



Use of Agricultural Machinery in Vegetable Crops: A Review

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Abstract

Agricultural production is one of the fundamental pillars of every country in order to provide food security for its population. Therefore, the use of agricultural machinery and equipment plays a key role in significantly increasing agricultural production. The significant development of agricultural mechanization in countries around the world has contributed to the widespread use of this mechanization in all aspects of the agricultural sector, including vegetable crops. Vegetable crops are widely grown and used around the world due to their important nutritional benefits, as they contain all nutrients, especially minerals, vitamins, and fiber, in addition to high water content.

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1. Introduction

Vegetables are one of the important crops in human livelihood. The vegetable area is about 21.7 million hectares (ha), and the production is about 892 million tons, which accounts for 19.3% of total food grain production in the world. In Ethiopia, vegetables are grown under various climatic conditions and altitudinal ranges. Vegetables play an important role in the economy and nutrition of rural and urban communities in Ethiopia. However, most of the production is traditional and with low input. Agricultural mechanization plays a key role in the development of agriculture to achieve food security, improve regional and household incomes, create employment opportunities, and promote rural development. Mechanization is also indispensable for efficient farm management as it empowers farmers to optimize the potentialities of other inputs (Ram, 2023) ^[60] (Milkias & Degefu, 2024) ^[46]. The extent of mechanization, particularly in less developed agriculture, is weak in tooling (and implements), coupled with agricultural machinery. In agricultural engineering research and outreach, the use of agriculture is poorly documented in general and vegetable crops in particular. Collection of such information is essential for planning Research and Development (R&D) projects, evaluating the existing research facilities against the research needs, and improving outreach strategy (Mavridou *et al.*, 2019) ^[45]. Agricultural machinery is any kind of machinery used on a farm (including farms from industrial to small-holding to supply the bulk of food and fibre). Farm machinery includes any kind of machine, tool, or implement, as well as irrigation and power supply equipment, used in raising agricultural products (including tillers, planters, cultivators, harvesters, and sprayers). Farming equipment can be categorized based on the establishment purposes (pre-crop preparation, planting, intercultural practice, harvesting, and postharvest) or the types of farm implements (tillage, seeding, and plant protection). Production and use of agricultural machinery (both tractors and power-operated agri-implements) is generally considered as an indicator of agricultural development. For mechanization as a whole to lead to increases in productivity, increased use of machinery or adoption of improved implements and methods must precede. Farm mechanization includes the use of machinery and equipment (operated by engine power or animal power or human power) directly or indirectly to carry out farm operations in agriculture and horticulture. The successful farm mechanization would result in reduced drudgery, decreased establishment costs, increase establishment of timeliness, increased income, reduced production losses, reduced cultivable area, water saving, mostly and less intensively crop establishment, and increased weed residue input to soil (Nosov *et al.* 2022) ^[51] (Puška *et al.* 2022) ^[56] (Asadullin *et al.* 2021) ^[4].

2. Importance of Agricultural Machinery

The use of small machines for cultivation is important in the growing field of horticulture. The production of specialty crops or the practice of horticulture differs greatly from the production of vegetable crops in irrigated and semi-arid regions. There is vast scope for the introduction of new machines or modifications to existing machines to make them suitable for growing crops under various conditions. For this aspect, research on machines produced by the commercial sector is limited on invention, design, development, and evaluation. In countries such as India, even though a variety of machines are produced and partially utilized in agriculture, the mechanization of horticultural crops is still at a nascent stage. Further, much research is needed justifying the basic concepts of commercial or indigenous machines available for horticultural crops under various growing conditions. (Satisha 2023)^[65] (Yadav *et al.* 2024)^[87] (Jha *et al.* 2022)^[31]. The introduction of large machines either manufactured locally or imported from developed countries in horticulture sometimes does not satisfy the needs of the growers. The result is sporadic failure in the total mechanization concept plus high costs in its purchase, operation, and maintenance. Standardization of essential practices and field layout should receive due consideration from research units dealing with machinery. The knowledge of the situation in agriculture in various parts of the country is a prerequisite before a mechanization program is drawn up. (Giller *et al.* 2021)^[22] (Wang *et al.*, 2021)^[83] (Liao *et al.*, 2022)^[38].

Engineering Research Institutions were started in India around nineteen fifty for the development of agricultural machinery and small farm tools for the benefit of the farming community. These institutions possibly have performed well in the transformation of large farms but mechanization of small landholders may be as an essential instrument of change. The recent pronouncement from higher authorities of the agricultural departments that “dark ages of sowing and planting by hand have gone” reflects perhaps the reality as well as the hope in agricultural mechanization. In this connection, additional needs of the farming community may now be to: (Jha *et al.* 2022)^[31] (Mangaraj *et al.*, 2022)^[42] (Krishna)

1. Produce larger number of machines as against the small number of massive machines.
2. Reduce the size and costs of machines by utilizing their labor-saving technology for small farms but in an affordable price range.
3. Produce somewhat different machines for each particular aspect of sowing/planting.
4. Contribute to the development of a comprehensive inventory of which would include both powered and human-powered machines with key statistics.
5. Produce machines that minimize the use of chemical weed and pest control.
6. Transform this whole idea of mechanization into workable plan formulated in conjunction with other disciplines. In view of the above, a broad classification of machines is presented along with their products and specifications. (Kudelina *et al.* 2021)^[36] (Weng *et al.* 2022)^[83].

3. Types of Agricultural Machinery

The stage of preparing and seeding of catching crops is mostly the same as with any cereal crops, except no herbicides is applied (Mavridou *et al.*, 2019)^[45]. It can go

down to 3 cm, taking care above roughest stones or twist corn rows on hard soils in spring. This is also the limit of seed depth in clayish soils. Working too deep will collapse minitables which are meant to protect the corn against dry out. It is important that the seeder has to be prepared for catching maize, therefore the spacing and the outriggers have to adjusted to 25 or 32 rows with an inter-row spacing of 70 cm or 75 cm respectively. Newly built catchers and safety cover for the pick mechanical was fitted in the seeder. The top of the pick head was also covered with HID lighting. The old cycloid motors for the picks had be renewed and replaced with new indexed ones (R. Aravind *et al.*, 2017)^[58]. The seeder with catching system was prepared and its front cover and lighting were installed and adjusted at the headland at the proper height. Drills can operate underneath a cover, while it is stowed above when it is operating (such as during the catch for beet). There is no filtering extractor above the feed space to take away dirt and herbs, only a lid is installed in the centre between the hoppers to cover the cup-plate elevators. (Hobbs, 2021)^[26] (Wallander *et al.*, 2021)^[79].

A tappet is engaged with the other shaft to remove accumulated dirt and herb from the bottom chutes and the cups and because of the angle of the slot it can get to a place before the cup. Drills how to make it in one part and provided with six small angles upwards. Dusting system is only working concerning the seeder as a whole. The whole seeder chassis, all the frames and the frames' tops were galvanised to avoid rusting. A new eight-rowed seeder for bean and another 1.5 m wide for maize were prepared. For the catching system dust or glittering cannot be used later in the season, otherwise, no herbicide will adhere to the seed. Catching system does not have operational height (they catch from below not above). V- and netted meshes were prepared and mounted for conditions of catching beans and maize. A 1 ton weight additional spring was equipped for obtaining proper transport performance. After summer, these modifications were carried out. (Keneni *et al.*, 2021)^[33] (HOFFMANN *et al.*).

3.1. Tractors

Agriculture requires tractors for field operations. Tractors have been a major contributor to the expansion of agricultural purview for more than 100 years. Tractors are now widely utilized as agricultural machinery in various countries. The Indiana farmer's 4200 H.P. tractor makes it one of the largest tractor sellers in the state. Since the establishment of the first tractor factory at Czechoslovakia in 1840, the tractor industry has undergone tremendous development across the world. Difficulties with transportation, damaged crops, and labor shortages were the primary reasons for its development and use. To maximize the cost advantage and minimize trampling, greater efforts have been made to build power tillers and implement smaller tillage machines for one- to two-manned tractor-drawn tillage. (Vorozhtsov *et al.* 2022)^[78] (Mocera *et al.*, 2023)^[47].

The most basic farm engine is the tractor. Modern large tractors have engines from 150 to 580 horsepower, and large agricultural manufacturers produce them in the Kent Area. Tractors are provided with power take-off gears (PTO gear) that allow them to attach equipment from balers to ditchers to front-end loaders. In the era of mechanized agriculture, tractors play a prominent role in a multitude of activities, kicking off the agricultural calendar by clearing and preparing the land, including soil tillage, planting,

fertilization, spraying activity, harvesting, and farm transport. Tractors, used alone or in conjunction with multiple types of machines, perform various tasks in the field. Tractors pull some machines (plowing while harrowing), while others are powered by them (spraying and harvesting). Under capital constraints, farmers tend to optimize their tractors rather than machines, and as a result, tractor resources are underused in terms of total machine-hours applied per year. Besides their rotation among different farms and different pieces of work, tractors are idle at the farm level for 42% of the time (Sahay *et al.*, 2017)^[63]. (Varani *et al.* 2022)^[77] (Angelucci & Mattetti, 2024)^[33].

3.2. Plows

Land preparation aims to create land that is suitable for planting, one of which is to prepare soil. In this case, in Indonesia, land preparation uses agricultural machinery and tools to meet the needs of agriculture. Preparation of the paddy field's land is prepared through at least three stages, depending on the power tool that is used. First stage is padded and plank. Soil humidity on paddy fields should be at a depth of ± 5 cm so that the paddy fields are ready to be ploughed. Fertility of the soil needs to be maintained so that it can still grow. Use of seeds needs to be mechanized in rows and regularly to facilitate the dispersion of fertilizer. Fertilizer needs to be mechanized to make it even. Fertilizer needs to be rowed by using the harrow and repeat it by using draught animals plough to loosen it up (Sutjana & Nyoman Adiputra, 2012)^[75].

The aim of this research is to compare the rice fields of land preparation by using agricultural machinery; plough, tractor, and cultivator. Side of the research is to find out the simpler and better way between plough, tractor, and cultivator that could be used effectively to prepare the land for rice planting. Everyone knows that preplanting is important in rice cultivation where the land preparation is the pretraining process before planting rice, which is very important to create land that is suitable for planting, so that the water management is easier. (MAIRGHANY *et al.*, 2022)^[41] (Rattanacharoen and Yamada 2021)^[61]

Tractor as a result of the development of science and technology, has positive and negative effects; on the positive side it can minimize the loss of time and labor in the field, while on the negative side the land gets damaged, and the people's traditional way of life has been changed, and the land was no longer fertile because most of them were used for planting paddy and sugar cane. To improve the effectiveness of soil processing by ploughing, shovelable tractor and tractor draw are commonly used in land preparation. (Gürsoy, 2021)^[25] (Umar *et al.*, 2021)^[76].

3.3. Seeders

Seeders are the machines designed to sow seeds in the soil evenly and accurately at pre-defined time. Generally, there are two types of seeders mechanical and pneumatic based on world standards. There should be a clear set of criteria to categorize seeding machines, which is defined in the national standards. The mechanical (also called as dry seeder) consists of seed drill, dibbler and planters whereas pneumatic type (also called as wet seeder) consists of air seeder, sugarcane planter, eagle eye/ seed dibblers and various multi-crop planters. In general, the seeder is categorized as (i) seeder for vegetable planting, (ii) tobacco seeders, (iii) rice and sugarcane seeders, (iv) broad-acre oilseed seeders and open

drill, (v) disc and double disk seeder (vi) furrow openers. In Australia generally, mechanical type of seeders or agronomists with at least 100 mm frame height for broadacre seeding of deep sowing crops like sorghum or cotton. Perfect frontal and rear ballast on the seeders enhance the planting depth or diffusion of 'Pre-emergent' chemicals. Soils with inherently high self-mulching texture and good cation exchange capacities such as Vertosols (with 35-70% clay), must receive sequestration as sand-sized aggregates and sub-unit yield zone attributes (A) High-fall, low-residual pH of 6.5 to 7; and (B) 2 to 7 mm size, smooth surfaced, silver fiesta quartz sand-coated particles that resist granulometric dispersion. On such soils, only minimum tillage is feasible or could possibly enhance profitability (Manpreet-Singh *et al.*, 2024)^[43]. (Xing *et al.* 2021)^[86] (Astanakulov *et al.* 2021)^[15].

3.4. Harvesters

Farmers can use combine harvesting, which can cut, thresh, and clean up soybean and other crops simultaneously and quickly. Some manufacturers create these harvesters, combining soybean and corn, in twin-row availability, which helps farmers be competitive. Most companies are currently working on innovations to enhance the harvesting experience, with some already introducing machines with a self-demo system for harvester adjustments (Sahay *et al.*, 2017)^[63]. These combine harvesters save approximately 80% of labor effort. For manual harvesting of beans, 2-3 workers are required to harvest an acre in 15-16 hours. However, these combine harvesters have increased productivity, wherein a 10-14 hours legume operations can be done with a minimum of 20-25 laborers. Since harvesting is done without much insect infestation and birds get little chance to consume the crop when cut away from the stem, bean harvesting losses are reduced with these harvesters conveying thresher cleaner through which the harvested crop is clean. Around 25-30% incidental crop is saved. (Nath *et al.* 2022)^[49] (Baur & Iles, 2023)^[6].

Vegetable harvesters, which cut, convey, and neatly stack crops in the bin, are not currently available on the market, but some small units are presently suitable for some vegetables like cabbage, potatoes, and carrots. A self-propelled, multi-vegetable harvester can harvest various vegetables and has made the harvesting task easier. These harvesters are used extensively for cucumber, cauliflower, and french beans. After arranging these crops into rows, these machines can harvest a 2-row stacked crop within a minute. From a single-row crop to a finished vegetable locker, these harvesters require 50-60 seconds for the harvesting process. They are capable of lifting & handling 1.25-1.5 tons of vegetables in one go. The demanded 450-600 kg net harvesters require a 24-35 HP tractor and consume 2-3 liters of diesel. The productivity of these machines reaches 10-12 acres or 4-5-hectare vegetable fields while yielding around 2700-3000 vehicles per harvest machine. (Hordiienko & Mozgovska, 2021)^[29] (Zakir *et al.* 2023)^[89].

3.5. Sprayers

For high quality crop protection, the quantity of liquid per hectare (l/ha) must be determined. This depends on the topography of terrain, density and distribution of plant, the choice of equipment. It is assumed that appropriate amounts of liquid were used as an optimum quantity for a long period of time. The measurements of this index on maize, sunflower and sorghum crops showed that insufficient or excess liquid

per hectare resulted in poor crop protection against weeds, pests and pathogens. Therefore, it has been considered that an optimum index of l/ha must vary narrow limits. For suitable vegetable crops ranging from 500 to 900 l/ha, the actual result are lower than the optimum (150 to 650 l/ha). Also the result generally exceeded the optimum dose for lettuce, tomato, bulbs, onion and brassicae varieties (950 to 1150 l/ha). Spraying conditions were evaluated through an assessment index of conditions and localized investigations of local sprayers for developing a sprayer with an adjustable atomization system. Analyzing the over-dose coatings, it was determined that during summer, nozzles with a lower order of interception sprayer must be placed on the upper half of the spray bar to achieve an optimum volume coverage. Different protective agents were tested for effectiveness against the Romanian striped bee. It was observed that on pretreatments, in the laboratory conditions the honeybee mortality was higher between 0.5 and 8 hours. The direct impact on combs, which can be considered a selection criterion for the environmental contamination, showed that no insecticides were detected in addicted hives exposed immediately after spraying. Although sprayers consider net technical works hours, during the vegetative period it was noted that the standard works hours must be lower than this. Also the number of works hours was found to be mainly affected by the used number of nozzles per sprayers, one of the most important element for reducing pollution being to reduce the norm of liquid per hectare, so generalizing treatments with low and ultra low volume too (Nitu (Rosu) *et al.*, 2016)^[50]. (Chibsa *et al.*, 2025)^[11] (Radwan *et al.* 2025)^[59] (de *et al.* 2023) (Pushpalatha & Gangadharan, 2024)^[55].

4. Mechanization in Vegetable Crop Production

Agricultural mechanization is considered all sorts of instruments and machines that are used during crop production. Mechanization is a critical process technique used for applied and effectively using the machines. Mechanization is the system's replacement of human power by using conventional and manual power by mechanical equipment or engines in either the form of dwarf engines or tractor draw a unit for the multiple crops. Mechanization is positively correlated with productivity. In low and minimum mechanization countries/areas, the use of technology and mechanization resulted in the maximum employment opportunity, but poor productivity obtained. In the variation of size and resource endowment in vegetable type crop production, vegetable crop production is in a high grade of labor-intensive agriculture production system even in abroad or in India. The tractor-power having 35hp is used a more number on this crop cultivation and makes to all the tillage operation effectively. Rented tractor lengthier in operation helped to grow the vegetable crops in a responsible time. More tractor made time variation on the same tilling production and effective way of cultural operation. (Bello *et al.* 2021)^[8] (Peng *et al.*, 2022)^[53].

Vegetable crop production is an agronomic practice that provides required food and nutrition along with a source of employment generation. The present study deals with a design and development of a prototype machine for seedling production. This is a lab prototype machine with conveyors being used for seeding tomato seeds in a 280 X 420 X 220 mm PVC polycontainers filled with soil. The CWT and fender are mounted with 168 mm diameter gear motor (175 RPM). The slotted belt conveyor is assigned for seed feeding

and seeding on a container belt conveyor. The belt conveyor is powered by 59 mm snood gear motor and PMS201R DC motor controller. The 30:1 ratio gear and sprocket mechanism are used for toggling movement with the limit switch for stopping toggle operation. (de *et al.* 2022) (Soomro *et al.*, 2021)^[74] (Peruzzi *et al.*, 2023)^[54].

However, mechanical exhausting and human labor shortage are under the consideration and a proper usable technique and mechanism. Presently, a rosette type seedling tray filling machine was developed and by using of belt conveyor and truncated catapult mechanism. This machine is useful for transferring and dropping filled soil or cocopeat based seedling trays either in polyolefin or regular tray size. Productivity (3060 slabs/hour) and suitable for 250 g cocopeat/briquettes with 1.5 HP motor capacity for mass production. Automatic filling of polyolefin seedling trays of multiple holes are in separate, cylindrical and rectangular shares are also obtained using the dual working principle for stopped filling and transport conveying features (R. Aravind *et al.*, 2017)^[58].

5. Benefits of Using Machinery in Vegetable Cultivation

The production and cultivation of vegetables has been hampered due to the limited involvement of mechanization in vegetable production. Research on the use of machinery in manpower poor regions has resulted in specific machines becoming economically feasible. Promotion of small low cost machines has greater immediate potential benefits than large high capacity machines. Vegetable crops can also be cultivated using power seeders, inter-cultivators, sprayers, and harvester-cum-grader machines. Economically viable machineries are flushed out to facilitate the year round cultivation of low volume high value vegetable crops. Cultivation of vegetable crops has been mechanized through three broad approaches: direct use of existing machines, development of low cost machines, and adaptation of imported machines. Machines for soil preparation, sowing, intercultural operations and harvesting are designed for hill areas, while power sprayers are beneficial for the entire state (Wang *et al.*, 2023)^[82]. Commercial vegetable production is closely related to the environmental and economic developments of the modern world. Mechanization is one of the approaches to enhance productivity of vegetables across the globe. For the proper implementation of agricultural mechanization at farm level, a matching between the land condition and farming system on the one hand, and the machinery technologies on the other hand is required. Small and marginal farmers cultivation profile may be out of reach of agricultural machinery manufacturers, as their fields are of small size and present in scattered form. Consequently, farmers have to go back to traditional tools and/or manual practices, resulting in higher cost of cultivation. Mechanization is an essential element to reduce the dependability on labours who are either diminishing in number or becoming more expensive. Generally, production of 10 tons of vegetables necessitates 150 man-hire hours under mechanical practices, while it goes up to 950 hours in the case of traditional tools including manual practices. (Gavgani *et al.* 2022)^[20] (Yang & Li, 2023)^[88] (Razu *et al.*, 2025)^[62] (Chukwunweike *et al.* 2024)^[12].

5.1. Increased Efficiency

Agricultural growth has been largely impacted by agricultural machinery technology. With increased land production,

increased efficiency, reduced labour requirement research has been done to ascertain the various machinery contributing to it. Simple and advanced agricultural machinery with modern technology like crop cultivation machines can help in farm productivity suitable to the climatic conditions of the area. This paper compiled all the information about agricultural machinery being used in the production of vegetables like planting, harvesting, weeding, spraying, tillage, and other post harvest operations adopting in various countries, researchers, and institutions. Mechanization is simply utilizing machines such as tractors, harvesters, sprinkler irrigation, potato diggers, and various other motorized vehicles (Sarkar *et al.*, 2021)^[64]. Mechanization is a vigorous support for agriculture in developed countries. Gridlock in labour supply, increased wage rates, farmer interest for enhancement and alternative systems, societal movement for labour rights, increasing land holdings, and global demand have changed the agriculture scene in developing and developed countries. Investment in machinery among farmers is increasing but still lower than countries such as United States of America, Japan and Western Europe. Search by farmers for machines with new capabilities in variable field conditions is reflecting interest in mechanization assisted agriculture. Total mechanization will be a daunting task; however, various levels of mechanization for diverse land types, size and cropping patterns will be a pragmatic effort for farm power supply. In lieu of these farm machinery and its inaugural estimation can help research community and policy makers for future initiatives and stakeholders for improvement in farm performance. (Wang *et al.* 2022)^[83] (Elbasi *et al.* 2022)^[17] (Soltani Firouz & Sardari, 2022)^[73].

5.2. Cost-Effectiveness

Agricultural tractors and machines were used for the preparation of land, fertilization, sowing, irrigation, harvesting, and selling/moving on yard and markets in a relay, using a great part of time for their optimum performance and they consume a great part of total cost (63.57%) in average under all tractor and machine owned were ready for work) in vegetable crops production under the existing problems in Aksum and surrounding. Maintenance/administration, repairing, tear and wear, fuel, lubricants/oils and land fees costs were the most expenses (maximum 93.34%). Cost analysis was shown that these expenses were increased along with job demand (hired) tractors and machines (O. Heady & D. Krenz, 2017)^[52]. It was concluded that in this area price reduction on fuel, oils and parts as well as education on tractors and machine maintenance will lower the total operational cost. In areas where tractor irrigation is to be applied for very important vegetable crops, gradually intensively tractor use with graduated subsidy systems from minimum to maximum allowances without serious operation problems should be given priority. There should be continuous special courses for training operators using tractors and machines having operation problems in all vegetable production. Some circuits should be constructed to form groups of vegetables producers which tractor/s and machine/s own in common in order to focus on education and lower total operational costs. Finally, especially up to 2000-ha vegetable production, markets should be founded to collect vegetable products to lower lot price with a customer sale guarantee. (Beligoj *et al.* 2022)^[7] (Ghobadpour *et al.* 2022)^[21].

As this machine was lighter, it could only be used for low-power and low-cost jigs. It couldn't substitute excavator and loader. The jiggings of this model were kept between eight and twelve number, easily covered with net or cord during moving. The machine is able to sift, separate different vegetable product, size and shape. It is adaptable for any soil and water irrigation systems. It is also distinguished by low upkeep cost, friendly work with operators, simple designs and structures. After production cost benefits appear, purchasing profits are predicted to develop positively for farmers. Customers will have improved working standards and quality of vegetables. This economic model is predicted to stimulate farmers to buy machines late and for bigger production areas. Further, similar models should be produced for separating soil from stones, specialists jigs for early vegetable crops. Last, in for selling of American science and technology, this model would be introduced in cooperation with Russian models and invited as consultant to Asia and the Middle East countries in vegetable products processing. (Xiao *et al.*, 2023)^[85] (Bhargava *et al.*, 2022)^[9] (Soltani Firouz & Sardari, 2022)^[73].

5.3. Labor Reduction

Worldwide, machine transplanting of vegetables is established, and hence, it is called Smart Agriculture. In India, it was only potato transplanters that were available in the late 1990s. Research and development took place regarding rice transplanters for Andhra Pradesh, West Bengal, and Tamil Nadu. Adaptation of sugarcane inter-row and hand tractors for threshing of vegetables was also initiated. Subsequently, the prototype of a semi-automatic vegetable planter was developed to transplant brinjal, chilli, and tomato on terrace farms. Strip tillage and auto-operated drip irrigation systems were developed and practiced in mid hills for horticultural crops by providing manufacturers technical inputs. NH-40 type ridger-planters were developed for sweet corn and paddy transplanting. As discussed in the previous chapter, there are different sugarcane processing cane harvesters and crushers of different makes and capacity. Pre-shredders are also being tried on Allahabad bhura. Different sugarcane planter excavators were designed, developed, and demonstrated to the farmers during the last decade. All the sugarcane reapers being developed in U.P. are used at the time of retirement of plants. However, one decade back HI-12, 4 row high capacity reaper of Punjab was brought to U.P. and demonstrated at S.D. Sugar, Shahjahanpur. (Khadatkar *et al.* 2021) (Sharma *et al.* 2022)^[69]

Under smallholder condition, direct seed incorporated-drip irrigation is promoted by the government. Farm machinery is developed and demonstrated under various schemes viz., Integrated Farming System for Holistic Development of Hill Areas Programme, Technology demonstration and transfer Programme on Value Addition, Agriculture Marketing Development Scheme, and essential interventions for enhancing productivity through Horticulture. To promote site-specific farm mechanization under the Convergence Programme, the government signed a memorandum of understanding (MOU) with two peak industry representatives. This is implemented in a public-private destination mode. Agrid machinery for vegetable crops is available from various manufacturers. Having reviewed past development efforts on farm machinery, it can be said that (Sharma & Khar, 2024)^[68] intervention in R&D in grower

desirables, sanitation of farm machinery for Malaysian conditions, built-in equipment for exact planting depth and transplanting speed, potato and vegetable seeders using disc mechanism for soft seed, spraying mechanism for horticultural crop spraying, improved skid steer portable drones, compost tea producer, tractor drawn sprayer for seed treatment, harvesting machine for mulched tomato and brassica, post-harvest machinery prospective around by the year 2030. (Hoque *et al.* 2025) ^[28].

5.4. Improved Crop Yields

Technological advancement is increasingly being adopted in agriculture sector for safer agriculture process with smooth operation. As it pertains to the production of vegetable crops, it is a group of crops grown utilizing more human labour than the mechanical one. The present review attempts to the use of agricultural machinery specifically for the production of vegetable crops starting with land preparation for tilling where plough, harrow, rotovator, cultural plough, ditcher, ridge maker, weeder and puddler are widely used. Primarily two types of vegetable planting on flat and ridge types are followed through paddy transplanter, drum seeders, impulse seeders, chain seeders, onion seeder, string seeder etc. For inter-cultivation of vegetable crops weeders, herbicides and plastic mulch are applied. For harvesting different types of tools & machines are used. Post-harvest machinery continued with thresher, sprayer and diesel engine. Malabar green variety of chauli popularly regarded as green gram is one of the important rainfed vegetables in India. In T1 treatment, weeding at 15 DAG within the crop row manually resulted in significantly ($p \leq 0.05$) highest seed yield (455.73 kg ha⁻¹) and heaped yield (661.16kg ha⁻¹) of green gram with lower weed density (7.67 m⁻¹) and index (22.92%) (Sarkar *et al.*, 2021) ^[64]. Research and farmers' field data on use of agricultural machinery in vegetable crop production throughout the world and especially in India has been presented. In India, scientific data base has been generated but not collected comprehensively and/or synthesized into a book dealing mostly with machine designs. Literature on vegetable seed production and nursery management is scanty and presented in few book chapters and articles in other general books. Hence realization of this treatise to the interest of wide readership among agricultural engineering and related disciplines. (Wang *et al.*, 2022) ^[83].

6. Case Studies on Machinery Use in Vegetable Crops

Case study on transplanters in tomato crop shows the survey based on ignorance of farmers about "transplanters". The people having large land holding (more than 3r) are of the opinion about use of transplanters but don't have any knowledge about it. (Sharma & Khar, 2024) ^[68] designed a semi automatic tractor mounted transplanter. The rig consists of 54V/100W permanent magnet DC motors, a suitable drive to rotational speed reduction of seedling trays with respect to wheel speed. The design and construction of a low-cost hand operated vegetable transplanter was developed. The machine was fabricated from easily available local materials and assembled to allow transplanting on flatbeds. The different parts of the machine were designed as per standard engineering formulae (Mavridou *et al.*, 2019) ^[45]. The foreign machinery is not suitable for Indian conditions due to high cost. So the agricultural training institutes and agricultural engineering departments should take the initiative for needed type of equipment for local conditions. The Residency in a

landlocked continent that is bordered by the Indian Ocean to the west and south and the Sahara desert to which it is emerging and developed are termed as developing countries. The semi-automated devolving and developed nation in agriculture to improve food production and consumption. This paper review is mainly focused on farmers and policy maker about agricultural machinery for vegetable crops in developing and underdeveloped countries which are reviewed in thorough gathering and collection of information for immediate action. (Kundu *et al.* 2021) ^[37] (Shivaprakash *et al.* 2022) ^[72].

7. Sustainability Considerations

Sustainability considerations focus on the impact of agricultural machinery propagation on climate change, biodiversity, soil health, and farmer livelihoods. There is a growing awareness that agricultural machinery propagation should not lead to negative consequences for any of these factors. More sustainable propagation pathways ensure that generational costs and benefits are balanced (Fischer *et al.*, 2018) ^[19]. For resilience, agricultural machinery is often a remedy but can also be a destabilizing factor. Preventive measures are necessary to enable short- and long-term resistance against unexpected shocks like a war or a pandemic. The transition towards the sustainability of agricultural machinery is analyzed and illustrated on two levels. Firstly, it is necessary to enable the five aspects of sustainability: climate, biodiversity, soil health, and farmer livelihoods. A case study highlights the rather complex interusability of the five aspects of sustainability in the ongoing transition. Secondly, the need for both incremental and radical changes in the propagation of agricultural machinery towards sustainable pathways is emphasized. Having defined a number of key questions or basic conditions, a comprehensive empirical assessment framework is proposed through the carbohydrates-based Agroecological Agriculture. This provides the basis for empirically describing and assessing the sustainability of the propagation of agricultural machinery in various contexts (Wang *et al.*, 2023) ^[82]. It is expected that the level of specificity can evolve over time. In grounding the sustainability considerations in specific empirical contexts, one may also discover issues or aspects of relevance that are not yet represented in the mentioned assessments and questions. It is contemplated that this ongoing case study effort provides inspiration for other regions, countries, or farmer communities around the world. (Bielykh, 2025) ^[10] (Liu *et al.*, 2023) ^[39].

7.1. Environmental Impact

Agricultural machinery is composed of physical assets which are used largely for the agricultural production of raw materials and food products. The direct advantages of using agricultural machinery are labor, time, and cost saving (Ma *et al.*, 2023). In addition to this, accurate processing and long-term working are some more advantages of agricultural machinery use. Furthermore, agricultural machinery has enabled timely execution of agricultural operations, proper inputs application, and soil conservation which favors crop growth. With the increasing plant population density, higher productivity and pest management options even for the challenging tropical climate are required. Additionally, labor constraints due to urbanization and foreign migration are making agricultural production costlier. Hence, universal

adoption and promotion of farm mechanization is important for efficient input application and crop yield index for different climates, especially for the northern region of India. (Liao *et al.*, 2022)^[38] (Mohammed *et al.* 2023)^[48].

Vegetable crops play an important role in the nutrition of human beings and earn more foreign currency than cereals. The crop yield is largely dependent on the growth and health of the plants. As a result crop husbandry practices such as proper crop sowing, intercultural operations, application of nutrients and agrochemicals, harvesting and post-harvest operations have to be carried out. In order to achieve this in an efficient and timely manner, use of agricultural implements is important. The implements used for the cultivation of vegetables can be broadly classified as sowing, tillage, planting, intercultural, harvesting and post-harvest machinery. However, not much attention has been paid to regulate and standardize the vegetable crop machinery. (Abdunazarov & Imomqulov, 2023)^[11] (Ahmed *et al.* 2024)^[2].

7.2. Soil Health

Soil health plays an important role in determining the sustainability of agriculture. Management practices including cover cropping, equipment repair, compost application, crop rotations and soil amendments are all reported to have a direct positive impact on soil health or functional capacity. However, many of these recommended practices are impractical for nitrosol microbial communities because compost restoration can take several years and equipment repair is very costly and time-consuming (Wang *et al.*, 2023)^[82]. Modified sprays, a fast-acting soil treatments based on biodecupacation and acetylene, do lead to significant soil health improvement, and the health is retained for more than 2 weeks after application. They are constructed in a simple manner and have potential for on-farm use where dried conditions are reported. Specific goals for continued research focus on how to improve the longevity of the carbon source and enzyme solution. Further attention is also warranted on pathogen and weed seed detection from soil as such studies could reduce pre-planting input costs. (Crystal-Ornelas *et al.* 2021)^[13] (Farmaha *et al.* 2022)^[18].

Remote sensing is a better tool for field operations of soil health assessment. In precision agriculture, hand-helds, drones and satellite imaging tools are widely reported for their cost-efficiency in mapping soil texture, moisture, compaction and fertility. Instead of trying to measure microbiomes in the lab, transfer methods are better suited for nD extraction in measuring soil microbial communities at project scale. Such estimations have strong impact on policy and practice while technologies based on bio-remediation need at least 10-20 years to have field tested and approved by regulatory authorities. Basal characterization of soil contamination and risk analysis has been performed previously but such input data are mainly collected from dozens of research soil samples. Despite having a potential for standard protocols to be developed for routine use, spatial distribution of agrochemical contamination needs assessment methodologies to be reviewed, modified or improved. Current challenges include balancing sampling density and geographic representation, cost minimization, and urgency. (Guo, 2021)^[24].

8. Future Trends in Agricultural Machinery

In the future, the development of agricultural machinery will focus on wear resistance, new materials, intelligent

monitoring, precision manufacturing, and green environmental protection. After decades of efforts, agricultural machinery has made significant progress and increasingly precise design, manufacturing, experimental test, and information management methods have been developed. However, issues related to durability remain to be resolved. The material and design of some matching parts are outdated and still rely on cheap low-weakness materials with low wear resistance. Furthermore, the use of lag experimental tests cannot meet the demand of efficient testing for changing design and materials (Wang *et al.*, 2023)^[82]. Therefore, tools and methods for wear prediction from the design stage are ideal, which requires theoretical analysis, experimental tests, and numerical simulations (R. Aravind *et al.*, 2017)^[58]. The mechanical characteristics of agricultural machinery, including imposed loads and boundary conditions, are complex and highly variable. It is challenging to develop general experimental setups for various machines and scenarios. Consequently, high-fidelity models involving coupled transient mechanics must be simplified or rely on robust computational resources, and powerful optimization algorithms are utilized to facilitate engineering design. However, the knowledge of wear prediction has matured in general engineering applications. The use of laboratory wear testing machines is routine and standards have been developed for metallic and non-metallic materials. Numerical models such as finite element method contact predictions and wear mapping algorithms have also been developed. Hence, it is highly demanded to develop new and rigorous wear analysis tools for agricultural engineering. Two main approaches can be considered: (1) developing new wear testing methods such as impact wear tests and new wear models aimed at farming applications, and (2) starting from rigorous wear models, inverse numerical simulations based on standard wear testing methodologies can be developed. These models will allow a deeper understanding of equipment wear in agricultural environments while also providing novel wear testing methods. (Marian & Tremmel, 2021)^[44] (Shah *et al.* 2025)^[66].

8.1. Precision Agriculture

Farm management information systems used for agricultural productivity enhancement are aided by geographical information systems, data mining, and remote sensing elections. Precision agriculture is a farming management concept based on monitoring, measuring, and responding to the variability in crops. Among the diversity of technologies that support precision agriculture, machine vision is one of the most widely implemented technologies (Mavridou *et al.*, 2019)^[45]. Providing answers to questions such as "What to do?" and "When to do it?" is essential to achieve better agricultural productivity and sustainability. Machine vision is a generic term that describes systems that perceive the environment using optical sensors such as cameras. Applications of machine vision in agriculture range from plant phenotyping to weed detection and robot system navigation. Featuring various form factors for sensing, machine vision offers an opportunity to provide automated solutions to agricultural tasks that are necessarily fulfilled by humans. The machine vision problem is mainly concerned with interpreting the data coming from optical sensors. (Shin *et al.* 2022)^[71] (Shaikh *et al.* 2022)^[67].

Machine vision offers accurate and efficient solutions that support various agricultural activities. For instance, crop

features, such as leaf number or plant geometry, are automatically measured using machine vision systems, allowing the computer-aided management of greenhouse plants. The raw data measured by a machine vision system is referred to as data per se, while the meaningful results extracted from a machine vision task are called information. The latter can be classified as descriptor, event, and performance information. Descriptors are quantitative measurements of the observed crops and the climate condition, while event and performance information semantically contains information concerning automatically detected events, maintenance actions, production plans, and fulfilment rates. Farming management information systems equipped with machine vision systems support traceability by automatically acquiring crop parameters and a vast amount of other data related to job spots, actions, and observations through attached instruments. (Qadri *et al.*2024)^[57] (Dawn *et al.*2023)^[14].

8.2. Automation and Robotics

Climate change, urbanization, the aging population, and labor shortages have increased the requirement for agricultural infrastructure, and the production of agricultural machinery proves to be expensive and underused (R. Aravind *et al.*, 2017)^[58]. As the robot industry matures, beyond autonomous navigation, the larger agriculture demand can be addressed. Ag machinery manufacturers speculate robots might evolve the way it did with tractors and combine harvester. (Gulati *et al.*2021)^[23].

Mobile robots are the primary hardware of flexible and intelligent ag machinery. Relying solely on global positioning system can be problematic, particularly in native environments with specific challenges like dust and vegetation. Recent laser pointer devices allow crop fields to be scanned for features like trees and buildings. Critical for robots performing non-cultivating tasks including capturing weeds, selling, and dormant application. Computer vision technologies classify plants and estimate their state, which allow for crop health assessment. (Jin *et al.*2021)^[32].

Hortibot is a highly flexible robot platform for in-field horticulture tasks. It consists of two subsystems, treating each as a mobile platform for the execution of tasks. Mobile robots autonomously weed carrot fields. Integration of marking, identification, and a vision-based robot control systems into weed detection and crop/weed discrimination robots. A laser weeder employing biological weed control is analyzed with its models. An automatic plastic film layer identification methods for strawberry picking robot to ensure the non-plant region is ignored by the manipulator camera. (Shi *et al.*, 2023)

The edible mushroom of king oyster is predicted to align with the increase in demand for mushrooms in Japan. Regarding mushroom agriculture, mushroom stem collection raises the difficulty with mushroom pickers mucking up mushrooms and mushroom stems. A perceiving method for automating the task of mushroom stem recognition during mushroom harvesting. (Jacob *et al.*2025)^[30].

9. Conclusion

The growth and productivity enhancement of vegetable crops are slowly moving towards mechanization, which is one of the steps toward agricultural modernization. But, in India, the effect of agricultural machinery and its appropriate working parameters on the efficiency of commercial vegetable crops

is reviewed by various researchers. Accordingly, technologies/efficiency of agricultural machinery used in the production of significant vegetable crops must be compiled for better awareness and adoption by the farmers. Intensive manual labor is generally prevalent in cultivation, harvesting, and transportation operations of vegetable crops in India. About 0.73 million skilled laborers are generally involved in seedbed preparation, transplanting, weeding, harvest processing, and packaging of vegetables cultivated in the hills of northwestern India.

Necessity for mechanization mostly arises to meet the consumption of high-priced vegetables by the urban and industrial population. Scarcity of skilled labor for transplanting and harvesting of early horticultural crops in shifting from 500 to 600 m altitude in villages surrounding market yards is also important for reducing postharvest losses which vary from 15 to 20% and depend upon the types of vegetable crops. Around 33,000 crops or agricultural machines are operating in the Punjab region cultivated in major vegetable crops like cauliflower, carrot, onion, chili, and tomato. Larger giant machines imported from Australia, Canada, the UK, and the USA are deployed in the state, but farm sizes are mostly limited to 1 ha in erstwhile 95% of marginal holdings. Therefore, the compatibility of the bought machines is often a concern. Acquisition of agricultural machinery worth crores happens without any consultation or involvement of different departments like horticulture, industries, co-operatives, and scientists has wasted millions of government funds. Likewise, similar initiatives were taken in the whole of India in order to mechanize horticultural crops without establishing any baseline information/schema prior to implementation. The full research papers on the availability, suitability, working, and efficiency of agricultural machinery suited in the paradigm of considerable vegetable crops available on the web page in southern, Midwestern, and even Himalayan states is reviewed in detail and referenced appropriately (Sahay *et al.*, 2017)^[63] (Sharma & Khar, 2024)^[68].

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