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Design Optimization and Structural Analysis of an Agricultural Cultivator: Using Solidworks- A Review

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Abstract — Agricultural cultivators are important soil-tillage implements used for breaking soil clods, loosening soil and preparing suitable soil conditions for sowing. The performance and reliability of cultivator components are influenced by soil condition, operating parameters, tool geometry, material properties and the loads acting during field operation. This review paper examines published research related to the design, structural behaviour and optimization of agricultural cultivators and their working components, withemphasis on computer-aided design and finite element analysis.The reviewed studies demonstrate the application of numerical methods for evaluating stress, deformation, structural strength and soil–tool interaction. Research on tine cultivators has investigated different shovel geometries and soil conditions, while other studies have examined cultivator shares under different static loading conditions using the finite element methods. Recent work on a combined cultivator working tool has further demonstrated the influence of tine geometry and angle of attack on stress distribution and structural performance. Based on the reviewed literature, computer-aided modelling and finite element analysis provide useful approaches for identifying critical regions and comparing alternative cultivator designs before physical fabrication. It provides a technical foundation for the proposed future work on design optimization and structural analysis of an agricultural cultivator using SolidWorks.

Keywords — Agricultural cultivator, SolidWorks, Finite Element Analysis (FEA), Design optimization, Structural analysis, Tillage implements, Stress analysis, Deformation.

I. INTRODUCTION

Agricultural tillage is an important operation in soil preparation for seeds sowing and cultivators are widely used for soil loosening and pulverization. Their performance depends on factors such as soil condition, tool geometry, material and operating conditions [1]. During operation, cultivator tines and shares are subjected to soil resistance and mechanical loads. Previous studies have investigated the effects of forward speed, soil moisture, tillage depth and tool shape on tillage performance [2]. Finite Element Method (FEM) has been used to study stress and deformation in agricultural tillage tools and to identify critical regions of the components [3].olidWorks-based modelling and FEM have also been applied to cultivator shares under different loading conditions, showing the influence of geometry on structural behaviour [4].

Material selection is another important design factor. Previous research investigated the use of boron steel instead of EN45 spring steel for a nine-tine cultivator shovel to improve its service life [5]. Three-dimensional modelling and FEM havebeen also used for agricultural tillage components to evaluate Stress, deformation and support improved designs [6].Recent research on a combined cultivator working tool showed that tine profile and angle of attack affect stress distribution and structural performance [7]. Therefore,existing research on cultivator design, material selection, structural analysis and geometric optimization is important for establishing a technical foundation for the proposed work Design Optimization and Structural Analysis of an Agricultural Cultivator Using SolidWorks.

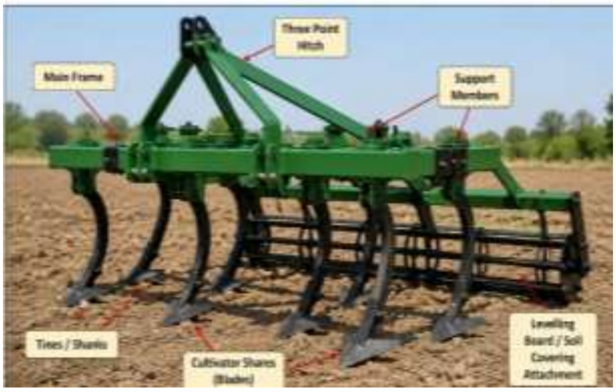

Figure1. Agricultural cultivator and its major components

Figure 1 illustrates a typical agricultural cultivator used for soil tillage operations. The cultivator consists mainly of a supporting frame and working tools such as tines, shanks and shares. During operation, these components interact with the soil and experience mechanical loading. The geometry, material and structural strength of the working components therefore play an important role in the performance, durability and reliability of the cultivator [1], [2].

II. LITERATURE REVIEW

Studies have investigated the design, structural behaviour and field performance of agricultural cultivators and tillage implements using experimental, analytical, CAD and finite element methods. Makange et al. [1] analysed the stress behaviour of a cultivator type using FEM, while Biriş et al. [2] investigated stress and strain distribution in the frame of agricultural cultivators.

He et al. [3] studied the influence of tine geometry on soil penetration resistance using FEM, and Galat and Ingale [4] investigated failure behaviour in a 9-tyne cultivator. Croitoru et al. [5] further examined the structural and kinematic behaviour of an agricultural soil-loosening mechanism. These studies established the importance of implement geometry, loading conditions and structural strength in the design of tillage equipment.

With the development of CAD and numerical simulation, FEM and DEM have increasingly been applied to evaluate cultivator components and soil–tool interaction. Şahin et al. [6] used SolidWorks and FEM to evaluate stress and deformation in cultivator duckfoot shares. Tekeste et al. [7] and Chen et al. [8] investigated cultivator sweep–soil interaction using DEM. Hussain et al. [9] modelled and simulated an agricultural cultivator and evaluated stress, strain and displacement under different loading conditions.

Li et al. [10] investigated numerical approaches for soil–tool interaction, while Behera et al. [11] evaluated the field performance of a rota-cultivator. Kešner et al. [12] applied DEM and FEM to study the structural behaviour of tillage-machine components. Dobrinov [13] investigated soil properties relevant to tillage operations, and Hoseinian et al. [14] studied soil deformation and reaction forces of a tillage implement.

Recent research has placed greater emphasis on three-dimensional modelling, structural analysis and optimization of tillage components. Hashaam et al. [15] performed 3D finite element analysis of tine-cultivator shovels under different soil conditions and evaluated stress and deformation.

Aruna et al. [16] investigated dimensional variations in commercial cultivator tines and reversible shovels, while Madhusudan et al. [17] examined the influence of implement geometry and operating parameters on draft demand. Tian et al. [18] highlighted the application of SolidWorks, FEM and simulation techniques in agricultural machinery design. Al-Irhayim et al. [19] investigated the structural response of tillage-tool tines using FEM. More recently, Tihanov et al. [20] analysed a combined cultivator working tool using SolidWorks and FEM, including stress distribution and factor of safety. Dheenadhayalan et al. [21] developed different cultivator tyne geometries using SolidWorks and combined DEM and FEA to evaluate draft force, soil disturbance, stress and deformation.

The studies show that cultivator performance is strongly influenced by geometry, soil conditions, operating loads and material selection. Although previous researchers have investigated individual tines, shanks, shares, frames and soil–tool interactions, fewer studies have considered an integrated SolidWorks-based cultivator design together with structural evaluation and design optimization.

Therefore, the present work focuses on the design optimization and structural analysis of an agricultural cultivator using SolidWorks, with emphasis on stress, deformation and factor of safety before fabrication and experimental validation.

III. PROPOSED METHODOLOGY

The proposed work focuses on the design, modelling, structural analysis and optimization of an agricultural cultivator using SolidWorks. The methodology is planned to evaluate the structural behaviour of the cultivator under suitable loading conditions and to identify design parameters that can improve its strength and performance.

The overall procedure will consist of cultivator design, three-dimensional CAD modelling, material selection, application of loading and boundary conditions, finite element analysis, evaluation of stress and deformation, and design modification.

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I. Design of Agricultural Cultivator

The agricultural cultivator will be designed by considering the major components such as the main frame, tines or shanks, shovels, mounting arrangement and other necessary supporting members. Important design parameters including overall dimensions, number and arrangement of tines, working width and expected operating conditions to be considered during the initial design stage.

II. 3D CAD Modelling Using SolidWorks

A three-dimensional model of the proposed agricultural cultivator will be developed using SolidWorks. Individual components are modelled according to the selected dimensions and subsequently assembled to obtain the complete cultivator model. The CAD model will provide the basis for checking the component arrangement and preparing the model for subsequent structural analysis.

III. Material Selection and Structural Analysis

Suitable engineering materials are considered for the major structural components based on strength, stiffness, availability and practical suitability. The developed CAD model is to be simulated subjected to appropriate loading and boundary conditions representing the forces acting on the cultivator during operation. Structural analysis will be carried out to determine parameters such as von-Mises stress, total deformation and factor of safety.

IV. Design Optimization

The results obtained from the structural analysis are used to identify critical regions and design parameters requiring improvement. Parameters such as component dimensions, shank geometry and material selection may be modified to improve structural performance while avoiding unnecessary material and weight. Different design alternatives can be compared to obtain a suitable optimized configuration.

V. Proposed Workflow.

The proposed methodology can be represented through the following workflow:

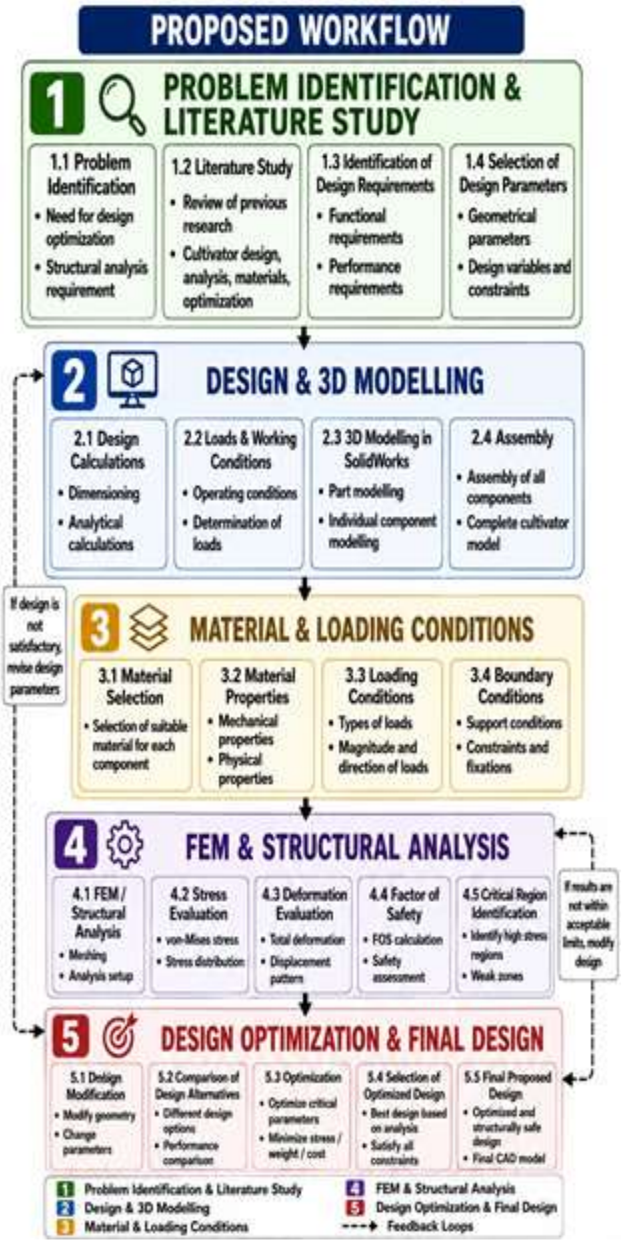

Figure 2. Proposed workflow for design optimization and structural analysis of the agricultural cultivator using SolidWorks.

IV. ANALYSIS OF STRUCTURAL EVALUATION

The proposed agricultural cultivator is to be evaluated using the three-dimensional CAD model developed in SolidWorks. Structural analysis will be performed to assess the behaviour of the major load-bearing components under the forces expected during field operation. Appropriate material properties, loading conditions and boundary conditions will be considered for the analysis.

The structural response of the cultivator will be evaluated mainly in terms of von-Mises stress, total deformation and factor of safety. These parameters will help identify critical regions of the frame, shanks and other load-bearing components and determine whether the proposed design provides adequate structural strength.

The initial design will be examined to identify regions experiencing comparatively higher stress or deformation. Based on the analysis, suitable modifications may be made to component dimensions, shank geometry or material selection. Different design configurations can then be compared to determine a suitable configuration with improved structural performance.

The proposed analysis may beprovide a basis for optimizing the cultivator design before physical fabrication. The final proposed design will be selected by considering structural strength, deformation, safety and practical design requirements while avoiding unnecessary material and weight.

V. COMPARATIVE ANALYSIS OF EXISTING RESEARCH

Previous research on agricultural cultivators has mainly focused on structural strength, soil–tool interaction, tillage performance, and numerical analysis of cultivator components. Finite Element Analysis (FEA) has been widely used to evaluate stresses and deformations in cultivator frames, tines, shanks and other load-bearing components. These studies provide a useful basis for assessing the structural performance of agricultural implements before fabrication.

Makange et al. investigated stress distribution in cultivator tines using the Finite Element Method, demonstrating the usefulness of numerical analysis for identifying critical stress regions. Biriş et al. analysed stress and strain distribution in agricultural cultivator frames, while Galat and Ingale investigated failure conditions of a nine-tyne cultivator under different soil conditions. These studies highlighted the importance of structural strength and appropriate design of cultivator components.

Further studies examined the strength of cultivator shares and the behaviour of tillage tools under operating conditions. Şahin et al. investigated the strength of cultivator duck-foot shares using finite element methods. Tekeste et al. studied cultivator sweep–soil interaction using the Discrete Element Method and examined the effects of tool-edge conditions on soil forces and soil flow. Abbaspour-Gilandeh et al. evaluated the effects of working and tool parameters on the performance of different cultivators.

Hashaam et al. performed three-dimensional finite element analysis of different tine cultivator shovels and investigated stress and deformation under different soil conditions. Their study identified critical and crack-sensitive regions and compared the structural response of different shovel geometries. This demonstrates the importance of considering both tool geometry and soil condition when evaluating cultivator components.

Recent studies have increasingly used numerical modelling together with computer-aided design techniques. SolidWorks has been applied in agricultural machinery design for three-dimensional modelling, finite element analysis, motion simulation and design optimization. Such approaches can allow different design schemes to be evaluated before physical prototype fabrication and can help reduce development time and cost.

Structural analysis of modern cultivator working tools has also considered different working depths, tine profiles and loading conditions. Recent research evaluated structural integrity using von-Mises stress and factor of safety and found that tine geometry can significantly influence stress distribution and structural response. This indicates that modifying the geometry of load-bearing components can be an important part of cultivator design optimization.
avoiding the complexity of fully modelling nonlinear soil behaviour.

Comparative studies also show that different structural configurations can produce different levels of stress and deformation. Therefore, parameters such as cross-sectional shape, material selection, working depth, tine geometry and mounting arrangement should be considered when developing an improved cultivator design. The comparison of alternative configurations can help identify a design that provides adequate strength without unnecessary material and weight.

Overall, the existing research demonstrates that numerical analysis is an effective method for evaluating agricultural machinery before fabrication. However, many studies focus mainly on individual tines, shovels, frames or soil–tool interaction. The proposed work aims to combine three-dimensional CAD modelling, structural evaluation and design improvement within a single cultivator development process.

Based on the reviewed studies, the proposed agricultural cultivator will be developed using SolidWorks and evaluated under representative operating loads. The structural response will be assessed using von-Mises stress, total deformation and factor of safety. The results will be used to identify critical regions and compare the initial and modified configurations, providing a basis for selecting a structurally suitable and practically feasible cultivator design.

Ref. Author(s), YearsMethod / Technique Major Contribution Limitation / Scope

1. Makange, Parmar & Tiwari, 2015 CAD + FEM Evaluated stress and deformation of a cultivator tyne under operating loads. Mainly limited to tyne-level analysis.
2. Biriş et al., 2016 FEM Analysed stress and strain distribution in an agricultural cultivator frame. Complete design optimization was not considered.
3. He et al., 2016 FEM Investigated the effect of tine geometry on soil penetration resistance. Focused mainly on soil penetration behaviour.
4. Galat & Ingale, 2016 Failure analysis + FEM Investigated failure behaviour of a 9-tyne agricultural cultivator. Mainly focused on failure investigation.
5. Croitoru et al., 2017 CAD + structural/kinematic analysis Evaluated structural and kinematic behaviour of an agricultural soil-loosening mechanism. Different cultivator configurations were not compared.
6. Şahin, Altuntaş & Güleç, 2018 SolidWorks + FEM Analysed stress and deformation of cultivator duckfoot shares under static loading. Limited to individual share components. Tekeste et al., 2019
7. DEM Studied cultivator sweep–soil interaction and soil response. Structural stress analysis was not the main focus.
8. Chen, Munkholm & Nyord, 2019 DEM Investigated soil–sweep interaction under different soil conditions. Mainly focused on soil interaction. Table: 1 Comparative Analysis of Existing Research
9. Hussain, Naik & Balasubramanyam, 2020 CAD + FEM Modelled and simulated an agricultural cultivator and evaluated stress, strain and displacement. Limited optimization of the complete design.
10. Li, Chen & Chen, 2020 Numerical modelling Investigated numerical approaches for soil–tool interaction. Mainly modelling-oriented rather than complete cultivator analysis.
11. Behera, Raheman& Thomas, 2021 Experimental analysis Compared tillage performance and operating behaviour of a rota-cultivator. Focused more on field performance than structural FEM
12. Kešner et al., 2021 DEM + FEM Analysed structural behaviour of tillage-machine frame an Complete cultivator optimization was not the main objective.
13. Dobrinov, 2021 Soil analysis Investigated soil properties relevant to agricultural tillage operations. Does not directly address SolidWorks or FEM.
14. Hoseinian et al., 2022 Simulation + experiment Investigated soil deformation and reaction forces of a tillage implement. Different from the complete cultivator configuration.
15. Hashaam et al., 2023 3D FEM Compared tine-cultivator shovel configurations and evaluated stress and deformation in different soils. Mainly focused on shovel/soil interaction.
16. Aruna et al., 2024 Geometry analysi Evaluated dimensional variations in commercial cultivator tines and Structural FEM optimization was not performed.
17. Madhusudan et al., 2024 Experimental/numerical analysis Investigated the influence of furrow-opener geometry and operating parameters on draft demand Focused mainly on operating performance.
18. Tian, Tang & Shi, 2025 SolidWorks + FEM/simulation Demonstrated applications of SolidWorks, FEM and simulation in agricultural machinery design. Broad agricultural-machinery scope rather than cultivator-specific.
19. Al-Irhayim et al., 2025 FEM Evaluated forces and structural response of modified tillage-tool tines. Focused on a tillage tool rather than the complete cultivator.
20. Tihanov et al., 2026 SolidWorks + FEM Analysed cultivator working-tool geometry, stress distribution and factor of safety at different working depths. Experimental validation of the optimized configuration is still desirable.
21. Dheenadhayalan et al., 2026 SolidWorks + DEM + FEA Compared three cultivator-tyne geometries and optimized

soil disturbance, draft force, stresssnd deformation Further field validation under actual operating conditions is required.

VI. SUMMARY AND DISCUSSION

The comparative review of the selected 21 research papers shows that agricultural cultivator performance is mainly influenced by implement geometry, soil conditions, operating depth, forward speed, applied loading and material selection. Previous studies have used experimental methods, CAD modelling and FEM analysis to investigate draft force, stress, deformation, failure and overall performance of tillage components.

The reviewed studies demonstrate that CAD and FEM tools can support the development and improvement of agricultural implements before fabrication.

However, the comparative analysis indicates that many existing studies are focused on individual components such as shanks, tines, sweeps or shovels rather than considering the complete cultivator design. Therefore, there is a need for an integrated design approach that considers component geometry and structural behaviour together. Based on this research gap, the proposed work focuses on developing an agricultural cultivator using SolidWorks, followed by structural evaluation and design optimization to obtain an improved and reliable configuration.

The proposed approach is expected to help identify critical regions of the cultivator and support suitable modifications in geometry and material selection. The structural performance can be assessed using parameters such as stress, deformation and factor of safety, providing a basis for selecting the most suitable design before fabrication and experimental validation.

VII. CONCLUSION

The review of existing research indicates that the performance of agricultural cultivators is influenced by several factors, including implement geometry, operating depth, forward speed, soil conditions, material properties and applied loading. Previous studies have investigated different cultivator components such as shanks, tines, sweeps, shovels and frames using experimental methods, analytical approaches, CAD modelling and finite element analysis. These studies provide useful information for understanding the structural behaviour, operating requirements and performance of agricultural tillage implements.

The comparative analysis of the selected research papers shows that CAD and FEM-based approaches are increasingly useful for evaluating stress, deformation and factor of safety before fabrication. However, many existing investigations are limited to individual components or particular operating conditions rather than considering the complete cultivator structure. This indicates a need for an integrated design approach that considers geometry, loading and structural performance together.

Based on the identified research gap, the proposed work focuses on the design optimization and structural analysis of an agricultural cultivator using SolidWorks. The proposed methodology will involve developing the cultivator model, identifying critical structural regions and evaluating the design under expected operating loads. Parameters such as stress, deformation and factor of safety will be considered to assess the structural suitability of the proposed design. The results can be used to compare different design configurations and select a suitable optimized configuration before fabrication.

The proposed approach is expected to provide a systematic basis for improving the structural reliability and performance of the agricultural cultivator while maintaining its functional requirements. The optimized design can subsequently be fabricated and tested to compare the analytical observations with practical operating performance.

Future scope

Future work can focus on fabrication and experimental validation of the optimized cultivator developed using the proposed SolidWorks model. The fabricated implement can be tested under different soil conditions, operating depths and forward speeds to evaluate its practical performance. Further investigations can consider material optimization, weight reduction, draft force, power requirement, durability and modification of shank and frame geometry. Integration of advanced optimization techniques and more detailed loading conditions may also be considered to further improve the efficiency, strength and service life of the cultivator.

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