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EQUIPMENT DESIGNS USED IN VEGETABLE PRODUCTION SYSTEM

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ABSTRACT

Methods for producing vegetable crops vary greatly depending on the crop and region. For some crops like sweet corn, production equipment requirements are similar to grain crops. However, most vegetable crops require production techniques that necessitate the use of special equipment. This paper outlines the basic cultural practices and equipment designs used in the production of vegetables. The variety of new and innovative equipment offers today's farmers many choices. Equipment provides the mechanism to accomplish much of the work carried out on a farm. The correct selection and application of equipment can improve farm efficiency, remove drudgery and reduce labor expenses. However, to ensure healthy profit margins it is important for small farmers to understand their economy of scale and the potential return per dollar for each piece of equipment purchased. The cost of equipment can quickly absorb profit margins. Consider if the piece of equipment is an essential component of the operation before purchases are made.

Key words : *Vegetable, transplanter, tillage, seeding, plasticulture*.

Vegetable production continues to be a significant component of the agricultural crop sector. In 2001, the USDA reported that 6.4 million acres of vegetables were harvested with a farm value of 14.8 billion dollars. Fresh market production exceeded 2 million acres with a value of 9 billion dollars, and vegetables for processing were grown on 1.3 million acres with a value of 1.3 billion dollars. The importance of these commodities to the U.S. population has grown as per capita consumption of fruits and vegetables increased 12% in the 1990s to 454 lbs annually (Anonymous, 2002). Indian vegetable industry is developing in faster rate. Many aspects on the vegetable improvement and the production practices are developed. Still some limitations of vegetable farming in India are existing like Vegetables are highly perishable, Ignorance on nutritive value of vegetables, Illiteracy and lack of technical knowledge of scientific cultivation, Lack of transportation facility, Lack of enough refrigeration and storage facilities, and mamy more. Even than in India, we have the potential to be the world's largest producer which is bestowed with one of the best natural resources in the world. Lots of work has to be done for production of vegetables, and various machines are required to be used in vegetable cultivation. In this paper, design aspects of the vegetable farming machines have been discussed.

Soil Preparation : Generally, good vegetable production is achieved on well drained soils with good soil structure, fertility, organic mater, and pH. Proper seedbed preparation is an essential part of commercial vegetable production. Objectives of soil preparation include developing proper soil structure for good seed–soil contact, controlling weeds, managing organic matter, incorporate soil amendments, improving water infiltration, reducing or eliminating the effects of compaction, and establishing a soil surface appropriate for a specific production method or crop (Glancey, 2003).

Tillage : The production of most vegetable crops utilizes intense tillage practices to insure good soil condition at planting. Adequate soil preparation is required to promote uniform germination and maturity, and eliminate the compaction that often occurs during the harvest of vegetables. In addition, the relatively small size of many vegetable seeds requires a soil structure with small soil particles to promote good seed–soil contact. Commercial vegetable production has traditionally relied on conventional tillage practices to achieve the soil conditions necessary for crop growth. Moldboard plowing is still utilized to develop and maintain good soil structure while burying weed seeds and organic residues that can harbor insects and diseases. Because the selection of labeled herbicides is limited for many vegetable crops, adequate weed control can only be achieved through primary tillage, subsequent cultivation, and crop rotation. Chisel plowing is used for crops such as sweet corn that have several commercially available pesticides, and may not be affected by crop residues. Secondary tillage may utilize a disc harrow after plowing; however, field cultivators have become an effective alternative. Reduced compaction and improved leveling of the soil surface are some of the reasons field cultivators have rown in popularity (Glancey, 2003).

Final tillage operations can serve two primary purposes in vegetable production. The first objective is firming the soil prior to planting. This not only promotes good seed-soil contact, but also helps insure accurate and consistent seed depth during planting. A second objective in final tillage may be to form the soil into the configuration required for a particular cultural practice. Wide beds can be formed using PTO-powered bed shapers for crops including tomatoes and melons.

These beds promote soil warming, facilitate furrow irrigation, and allow crops including lettuce, spinach, onions, and cucumbers to be planted in multiple rows on a bed. Other bed shapers are available for narrow or single row beds, and may not be PTO-powered. Reduced or conservation tillage practices have been used for some vegetables including sweet corn, tomatoes, snap beans, lima beans, and pumpkins. Unlike agronomic crops, input costs for most vegetables are high and the resulting savings from reduced tillage may be small compared to total production costs. In addition, risks associated with conservation tillage include compaction, low soil temperatures, additional insect, disease or weed pressures, and poor drainage. Together, these factors have limited the adoption of reduced and no-till tillage practices (Glancey, 2003).

Deep tillage is a practice that has been utilized in the production of several vegetable crops, especially where mechanical harvesters are used. Wet soil conditions at harvest coupled with the large mass of some harvesters often result in severe, deep compaction. Subsoilers have traditionally been used to eliminate compacted zones, however, a more recent practice has been toward rippers configured with a variety of shanks and chisel points. Among the more common configurations are straight shanks with winged point geometries that promote significant subsurface soil fracture with minimal surface disturbance (Glancey, 2003).

Plasticulture : The use of plastic mulches to promote rapid and early plant development by increasing soil temperatures has been used to grow vegetables since the 1960s. A plasticulture system typically consists of a polyethylene plastic film used as a ground cover or mulch, a raised bed, and drip irrigation. Clear film, often used in early sweet corn production, provides excellent soil warming but no weed control; black film not only promotes elevated soil temperatures but also reduces weed pressure and conserves soil moisture for a variety of crops including watermelons, tomatoes, cucumbers, and peppers. Recent advances in plastic technology have provided wavelength selective films that allow light penetration but still provide good weed control (Glancey, 2003).

Equipment for plasticulture production is available in a wide variety of configurations. A one-row black plastic layer that forms the soil bed, dispenses the plastic, and covers the edges of the plastic with soil. Some plastic layers are also equipped with features that place drip tubing under the plastic. Although some biodegradable plastics have been developed, most plastic is pickup at the end of the growing season; some equipment has been developed and is commercially available for gathering plastic.

In addition to bed covers, plastic is also used to create tunnels over early seeded crops. The clear tunnels promote in-the-row soil warming and some moisture conservation, and are removed when the ambient temperature is high enough to facilitate plant growth.

Plant Establishment : A vegetable crop can be established using two methods. Direct seeding is most frequently used for a variety of vegetable crops in which seeds are sown directly into the soil. Variations of this technique include the seeding of primed seeds, pregerminated seeds, and seeds that are encapsulated in a gel. Alternatively, crops can be transplanted using machines that allow plants established in a greenhouse or warmer region to be placed in the soil. Although transplanting is usually more labor intensive than direct seeding, it promotes earlier harvest and provides a means of field production for crops that are best germinated in a greenhouse. Crops that are typically transplanted include broccoli, cabbage, lettuce, and peppers, however, for small scale production, almost any vegetable crop can be transplanted (Glancey, 2003).

Seeds and Seeding Requirements : Precise row and plant spacing, good seed–soil contact, and accurate and consistent depth of seed placement are among the most important factors in establishing good vegetable crops. Crops that are properly planted are more likely to produce uniform fruit and higher yields at a lower cost. For the purposes of planter design, the most relevant classification of vegetable crops is based on seed size. Typical seed sizes vary greatly for vegetables; sweet corn averages 50 seeds per 10 g sample, while celery may have as many as 25,000 seeds in a sample of the same mass. As a result, equipment to meter seeds and establish good seed–soil contact are typically designed for crops with similar seeds and seeding requirements. A summary of average seed sizes for most vegetable crops is provided in Nonnecke (1989), typical seeding requirements (plant and row spacing) for vegetable crops are provided in Fordham and Biggs (1985). In order to insure good germination, seeds must be properly handled and treated. Generally, corn, pea, and bean seeds are most susceptible to mechanical damage, and need to be handled carefully. Seed treatment methods are used to kill organisms or pathogens within or attached to the seed. Once planted, treatments protect the seed from rot and fungi, or can be used as inoculums to promote nodule formulation on legume roots. Seed treatments can be applied dry prior to planting as a power or slurry.

Direct Seeding : Planters for direct seeding vegetables are generally designed for specific vegetable crops. Exceptions are sweet corn in which a conventional field corn planter with finger (plateless) or plate-type metering is used, peas in which a grain drill is used for seeding, and beans (snap, lima) in which bulk metering cups are used with a conventional row crop planter. Despite these examples, most direct seeded vegetable crops require precise seed metering and placement in the soil. Precision seeding, defined as the precise placement of seeds at the correct in-row spacing and depth, is commonly used as a standard practice in most production systems. Although planters for precision seeding are expensive, the efficient use of seed, the improvement in uniformity and germination, and the elimination of subsequent population thinning operations usually make this planting method economically viable. There are three basic types of precision planter metering designs that are currently used for vegetable planting, each with advantages and disadvantages.

Plate : A rotating horizontal plate with notches is used to singulate and move seeds to a drop tube. Most planters are ground drive and correct in-row seed spacing is achieved by changing the drive ratio between the plate and drive wheel. These planters are best suited for round seeds that singulate well. With the correct plate selection, they can be used for large and medium seed sizes.

Belt : Holes in a conveyor belt capture and move seeds to a drop tube. Most planters are ground drive and correct inrow seed spacing is achieved by changing the drive ratio between the plate and drive wheel. Seed singulation is best with spherical seeds.

Vacuum : A rotating vertical plate with equally spaced through-holes near the outer circumference and a vacuum applied on the back side of the plate are used to singulate individual seeds. Both the drive ratio between the plate and the drive wheel as well as the number of holes in the plate can be used to change the in-row seed spacing. Additionally, plates with different hole sizes can be used to accommodate a wide variety of seed sizes. With the correct selection of plate hole size, this metering system design is less sensitive than other systems to the shape of the seed.

Several studies have been conducted to evaluate the metering performance of precision planters. Generally, proper configuration of the metering unit coupled with good quality, uniform seed provide acceptable performance. However, comparisons of vacuum and belt-type metering characteristics for non-uniform seeds found surprising results (Parish el al., 1998). Neither of the belt configurations used in the belt-type unit nor the vacuum unit demonstrated good performance for graded and ungraded turnip seeds; both skips and doubles were excessively high. Additional work with belt-type planters found significant variations in performance among six identical metering units (Parish el al., 1999). Seed delivery was found to vary as much as 116% between metering units operated under the same test conditions.

Planter frame designs are similar to other conventional planters. Accommodations for starter fertilizer are common; some planters also provide hoppers and metering units for fungicides or other seed treatments to be applied in-row. Individual planter units can be moved laterally on the toolbar to provide different row spacing; some designs can be configured with row spacings as narrow as 20 cm for planting multiple rows on raised beds. Furrow openers and press wheels are similar to conventional planters. For some crop like sweet corn and pumpkins, no till coulters are available.

Potato planters differ from other vegetable planters because they must handle pieces of cut potatoes. Traditionally, metering has been achieved with either pick- or cup-type conveyor mechanisms. Pick-type metering units utilize metal spears mounted on a conveyor chain; singulation is achieved as the spears pierce and then transport individual potato pieces to a drop tube where a knock-off mechanism removes the pieces from the conveyor. The cup-type metering unit uses a similar principle, however, a conveyor with cups is used to capture and transport potato pieces. More recently, vacuum type metering systems have been commercially introduced.

Direct seeding for plasticulture production systems is accomplished with a punch planter. A typical punch planter consists of a rotating drum with hollow punches geared to the seed metering unit (Shaw et al, 1989). As the drum rotates, the punches puncture holes in the plastic mulch, and also create cavities in the soil to accommodate seed placement. Once the seed is dropped, the punch is removed and a press wheel is used to firm the soil around the seed.

Transplanters : Vegetable transplants are available either with bare roots, or contained in a growing tray with the growing media (peat) still attached to the roots. The handling and subsequent planting of each of these two types of transplants are fundamentally different, and transplanting machines are typically classified as either bare root or cell type. The most common designs today still require manual placement of the transplant into the mechanism that delivers to transplant to the desired location in the soil. A person typically ride on the planter and is responsible for transferring transplants to the delivery system for one or sometimes two rows.

The delivery mechanism is typically ground driven and can consist of a rotating carousel or drum in which an operator loads transplants. In-row spacing is adjusted by changing the drive ratio between the ground drive wheel and carousel or drum. During operation, once the carousel or drum rotates to the proper location, the transplant is ejected and placed in a furrow or opening created by a shoe. Wheels are pressed firmly in the soil around the transplant once it is placed in the soil. Typically, fertilizers and pesticides are not applied with the transplanter.

Multiple row transplanters are common for large scale production. Planter units are mounted on a tool bar that allows for adjustable row spacings. Automatic or selffeeding transplanters have been studied (Munilla et al., 1987) and developed experimentally (Suggs et al., 1989) but have limited commercial availability and acceptance.

Chemical Application : Agricultural chemicals are an integral and essential component of commercial vegetable production. They are applied to plants and the soil as a means to control weeds, diseases, and insects. In addition, chemicals are used as soil amendments to improve fertility and adjust pH. In vegetable production, chemicals may be applied prior to, during, or after planting, and may be applied as solid, liquid, or gas. As a result, the choice of application equipment is a function of both the timing and form of the application. The most common applicator used in vegetable production is the boom-type sprayer. A typical applicator can be used to broadcast or band fertilizers, pesticides, or mixtures of chemicals. Smaller boom sprayers can be three-point-hitch mounted or towed by a tractor; larger sprayers are typically self-propelled.

Generally, boom sprayers are equipped with low-pressure systems for vegetables; nozzles type and system pressure can be changed to provide sufficient atomization for the chemical being applied. One advantage of this type of applicator is the ability to tank-mix fertilizers and pesticides. This practice, common in vegetable production, can save time, reduce costs, and enhance the action of some herbicides.

Extremely low thresholds for disease and insect damage on most vegetable crops necessitate pesticide postplanting applications during the growing season. As a result, high clearance self-propelled sprayers have been developed. Hoods can also be incorporated to isolate vegetable plants from the pesticide being applied. Typically, hooded sprayers are used in vegetable production for herbicide application to control weeds between crop rows.

Within the last 20 years electrostatic sprayers have become commercially available, and have been used in production. For vegetables, these sprayers have usually been configured as boom sprayers and improve chemical deposition, especially under the leaves wheremany insects reside. In addition, the potential for reduced spray drift provides a larger window of opportunity for insecticide application, which is critical for the control of insect damage in vegetables. Aerial applicators have several advantages in vegetable production including the ability to apply pesticides when ground equipment can no longer drive through a crop. Aerial applications of insecticides are common, especially on crops like peas and cucumbers that cannot accommodate wheel traffic later in the growing season. Airplanes are used for most aerial applications, however, helicopters have been used in some instances. Although this method provides rapid and timely coverage, cost per hectare compared to ground applicators is higher, and the increased potential for drift can limit use.

Subsurface application of chemicals is a practice used for both fertilizers and pesticides. Anhydrous ammonia is occasionally used as a preplant nitrogen source for some vegetables. In soils that are infested with soil-borne pathogens or nematodes, the subsurface application of a soil fumigant can be used to reduce pest populations. Prior to a fumigant treatment, fields must be relatively free of debris and the soil must be sufficiently loose to allow for penetration of the gaseous fumigant. Most fumigants and other low-pressure liquids should be injected to a depth of at least 15 cm; after application, the soil should be rolled or dragged to reduce volatilization losses (Kepner et al., 1977). Some fumigants like methyl bromide require the use of a plastic film cover over the soil to prevent losses.

Electronic controllers for chemical applicators have become an integral part of most dry and liquid applicator configurations. Monitoring and control of chemical application information coupled with geo-referenced location data provide the ability to record as-applied spatial maps of pesticides and fertilizers. In vegetable production, this provides managers with convenient and accurate documentation of chemical application information for nutrient and pesticide management plans. This is especially important in developing crop rotation plans since several vegetables are sensitive to pesticide carry-over effects.

Postplanting Operations : Vegetable production frequently requires operations subsequent to planting to control pests and insure fruit uniformity and quality. In many cases, limited commercially available herbicides also necessitate cultivation for controlling weeds.

Mechanical Cultivation : The primary objective of cultivation is to reduce weed pressure to acceptable levels. This not only reduces competition for nutrients and light, but also improves harvested product quality by reducing foreign material in some mechanically harvested crops. However, excessive cultivation may promote soil moisture loss and impede effective fruit recovery during vegetable machine harvest because of unlevel soil conditions. In vegetable production, a number of different cultivation methods and configurations are available, each with advantages and disadvantages (Glancey et al., 1996a and Glancey et al., 1996b).

Cultivator Designs : Types of mechanical cultivators include rigid, spring tooth, finger-wheel, rotary hoe, and rolling basket. Most individual tools or gangs of tools are mounted on a ridge tool bar that allows variable tool spacing to accommodate different crop row spacings. Depth of cultivation is controlled by gauge wheels, however, some fully mounted cultivators may also rely on the tractor three-point-hitch to assist in controlling depth.

In case of spring tooth type cultivator with S-tine shanks design, the tine is allowed to vibrate as it moves though the soil, thus promoting soil fracture and weed disturbance. Several types of tools have been used for vegetable cultivation. The most common type is a sweep, which can be configured for significant soil disturbance, or to sever weed roots under the surface of the soil at lower speeds. A finger-wheel cultivator has also been shown to be effective in vegetable production, even for small crops. In one study, at operating speeds of approximately 8 km hr^{-1}, tests in mustard, kale, and spinach crops found the finger-wheels were effective in weed control and did not induce crop damage or reduce yields (Parish et al., 1996).

Rotary Tillers : Rotary tillers are PTO-powered, and consist of several sections of rotating L-shaped blades. Shrouding around the rotating tools promotes soil pulverization and prevents soil from being thrown out of the row. Although these cultivators require additional power and are heavier than conventional cultivators, rotary tillers are very effective in weed control. In addition, they provide excellent leveling of soil between rows, and are sometimes used for machine harvested vegetables like pickling cucumbers and lima beans that can be difficult to harvest if unlevel ground surfaces or furrows are present between crop rows.

Other Postplanting Practices : Flame cultivation has been used to control weeds in some culture systems. Typically, heating chambers located between crop rows are mounted on a three-point-hitch, and burning propane or other fuel is used to heat the weed plants sufficiently to kill the plants. Guards are used to insulate the vegetable plants from the heating chamber. Although this technique provides an alternative to herbicides, commercial adoption is limited because throughput rates are low and the amount of fuel required for large plantings is costly (Parish et al., 1997).

Thinning is occasionally used to remove plants and achieve desired plant populations. Although the advent of precision planting has reduced the need for this practice, mechanical thinning may still be performed early in the growing season. One method to eliminate unwanted plants is cross-blocking; cultivator shanks mounted on a toolbar are operated perpendicular to the row. Another technique consists of a blade that oscillates laterally as it is moved down the row. Each of these methods is non-selective; selective techniques are inherently more complex and are still being developed.

Biological control of pests is a method that has been studied for several decades. Research has demonstrated that deploying parasitic or predatorily insects (or their eggs) that feed on harmful pests can be an effective alternative to chemical. Mechanical systems to transport and distribute beneficial insects to standing vegetable crops have been designed and tested; performance has been positive both in terms of uniformity of application and efficacy of the organisms (Gardner et al., 1997). Some “biosprayers” are commercially available; however, biological control can be expensive due to the cost associated with the large quantities of insects required for adequate pest control.

New technologies : The study of site-specific management of chemicals has been under investigation for several years. Because of the intense use of fertilizers and pesticides, coupled with the need for crop uniformity, this approach has the potential to significantly improve several vegetable crops. Using differential global positioning systems (DGPS), spatial data has been collected regarding nutrient, pH, weed, and pests. Variable rate applicators equipped with DGPS, have then been used to apply fertilizers, lime, and pesticides only where they are needed. Although the performance of the equipment has generally been acceptable, the economic and environmental consequences of this approach in vegetable production are not well understood and need additional research (Roberson, 2000).

One of the most promising new technologies for vegetable production is guidance systems. Tractors equipped with DGPS capable of real-time kinematic (RTK) positioning have been used for several vegetable field operations (Upadhydya et al., 2000). Although the costs are relatively high for this equipment, the benefits, especially for vegetable production, are significant. Precision steering not only reduces the variation in row spacing between adjacent planter spacing, but also provides exact position information in which the row location is recorded. As a result, postplanting operations can utilize the row position information for machine guidance purposes. For example, once a crop has been planted with a precision guidance system, cultivation can be performed in close proximity to the crop without damaging roots; subsurface irrigation tubing location is known and can be avoided. In addition, some operations can be performed at a higher velocity, and in the dark. Specific production systems that utilize these technologies are currently under development (Rosa et al, 2000).

Machine vision systems have been developed and used to enhance performance of several vegetable operations. Cameras have been used to identify tomato plants from weeds for the purposes of weed control (Tian et al., 1997). Robotic systems have been tested for cultivation in which a vision system is used to identify in-row weeds. Once a weed is located, a microprocessor based controller selectively applies herbicide using a precision chemical metering system (Lee et al., 1999). Although not commercially available, these prototype spraying systems have been tested in commercial settings, and can operate at speeds of 1.2 km hr^{-1}. Other similar systems have visually identified the crop row and controlled the lateral position of a cultivator to provide precise cultivation in close proximity to the crop row.

CONCLUSIONS

Several innovations have recently been introduced that have the potential to significantly enhance several aspects of vegetable production. The objectives with these new approaches include improving performance of existing equipment, reducing labor requirements, providing more efficient use of pesticides, and reducing the potential environmental impact of production. One of the most promising new technologies for vegetable production is guidance systems. Tractors equipped with DGPS capable of real-time kinematic (RTK) positioning have been used for several vegetable field operations. Still several development works are under progress, as far as design of vegetable cultivation machinery is concerned.

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