

Design and Development of Digger System for an Automated Multi- Vegetable Transplanter

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Abstract: *In agricultural automation, soil preparation for seedling placement remains a critical operation influencing crop establishment and yield. Traditional manual digging methods are labor-intensive, inconsistent, and unsuitable for large-scale precision farming, while existing mechanized systems often lack adaptability for small-scale agricultural conditions prevalent in countries like India. This review examines the development of mechanically driven digger systems integrated with automatic vegetable transplanters. Particular emphasis is given to five-bar linkage-based digger mechanisms synchronized with transplanter motion for achieving uniform furrow creation at adjustable depths and intervals. Reported studies demonstrate digging success rates of 85–90% with operational capacities reaching 1,800–2,000 planting sites per hour. The mechanical simplicity, affordability, and ease of maintenance of such systems make them suitable for resource-constrained agricultural environments. The review highlights the role of optimized soil disturbance, depth control, and modular blade systems in reducing labor dependency and improving planting accuracy.*

Keywords: Automatic Vegetable Transplanter, Digger Mechanism, Soil Preparation, Agricultural Automation, Rotary Blade System, Furrow Consistency.

I. INTRODUCTION

Agriculture supports more than 58% of India's population and contributes approximately 17% to the national GDP. Vegetable cultivation forms a significant subsector but continues to rely heavily on labor-intensive soil preparation methods. Manual digging tools result in inconsistent furrow depths (± 30 mm variation) and improper spacing, leading to 20–30% yield reduction in high-value crops such as tomatoes and chilies. Excessive soil compaction (>25 kPa) caused by improper manual practices further damages seedlings and lowers germination rates.

Although advanced mechanized systems developed in industrialized nations provide high precision (± 5 mm depth accuracy), their high capital costs limit adoption among smallholders managing less than 2 hectares of land. Tractor-mounted plows and semi-mechanized adaptations often fail to address heterogeneous soil conditions and may aggravate soil degradation.

Recent developments focus on low-cost mechanical digger systems integrated into automatic vegetable transplanters. These systems utilize modular rotary blades and linkage mechanisms to achieve precision comparable to expensive hydraulic systems, while maintaining affordability suitable for small-scale farming.

II. LITERATURE REVIEW

Digging tools form the backbone of precision agriculture, facilitating soil preparation, seedling placement, and resource-efficient farming. Over time, technological advancements have improved furrow consistency, depth accuracy, and operational efficiency. However, limitations such as high manufacturing cost, rapid blade wear, and high energy consumption remain major barriers to widespread adoption.

Studies from Japan reported serrated blade systems achieving up to 95% furrow consistency in clay soils, though frequent blade replacement was required due to abrasive wear. European developments introduced planetary gear

synchronization mechanisms capable of multi-blade operation at high rotational speeds, but maintenance complexity restricted their practical use. Hydraulic digger systems provided high depth precision but demanded greater power input, making them unsuitable for fuel-constrained agricultural environments.

In developing countries, semi-mechanized plows frequently exhibit poor depth control, resulting in high seedling mortality. Low-cost auger systems developed for sandy soils demonstrated reduced efficiency in clay-heavy conditions. African and Southeast Asian innovations introduced ox-drawn and spring-loaded blade mechanisms that reduced labor dependency but lacked durability and scalability.

Durability remains a key technical challenge. Carbide-tipped blades improve wear resistance but increase manufacturing cost. Fatigue studies on cold-rolled steel components indicate stress limitations under cyclic loading, emphasizing the need for optimized structural design. Energy-efficient alternatives such as solar-powered diggers show potential but suffer from reliability concerns during adverse weather conditions.

Automation trends include IoT-based depth control, LiDAR-assisted soil monitoring, and robotic path planning. While technologically advanced, these systems require significant investment and technical expertise, excluding small-scale farmers.

Major research gaps include affordability, soil adaptability across heterogeneous conditions, blade durability in abrasive soils, and reduction of power consumption.

III. METHODOLOGY

The following flowchart outlines the step-by-step process used to study and develop the digger system for tasks like soil preparation and planting saplings. This structured approach focuses on gathering and analyzing relevant data, ensuring the system is efficient, durable, and cost-effective. Each step highlights the integration of scientific principles and engineering practices to achieve optimal performance in agricultural applications.

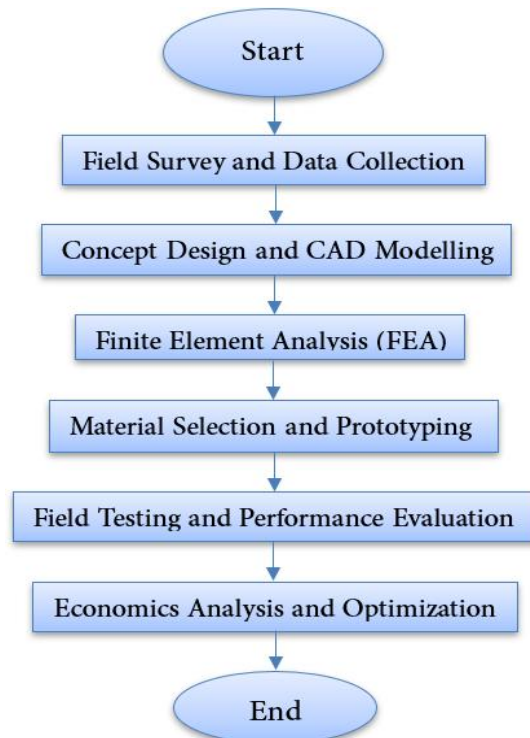


Fig.-1: Flow Chart

The methodology for developing the low-cost digger system was structured into five sequential phases to ensure systematic design, testing, and optimization. The process began with field surveys and data collection across 15 farms in Maharashtra, India, to analyze soil heterogeneity and gather farmer feedback on existing manual tools. Key parameters such as furrow depth.

Measurements such as furrow depth variation (± 30 mm), soil compaction exceeding 25 kPa, and manual labor demands (8–10 hours per acre) were recorded to define initial performance benchmarks [10, 11]. Subsequently, a 3D CAD model was constructed using PTC Creo software, featuring a modular five-bar mechanism and adjustable linkages to regulate digging depth between 50 and 150 mm. Structural integrity was verified through computational stress analysis in ANSYS, which showed that essential components experienced stresses below 180 MPa under typical working conditions [12, 13]. For the prototype construction, high-carbon steel with a hardness rating of 55 HRC was chosen for the blades to ensure durability in abrasive soil environments, while cold-rolled steel (CRS), offering a yield strength of 250 MPa, was used for the framework. Components were produced employing a laser cutting machine and arc welding techniques, with an emphasis on minimizing costs and simplifying assembly [14, 15]. The prototype was then subjected to extensive field evaluation through more than 50 trials across varying soil types. Performance indicators measured included depth uniformity (achieving 85–90%), power requirement (ranging from 2.0 to 3.0 HP), and blade deterioration rate (0.2 mm per hour). To enhance operational effectiveness, continuous refinements were made to blade rotational speed (adjusted between 100 and 200 RPM) and linkage configuration [16, 17].

Finally, an economic analysis revealed a manufacturing cost of ₹18,500, with a projected return on investment (ROI) of six months through labor cost savings (70% reduction). This methodology balanced technical rigor with affordability, addressing gaps in existing mechanized solutions while aligning with the socio-economic realities of Indian agriculture.

IV. NEED FOR DIGGER SYSTEM IN MULTI VEGETABLE TRANSPLANTER

The digger system is the most critical component of a vegetable transplanter because it directly interacts with the soil and determines the quality of seedling establishment. Its primary function is to create holes or furrows for planting while maintaining uniform depth, which is essential for healthy root development and proper nutrient absorption. surrounding soil, improves aeration, and facilitates better water infiltration around the root zone. Properly prepared soil ensures firm root anchorage, reduces air pockets, and minimizes transplant shock, thereby improving plant survival rate and promoting uniform crop growth.

In multi-vegetable applications, the importance of the digger system increases because different crops have varying root lengths, stem diameters, and spacing requirements. For example, leafy vegetables may require shallow planting depth, whereas crops like tomato or brinjal need deeper placement for stable growth. Therefore, the digger must provide adjustable depth control typically ranging from 20 to

100 mm depending on crop type. It should also allow variable plant-to-plant spacing and row spacing adjustments to accommodate diverse cultivation patterns.

Furthermore, the digger system must be capable of operating efficiently under different soil conditions such as clay, sandy, loamy, and semi-moist soils. Clay soils demand higher penetration force and stronger blade materials, whereas sandy soils require controlled penetration to prevent excessive soil collapse. The system must maintain consistent performance despite soil hardness variations, surface residues, and minor field undulations. Efficient digging also reduces draft force requirements, minimizes fuel consumption, and prevents excessive soil compaction, which can negatively affect root growth.

Another critical requirement is synchronization with the planting and soil covering mechanisms. Improper timing between digging and seedling placement can result in collapsed holes, misaligned planting, or root bending. Hence, the digger must operate in coordinated motion with the transplanting unit to ensure precise and continuous operation. Durability is also essential, as digging components are subjected to abrasive wear and cyclic loading. Selection of suitable materials and proper structural design enhances lifespan and reduces maintenance frequency.

Overall, the digger system is not merely a soil-cutting tool but a precision-controlled mechanism that directly influences planting accuracy, crop uniformity, field efficiency, and overall agricultural productivity. Its optimized design is fundamental to the successful development of an automated multi-vegetable transplanter.

V. DESIGN CONSIDERATIONS OF DIGGER SYSTEM

5.1 Functional Requirements

The digger system must ensure uniform hole formation, consistent depth control, smooth soil penetration, and proper synchronization with the planting unit. The penetration and withdrawal of the digging element should occur without excessive soil disturbance to preserve soil structure around the root zone. The mechanism must also minimize vibration and impact forces to prevent damage to delicate seedlings during placement. Another important functional requirement is quick adjustability, allowing farmers to modify depth and spacing settings according to crop type without complex recalibration. Reliability, low maintenance requirement, and ease of operation are equally important to ensure field adaptability and user convenience.

5.2 Design Parameters

The depth of digging depends on crop root length and typically ranges between 30 and 80 mm for most vegetables, although certain crops may require depths beyond this range. The width and geometry of the furrow must correspond to the root plug or soil ball dimensions to avoid excessive soil displacement and ensure firm root contact with the surrounding soil. Tool geometry, including rake angle, clearance angle, and cutting edge profile, significantly influences soil penetration efficiency and draft force requirement.

Soil type plays a critical role in design optimization. Clay soils demand stronger structural members and higher penetration force due to greater cohesion and resistance, whereas sandy soils require controlled penetration to prevent hole collapse. Loamy soils provide moderate resistance and are generally considered ideal for transplanting operations. Soil moisture content also affects performance; excessive moisture increases sticking and clogging, while very dry soil increases penetration resistance. Operational speed directly impacts digging accuracy and synchronization with the planting mechanism. Higher forward speed increases field capacity but may lead to depth variation and improper hole formation, whereas lower speed improves precision but reduces productivity. Therefore, an optimal balance between speed and accuracy must be maintained. The power requirement depends on soil resistance, working depth, and mechanism type, and it may be supplied manually, through an internal combustion engine, tractor PTO, battery-powered electric motor, or hydraulic drive system. Structural strength analysis, stress distribution, and fatigue life estimation must be considered during design to ensure durability under continuous operation.

5.3 Types of Digger Mechanisms

Different types of digger mechanisms are selected based on soil conditions, crop requirements, and desired precision. Shoe-type diggers are simple in construction and economical, making them suitable for soft and well-prepared soils; however, they offer limited depth control accuracy. Rotary diggers utilize rotating blades or discs to cut and loosen hard soil, improving penetration efficiency but requiring continuous power input and higher maintenance. Furrow openers create continuous trenches and are ideal for row-based transplanting, though they may cause greater soil disturbance compared to hole-type mechanisms.

Auger-based diggers produce precise vertical holes with controlled diameter and depth, making them suitable for high-accuracy transplanting systems; however, they involve more complex design, higher manufacturing cost, and increased power demand. Linkage-based mechanisms, such as four-bar or five-bar systems, convert rotary motion into controlled reciprocating motion, enabling accurate depth control with relatively simple power transmission. Cam-follower-based systems allow programmable digging profiles and improved synchronization with planting arms. Selection of the appropriate mechanism depends on trade-offs between cost, precision, energy consumption, soil adaptability, and maintenance requirements.

Overall, careful consideration of functional, structural, and operational parameters is essential to design a digger system that ensures precision planting, durability, and adaptability for multi-vegetable transplanting applications.

VI. WORKING PRINCIPLE OF DIGGER SYSTEM

The digger system operates by penetrating the soil through the application of controlled mechanical force and forming a cavity suitable for seedling placement. The operation begins when rotary motion from the prime mover (engine, motor, or ground wheel) is transmitted to the digging mechanism through a linkage, cam, crank, or rotary drive arrangement. This motion is converted into vertical or inclined penetration of the digging tool into the soil. As the tool enters the soil, it cuts, displaces, or shears the soil mass depending on its geometry and working principle, thereby creating a hole or furrow of predetermined depth and width. During penetration, the cutting edge overcomes soil resistance, which includes adhesion, cohesion, internal friction, and compaction forces. Proper tool geometry such as rake angle, clearance angle, and tip shape ensures smooth soil entry with minimum draft force and reduced energy consumption. In some mechanisms, such as auger or rotary systems, soil is lifted and partially removed to maintain cavity shape, while in shoe-type or furrow opener systems, soil is displaced sideways. The depth of penetration is controlled either mechanically through adjustable linkages and stops or through sensor-based depth control systems in advanced designs.

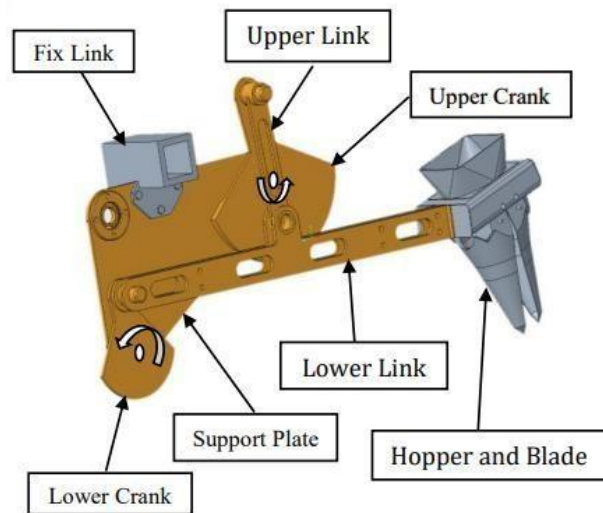


Fig:2: Digger Mechanism Schematic

Once the cavity is formed, the seedling feeding and placement mechanism synchronizes with the digger system to position the seedling precisely into the prepared hole. Accurate timing between digging and placement is crucial; if the seedling is placed too early or too late, improper root alignment or hole collapse may occur. After placement, soil covering and compaction devices press the displaced soil gently around the root zone to ensure firm contact between roots and soil particles. This step eliminates air gaps, improves moisture retention, and enhances nutrient absorption.

The working cycle of the digger system must be continuous and synchronized with the forward motion of the machine to maintain uniform plant-to-plant spacing. In automated systems, ground wheel rotation often determines the timing of digging and planting operations to ensure proportional spacing with travel speed. The entire process— from penetration to covering—must minimize excessive soil disturbance to preserve soil structure and prevent unnecessary compaction.

Overall, the working principle of the digger system combines controlled soil penetration, precise cavity formation, synchronized seedling placement, and effective soil compaction. Efficient coordination of these stages ensures accurate planting depth, higher plant survival rate, uniform crop growth, and improved field productivity in multi- vegetable transplanting operations.

VII. INTEGRATION WITH AUTOMATED TRANSPLANTER

The digger system must operate in complete coordination with all major subsystems of the automated transplanter to work in synchronization with the seedling feeding mechanism, planting arm or gripper assembly, frame and mobility system, soil covering unit, and power transmission system. The seedling feeding mechanism supplies individual seedlings at predetermined intervals, while the planting arm or gripper accurately positions each seedling into the cavity created by the digger. Any mismatch in timing between digging and seedling placement can result in missed planting, improper root orientation, or hole collapse. Therefore, mechanical or electronic synchronization is essential for maintaining accuracy.

The frame and mobility system provide structural rigidity and maintain consistent machine alignment across uneven field surfaces. Since the digger directly interacts with soil, it experiences significant reaction forces and vibrations. These forces are transmitted to the chassis; hence, proper frame design and vibration damping mechanisms are required to maintain stability and prevent misalignment. Wheel spacing, ground clearance, and weight distribution also influence digging depth consistency and overall machine balance during operation.

The power transmission system drives both the digger and planting mechanisms. Power may be supplied through tractor PTO, ground-driven wheels, internal combustion engines, electric motors, or hydraulic systems. In ground-driven systems, digging and planting operations are automatically synchronized with forward motion, ensuring proportional plant spacing. In motor-driven systems, gear trains, chains, belts, cams, or crank-linkage arrangements convert rotary motion into controlled reciprocating digging action. Proper gear ratios and transmission design are critical to maintaining depth accuracy and operational speed. Integration also involves coordination with soil covering and compaction units. After seedling placement, press wheels or soil closing mechanisms must operate immediately to secure the plant in position. The timing sequence typically follows a cyclic pattern: digging → seedling placement → soil covering → compaction → forward movement to next position. Any delay or overlap in this sequence can reduce planting efficiency.

Advanced automated systems may incorporate sensors for depth monitoring, electronic controllers for timing adjustment, and GPS-based navigation for maintaining straight rows and uniform spacing. These technologies enhance precision but increase system complexity and cost. Therefore, the integration strategy must balance simplicity, reliability, and performance.

Overall, successful integration of the digger system with the automated transplanter ensures uniform planting depth, accurate spacing, minimal seedling damage, reduced operational errors, and higher field efficiency.

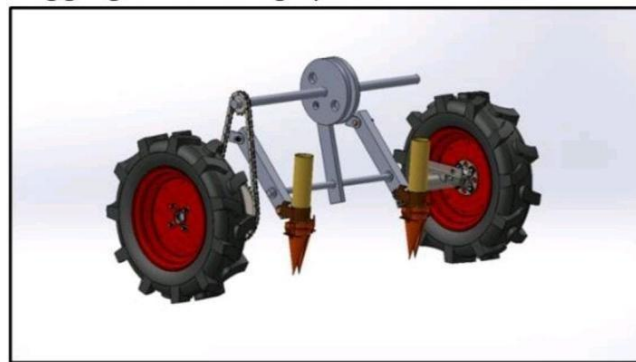


Fig:3: Digging & Planting System

VIII. CHALLENGES AND LIMITATIONS

Despite its numerous advantages, the digger system faces several technical and operational challenges that can affect its overall performance and reliability. One of the primary limitations is soil variability. Changes in soil texture, moisture content, compaction level, and presence of stones or crop residues significantly influence penetration resistance and

digging efficiency. In highly compacted or clayey soils, excessive draft force may be required, leading to higher power consumption and potential structural stress on components. Conversely, in sandy or loose soils, maintaining stable hole geometry becomes difficult due to soil collapse.

Proper calibration is another critical requirement. Depth settings, spacing adjustments, and synchronization with the planting mechanism must be accurately tuned before operation. Incorrect calibration may result in uneven planting depth, misaligned seedlings, or increased transplant shock. Frequent field adjustments may be necessary when shifting between crops or soil types, which can reduce operational convenience.

Higher initial investment compared to manual transplanting tools remains a limitation, particularly for small and marginal farmers. Although the system reduces long-term labor costs, the upfront cost of fabrication, power transmission components, and precision mechanisms may discourage adoption. Additionally, complex mechanisms such as cam-linkage or auger systems increase manufacturing and maintenance costs.

Wear and tear of digging components is another significant challenge. Since the digger directly interacts with soil, it is subjected to abrasive wear, impact loads, and cyclic stresses. Continuous operation in gritty or stony soils accelerates tool degradation, affecting digging accuracy and increasing maintenance frequency. Regular inspection, sharpening, and replacement of cutting edges are required to

IX. FUTURE SCOPE

Future development of the digger system for automated multi-vegetable transplanters is expected to focus on enhancing precision, intelligence, adaptability, and cost-effectiveness. One major advancement lies in sensor-based automatic depth control systems that can continuously monitor soil surface level and adjust digging depth in real time. The integration of proximity sensors, ultrasonic sensors, or load sensors can help maintain uniform penetration even under uneven field conditions, thereby improving planting consistency.

Artificial Intelligence (AI) and machine vision technologies may be incorporated to enable crop recognition and adaptive planting control. AI-based systems can identify seedling size variations and automatically adjust hole depth and spacing accordingly.

GPS-based autonomous navigation and real-time kinematic (RTK) positioning systems can enhance row alignment, spacing uniformity, and field efficiency. Autonomous operation reduces operator dependency and ensures straight-line planting with minimal overlap or missed areas. Integration with Geographic Information Systems (GIS) can further enable precision farming practices by optimizing planting patterns based on soil maps and fertility zones.

Structural advancements may include the use of lightweight, high-strength materials such as advanced alloys or composite materials to reduce machine weight while maintaining durability. Reduced weight decreases soil compaction and energy consumption, improving sustainability. Modular design concepts may allow easy replacement or upgrading of digging units for different crops or soil types.

Energy-efficient drive systems, including electric or hybrid power units, can reduce fuel consumption and environmental impact. Integration with IoT platforms will enable remote monitoring of operational parameters such as digging depth, field capacity, power usage, and maintenance alerts. Cloud-based data storage and analytics can help farmers make informed decisions and optimize transplanting operations.

Future research may also focus on adaptive digging geometry, self-sharpening cutting edges, improved wear-resistant coatings, and automated self-cleaning mechanisms to prevent soil clogging. Cost optimization strategies, including simplified manufacturing processes and standardized components, will be essential to increase adoption among small and medium-scale farmers.

Overall, the future scope of digger system development lies in combining mechanical precision with smart automation technologies to achieve higher efficiency, lower operational cost, improved sustainability, and enhanced productivity in vegetable transplanting operations.

X. CONCLUSION

The digger system is a fundamental component of an automated multi-vegetable transplanter, as it directly influences planting accuracy, soil preparation quality, and overall crop establishment. Its proper design ensures uniform hole formation, consistent depth control, minimal soil disturbance, and precise synchronization with seedling placement mechanisms. These factors collectively improve root development, plant survival rate, crop uniformity, and final yield. An efficiently designed digger system not only enhances operational precision but also reduces labor dependency, production time, and long-term cultivation costs.

For modern agriculture, particularly in regions dominated by small and medium-scale farmers, the development of an adaptable, durable, and economically viable digger system is essential. Adjustable depth and spacing mechanisms allow multi-crop compatibility, increasing machine versatility and return on investment. Robust structural design, optimized tool geometry, and appropriate material selection improve wear resistance and service life under diverse soil conditions. Efficient power transmission and minimized draft force contribute to reduced energy consumption and better field efficiency.

Furthermore, integration with automated planting, soil covering, and mobility systems ensures smooth and continuous transplanting operations. As agricultural mechanization advances, combining mechanical reliability with intelligent control systems will further enhance system performance. Innovations in sensor integration, lightweight materials, modular design, and smart monitoring technologies will strengthen the role of digger systems in precision farming. In conclusion, the continuous improvement of digger system design is crucial for advancing automated vegetable transplanting technology. A well-engineered digger system not only improves productivity and sustainability but also supports the broader objective of modernizing agriculture through efficient, affordable, and scalable mechanized solutions.

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