement

Despite the proven benefits of conservation tillage, the implementation of no-tillage systems in Uzbekistan remains limited, mainly due to the absence of locally adapted machinery. Existing imported equipment is either economically unviable for small-scale farmers or unsuited to the physical characteristics of regional soils, which are typically grey loams with moderate salinity and variable compaction.

Research Objectives

1. To design and theoretically model a no-tillage soil-preparation machine capable of loosening soil beneath mulch film without inversion.
2. To determine its optimal technological and operational parameters through mathematical modelling and field trials.
3. To assess its agronomic and environmental performance, comparing it with conventional tillage practices in open-field tomato cultivation.

Literature Review

Conservation tillage has been recognised globally as a foundation of sustainable agriculture. The FAO (2020) defines it through three principles: minimum mechanical disturbance, permanent soil cover, and crop diversification. In Mediterranean and Indian conditions, studies by Campiglia et al. (2011) and Shilpa et al. (2018) have proven that combining no-tillage with mulch film enhances soil moisture by up to 20 % and increases yields by 25–35 %.

From the mechanical viewpoint, the interaction between soil and tillage tools can be modelled as a function of tool geometry and soil properties. Kushwaha and Zhang (1998) proposed the empirical relationship:

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$$R = k_1 b h^2 + k_2 h v$$

where R is draft resistance (kN), b is tool width (m), h is working depth (m), and v is speed (m s^{-1}). This model forms the basis for predicting power requirements in conservation systems.

Yet, few studies have explored such mechanics under mulch conditions. Therefore, this research addresses an important gap by combining mechanical design and agronomic evaluation under Uzbekistan's semi-arid context.

Materials and Methods

The research was conducted in the experimental field of Karshi State Technical University (38°51′N, 65°48′E). Soil was classified as grey-brown loam with medium salinity. The no-tillage prototype included a steel frame, parabolic tine, depth-control wheels, mulch-film roll unit, drip-tape feeder, and press wheels. It was designed to prepare a 0–20 cm layer and lay the film simultaneously, powered by 35–45 HP tractors.

Field trials used a Randomised Complete Block Design (RCBD) with three treatments:

CT – Conventional tillage (two-pass ploughing),

NT – No-tillage without mulch,

NT-M – No-tillage with mulch (proposed machine).

Draft resistance was measured using a dynamometer; soil moisture and bulk density were determined by the core method. Yields, fruit weight, and irrigation frequency were recorded and analysed by ANOVA at $p \leq 0.05$.

Results

Draft Resistance

Theoretical and actual results matched closely ($R^2 = 0.93$). At 0.18 m depth and 1.2 m s^{-1} speed, resistance averaged 5.9 kN, confirming model validity. Power demand was 6.8 kW — 38 % lower than conventional ploughing.

Soil Physical Properties

After cultivation:

Treatment	Bulk density (g/cm³)	Soil moisture (%)
CT	1.35	68
NT	1.25	74
NT-M	1.18	81

Soil density reduced by 12 %, and moisture retention improved by 19 % under NT-M compared to CT.

Energy Use and Yield

The NT-M treatment reduced energy use to 78 kWh/ha (vs 100 kWh/ha under CT). Tomato yield increased from 64.0 t/ha (CT) to 82.1 t/ha (NT-M). Specific energy consumption dropped to 0.95 kWh/t, showing better efficiency.

Irrigation Efficiency

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Irrigation frequency decreased by 25 % (6 vs 8 cycles). The mulch film reduced surface evaporation and maintained a stable root-zone temperature.

Discussion

The no-tillage mulch system demonstrated significant **energy and water savings** and **yield improvement**. These gains stem from reduced soil inversion, improved capillarity, and enhanced aeration. Results correspond with Campiglia et al. (2011), Shilpa et al. (2018), and Sainju & Singh (2008), who all observed similar yield benefits under reduced tillage.

Mechanically, the parabolic tine performed efficiently due to lower friction and soil disturbance. The quadratic relationship between resistance and depth confirmed the machine's optimal design. Agronomically, the higher soil moisture and organic matter supported better root development and nutrient uptake.

Socio-economically, the machine is suitable for small Uzbek farms, offering 15–18 % cost reduction per hectare and promoting climate-smart mechanisation aligned with **SDG 2, SDG 12, and SDG 13**.

Conclusion

This study confirms that **no-tillage soil preparation under mulch film** is both mechanically viable and agronomically superior for open-field tomato cultivation in semi-arid regions.

Key achievements:

1. Optimal parameters: 0.18 m depth, 1.2 m s^{-1} speed, 0.27 m tool width.
2. 20–25 % energy reduction and 28 % yield improvement.
3. Soil bulk density reduced by 12 %, moisture retention increased by 19 %.
4. Irrigation frequency decreased by 25 %.

These outcomes validate the machine's effectiveness for sustainable, water-efficient, and low-carbon tomato production.

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