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Advances and Automation in Vegetable Cultivation

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Vegetable mechanization is becoming increasingly essential due to challenges faced by traditional manual farming methods, such as labor scarcity and inefficiency. This approach entails integrating machinery and technology to streamline various aspects of vegetable cultivation, harvesting, processing, and transportation. By reducing dependency on manual labor, mechanization offers increased efficiency, improved quality control, and the ability to scale up production to meet growing demand. However, its widespread adoption is hindered by challenges such as high initial investment costs, inadequate infrastructure, and limited awareness among farmers. Furthermore, embracing innovation beyond traditionalsoil-based methods, soilless cultivation systems are revolutionizing vegetable farming. By leveraging hydroponics, aeroponics, and aquaponics, farmers are cultivating high-quality vegetables in controlled environments, minimizing water usage, and maximizing resource efficiency. This article explores the advancements in essential operations such as transplanting, harvesting, and weeding, from innovative handheld tools to cutting-edge robotic systems.

Transplanting

There are three major types of vegetable transplantation techniques:

- Handheld vegetable transplanting
- Semi-automatic vegetable transplanting
- Robotic vegetable transplanting

a) *Handheld vegetable transplanter*

Handheld transplanters are powered by human hands and consist of a handle, hopper, seedling delivery tube or hollow pipe, jaw opening lever, and jaw mouth as major components. For transplanting, the jaw mouth penetrates the soil by applying a little force on the clutch while holding the handle. The upward movement of the clutch lever conveys the seedling into the furrow and covers it with the surrounding soil to a vertical planting depth of 2 cm, following the pushing, punching, and earthing mechanisms. A type of handheld transplanting unit developed by Sharma and Khar in 2022 is shown in Figure 1(a).

b)*Semi-automatic transplanting*

Semi-automatic vegetable transplanters consist of an engine that generates power, a transmission system that distributes the power to the driving wheel and transplanting device, a seedling cylinder where seedlings are manually placed, a transplanting device that plants the seedlings supplied from the seedling cylinder into the soil, a control section that manages the operation of the transplanter, and a plant-spacing control device. The operator manually feeds seedlings into the hopper, after which the transplanting process is automated. Tractor-drawn, semi-automatic vegetable transplanters include a seat for the worker, who loads the seedlings into the planting unit. An example of a semi-automatic robotic transplanter unit is depicted in Figure 1(b).

c) *Robotic transplanting*

Robotic vegetable transplanting represents a significant leap forward in agricultural technology. These advanced systems utilize robotics and automation to precisely plant seedlings in the field, offering unparalleled accuracy and efficiency compared to traditional methods. The robotic transplanter consists of sophisticated algorithms and robotic arms, these systems can handle delicate seedlings with care while ensuring optimal spacing and depth for optimal growth. Robotic vegetable transplanting not only streamlines the planting process but also reduces labor costs and enhances overall productivity in vegetable cultivation.

The robotic transplanting may consist of a manipulator, arm, Sensors, Control System, Vision Systems, Seedling Delivery Mechanism, grippers etc. By integrating these components, robotic transplanters offer a sophisticated solution for automating the transplanting process in vegetable cultivation. Khadatkar et al. 2023 designed and developed a robotic transplanter (figure 1c) for plug-type seedlings and reported impressive results from their study, indicating a seedling success rate of 95.1% alongside a leakage rate of 7.6%. Moreover, their findings revealed a remarkable transplanting efficiency of 90.3%.

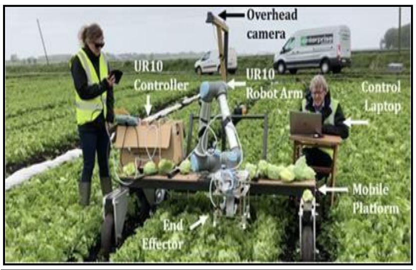
Robotic harvester

Robotic harvesting stands as a prominent component mecha-nization in vegetable cultivation.

a) b) c)

A picture of a) Hand-held vegetable seedlings transplanter, b) Semi-automatic transplanters, c) Robotic system for transplanting.

Advanced robots are equipped with sensors capable of identifying ripe vegetables and employing gentle grippers or cutting mechanisms for precise harvesting. This technology not only reduces reliance on manual labor but also minimizes damage to the crops, potentially leading to higher quality produce and reduced waste. However, the operation of robotic harvesting is more complex than robotic transplanting. It involves a vision system that identifies and classifies the vegetables for harvesting. Additionally, a challenge of differentiating ripe and unripe vegetables and dealing with variability within different varieties presents a major hurdle for the operation. The robotic harvester "Vegebot," developed by Birrell et al. (2023) for lettuce harvesting, achieved an 88% harvest success rate and an average harvest time of 31.7 seconds in field tests.



View of Vegebot developed by Birrell et al. (2023)

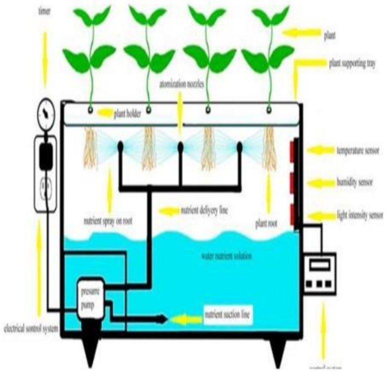
Weeding

Vegetable production has been seriously affected by weeds for a long time. Weeds compete with crops for sunlight, water and nutrients in the field, which leads to a decline in yield and quality and causes great losses to the agricultural economy. The traditional weeding methods are labor intensive and costly; the overuse of agricultural chemicals has also resulted in serious environmental pollution and public health concerns. With the advancement of agricultural mechanization and information technologies, automatic weeding robots that can improve weeding efficiency, save resources, reduce environmental pollution, and improve the yield and quality of agricultural products can gradually supplement and even replace traditional weeding methods. Also, research has been carried out on laser weeding techniques. This method utilizes precision laser technology to target and eliminate weeds without harming surrounding crops. A laser robotic weeding system (anonymous, 2022) and a robotic weeding system (anonymous, 2020) are shown in the below Figures.

View of laser weeder (top) robotic weeder (bottom)

Soil-less vegetable production

Soil-less cultivation is a new advanced method for improving cultivation of different vegetable crops. It is a method of growing vegetables without the using soil as a rooting medium, in which the inorganic nutrients absorbed by the roots are supplied through irrigation water. It includes hydroponics, aeroponics and aquaponics. Hydroponics(figure 4) is the growing of vegetables in an fed with a solution containing a mixture of macro and micro-nutrients. Aquaponics is the technique in which, aquatic animals such as snails, fish, crayfish, prawns, etc., are grown in tanks with combination of hydroponics with vegetables are grown in water in a symbiotic environment. In aeroponics system, sealed root chamber is used as reservoir for nutrient solution where the plants above the reservoir cover with polystyrene/other material. It must be supported or hanged through holes in the expanded cover and are misted with nutrient solution to keep it always moist. Soil- less cultivation has been followed in number of vegetables such as, tomato, chilli, brinjal, green bean, bell pepper, cauliflower, cucumber, melons, radish, onion, lettuce, beet, winged beans, water spinach, spinach, coriander, and so on. Soil-less cultivation helps in early nursery raising and easy management, production of healthy vegetable seedlings free from disease, insects and pest.



From robotic transplanters to automated harvesters, these innovations are not only increasing efficiency and productivity but also paving the way for a more sustainable and resilient agricultural future. automation in vegetable cultivation faces challenges such as high initial costs and technical complexity, requiring collabo-rative efforts of stakeholders, including farmers, researchers, policymakers, and technology developers, to develop solutions that maximize the benefits of automation while minimizing its potential drawbacks.

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