Current Developments in Seeders and Transplanters for Vegetable Crops

Richard L. Parish¹

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SUMMARY. This article is a review of the current status in planting and transplanting equipment and practices for vegetable crops. A review of horticultural and agricultural engineering literature is supplemented by information from an informal survey of members of American Society of Agricultural Engineers (ASAE) committee PM-48, Fruit and Vegetable Production Engineering, and other engineers and horticulturists working in this field. Areas covered include precision seed metering, seed placement, and high-speed transplanting with automated plant handling.

CURRENT DEVELOPMENT—SEEDERS. Crops that can be grown under optimum growing conditions and a long growing season are best suited to direct seeding (Orzolek, 1991). Precision seeders are generally used with small, expensive seeds to minimize the waste of overseeding and thinning. The advantages of precision seeding over conventional seeders include a reduction or elimination of thinning costs, reduced seed cost, reduced competition between young plants, and reduction or elimination of shock to plants from thinning (Roberson, 2000). Disadvantages include the need to protect the stand after emergence, more critical seedbed preparation, the requirement for seed treatment or

coating in many cases, and the higher cost of planting equipment.

The use of precision seeders is a well established practice in commercial vegetable production. Bracy et al. (1991) discussed the use of precision seeders as part of a precision cultural system for vegetables. They mounted precision seeder units directly on bed shapers so that the rows would be precisely located on the beds and therefore easy to cultivate precisely using cone guide wheels.

Vacuum seeders (Fig. 1) are one of the most common types of precision seeder currently used for commercial vegetable production. They can do an excellent job of singulating seeds, if properly adjusted, but a belt-type seeder (Fig. 2) has been found to deliver better seed uniformity on the ground (Bracy and Parish, 1998, 2001). Belt seeders deliver more consistent seed spacing than vacuum seeders with seeds

that are nearly spherical, but are not as effective as vacuum seeders with odd-shaped seeds. Seed spacing uniformity of a precision vacuum seeder (expressed as a percentage of theoretical spacing) increased with increasing seed spacing (Bracy et al., 1999). This effect was thought to result from varying seed trajectories after seed release caused by the high seed release point on the seeder. Since the trajectory variations were relatively constant in absolute terms, the percentage error decreased with increasing theoretical seed spacing. This effect did not occur with a belt seeder having a much lower seed release point.

Improving the uniformity of seed placement has been a long-term goal of agricultural engineers. One problem area that has been identified is the height (or length) of the seed drop zone after metering. The higher the seeds are released above the bot-

Fig. 1. Typical vacuum seeder for vegetable crops. This seeder is set up for multiple rows on wide beds.

Fig. 2. Belt-type seeder metering unit. In this opened view, the wheel (center of photo) that forces the seeds through the holes in belt can be seen.

Hammond Research Station, Louisiana State University AgCenter, 21549 Old Covington Highway, Hammond, LA 70403

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¹To whom reprint requests should be addressed. E-mail address: dparish@agcenter.lsu.edu

tom of the seed furrow, the greater the likelihood of the seeds varying in trajectory and thus losing the uniformity attained with precision metering. Parish and Bracy (2003a) attempted to improve the seed spacing uniformity of a precision vacuum vegetable seeder by guiding the trajectory of the seed drop zone. The various guide systems tested did not improve seed spacing uniformity.

The sources of variability in seed spacing achieved with an agronomic seeder were found to be different than with vegetable seeders (Moody et al., 2003). In that study with cotton (*Gossypium hirsutum*) and corn (*Zea mays*), the largest component of spacing variability appeared to be the seed meter rather than the seed drop zone.

Statistical procedures for analyzing and reporting seed spacing uniformity were discussed by Kachman and Smith (1995). Their methods are based on an International Organization for Standardization standard (ISO, 1984). The methods of Kachman and Smith (1995) were used to compare laboratory and field performance of seeders for sugarbeet (*Beta vulgaris*) (Panning et al., 2000). They found that uniformity in the field was not as good as predicted in the laboratory. They recommended using laboratory tests to screen out the less uniform seeders, then using field tests for final evaluation.

At least one model of vacuum seeder (Fig. 3) is available for single-row small plot research or small-scale commercial production. This model uses a shop vacuum powered by the tractor electrical system through an inverter.

Variable rate controls can be applied to seeders to give the operator the opportunity to adjust seed population on the go to match optimum field requirements (Roberson, 2000).

Seed priming and soil amendments used as seed covers have been evaluated as means to improve seed establishment. Seed priming and pregermination in combination with soil amendments (seed furrow covers) were considered as means to increase stand establishment with direct-seeded tomato (*Lycopersicon esculentum*). Priming and pregermination improved the speed and percentage of germination. Soil amendments improved germination only in combination

with priming and pregermination. Primed seeds combined with specific soil amendments can improve lettuce (*Lactuca sativa*) stand establishment under various field conditions (Odell et al., 1992; Seale et al., 1994).

Fluid drilling has been evaluated for use in vegetable seeding. A thorough review of work in this area noted that fluid drilling can give 1) earlier, greater, and more uniform seedling emergence; 2) earlier and greater yields; and 3) in some crops, more uniform maturity than conventional methods of sowing dry seeds. It was predicted that the use of pregerminated seeds probably will be reserved for the production of bedding plants or transplants. The sowing of untreated dry seeds in streams of fluid-drilling gel has improved stands compared to conventional dry-seed sowing. It was further predicted that the future of fluid drilling lies predominantly in the use of primed seeds (Pill, 1991). Fluid drilling requires mixing a gel suspension and it may not be possible to hold the seeds in the gel without

them germinating if seeding must be interrupted for a few days.

A hydropneumatic seeder for tomato seeds was developed (Far et al., 1994). The seeder yielded field performance equivalent to a vacuum seeder. Using primed seeds with the hydropneumatic seeder resulted in faster germination and greater seedling vigor than using raw seeds.

Another method of achieving seed spacing uniformity is the use of a seed tape system (Chancellor, 1969). With a seed tape system, the problem of uniform singulation is addressed under laboratory conditions, and it is then necessary only to roll out and cover the seed tape in the field. This system has been used more for small gardens than for commercial vegetable production. The cost of the tape makes it impractical in many field situations. Maintaining good seed-to-soil contact with a tape is another potential problem.

CURRENT DEVELOPMENTS—EQUIPMENT FOR SEEDING INTO CONSERVATION TILLAGE FIELDS, VEGETATIVE MULCHES, AND PLASTIC MULCH. There

Fig. 3. One-row vacuum seeder with shop vacuum driven from tractor electrical system. This configuration is useful for small operations or research/demonstration plots.

are several problems specific to seeding under conservation tillage or vegetative mulch conditions. These include plant residue plugging planter openers, clods, the potential for poor seed-to-soil contact, inconsistent depth control, and moisture loss since there may not be a good soil surface seal. Seeding through plastic mulch presents different problems in that the seeder must punch through the plastic to place the seed(s), but do minimal damage to the plastic and not initiate tearing.

Seeding sweetcorn under no-tillage conditions reduced plant count but not yield per plant (Cline and Silvernail, 2002).

Methods of preparing cover crop fields for direct seeding of vegetable crops were evaluated by Parish et al. (2002). They evaluated six methods of destroying the cover crop of southernpea (*Vigna unguiculata*) and pearl millet (*Pennisetum glaucum*): herbicide, rolling with a spool bed shaper, mowing with a sicklebar, rolling with a flail mower [power-take-off (PTO) disengaged], mowing with a rotary cutter, and mowing with a flail mower; each followed by nine implements for preparing a seedbed: dibble-type plant setter directly in the mulch, tiller/cultivator on sides of bed top, tiller/cultivator centered on bed top, standard rolling cultivator, straight rolling cultivator, mulch lifter, subsoiler running shallow, disk openers on a grain drill, and wavy coulters. They found that the tiller/cultivator and the rolling cultivator were best able to prepare a planting bed in the vegetative mulch. A continuation of that study evaluated four methods of direct seeding squash and cucumber (*Cucumis sativus*) into a vegetative mulch of southernpea and pearl millet (Parish and Bracy, 2003b). Treatments were a dibble-type mulch seeder and a vacuum precision seeder, with and without prior strip tillage. The dibble-type seeder worked under all planting conditions, but metered poorly while the vacuum seeder worked on plots where the planting strip in the center of the bed had been killed with herbicide early in the season.

A punch seeder was developed for direct seeding under conservation tillage conditions (Molin, 2002). This punch mechanism allowed the seed (i.e., dibble) spacing to be adjusted.

Direct seeding into plastic mulch can be done by hand or with dedicated

mulch seeders. A dibble-type mulch seeder for planting several vegetable crops into plastic mulch was evaluated (Parish and Bracy, 2003c) (Fig. 4). A stand was not obtained in many cases with the dibble-type mulch seeder, apparently due to poor metering, poor depth control, and erratic seed placement.

Whether transplanting or direct seeding, a mechanized system must include a means of perforating the plastic mulch. This is often done by burning a hole in the mulch (Parish and Bracy, 2003c) but can be done mechanically.

CURRENT DEVELOPMENTS—TRANSPLANTERS. Transplants are used for some crops because they result in earlier harvesting, enable warm-season crops to be grown in regions too cold for direct-seeding, and develop better root systems (Orzolek, 1991). Field-grown bare-root transplants are generally less costly than tray-grown plants, but may have a higher rate of mortality in the field after transplanting.

Sweetcorn (*Zea mays* var. *rugosa*) is a crop normally grown from seed; however, poor germination and seedling vigor of sweetcorn containing the shrunken-2 (*sh₂*) gene has led to interest in transplanting. Transplanted *sh₂* corn matured earlier than seeded corn but yield and quality were higher with direct seeding (Welbaum et al., 2001).

Manual transplanting on a large commercial scale is labor-intensive and

less uniform compared with mechanical transplanters (Orzolek, 1996). It is also expensive.

Mechanical transplanters are ubiquitous in vegetable operations, but have been slow and required significant hand labor to feed and operate. Automatic plant handling systems for feeding transplanters are gradually being developed and becoming accepted by growers. LandTechnic, Inc. (Gainesville, Fla.) (Fig. 5) and Faulring Mechanical Devices (North Collins, N.Y.) (Fig. 6) have developed transplanters with automatic plant handling.

There is a need for standardization of plug trays for growing seedlings (Shaw, 1993). Without both standardization and selection of trays for automated mechanical handling, automation of planting cannot progress. It is impossible to design a transplanter to handle all of the sizes of trays available, and some types of trays may cause significant impediments to automated mechanical handling. Horticulturists, engineers, and tray manufacturers will need to work together to make automated mechanical transplanting an accepted practice.

A seedling pick-up device to mechanically extract seedlings from a 200-cell tray and transfer them to a position from which they could be transplanted was developed and tested by Choi et al. (2002). The device used a five-bar linkage driving pick-up pins. Laboratory testing showed that the device could extract 30 seedlings/min

Fig. 4. Dibble seeder for seeding through vegetative or plastic mulch. This machine first burns holes in the plastic, then places the transplants, and finally waters the transplants.

with a success rate of 97% using 23-d-old chinese cabbage (*Brassica rapa* Pekinensis group) seedlings.

The effect of transplant depth on tomato yield and maturity was studied by Vavrina et al. (1996). They demonstrated increased early yields with deeper planting (to the first true leaf or to the cotyledon leaves), but the effect was diminished with successive harvests.

An experimental single-row automatic transplanter to drop bare-plug seedlings from shipping modules into static cassettes, then into rotating dibbles that plant them was designed and built by Brewer (1995). Planting rates were 60–300 seedlings/min. In some test runs, 100% of the seedlings were transplanted correctly. Short, sturdy seedlings were required. Additional work is needed before the machine can be commercialized. Brewer (1997) determined that a commercial manually-fed transplanter could be automatically fed at several times the rate of hand feeding, but did not build and test a prototype.

Automated transplanters offer many advantages but are complicated and expensive. They also require a very high level of plant quality and uniformity.

Even without automated plant handling, it is possible to improve the efficiency of mechanical transplanting by using some type of cassette to allow multiple loading locations in which the operator can place plants (Fig. 7). This allows the operator to place several plants rapidly, then have a brief time to untangle plants or remove plants from cells rather than having to maintain exact timing for each plant.

CURRENT DEVELOPMENTS—EQUIPMENT FOR TRANSPLANTING INTO CONSERVATION TILLAGE FIELDS, VEGETATIVE MULCHES, AND PLASTIC MULCH. A review of the literature on no-till production of vegetable crops was published by Morse (1999). He emphasized transplanting, although he also discussed no-till seeding. He discussed the past limitations of no-till vegetable production (inadequate equipment; poor, uneven stands; loss of precocity; and weed control problems) then reviewed solutions to those problems including the development of improved transplanters and seeders, effective residue management techniques, and the advent of more effective herbicides. He outlined four

critical objectives for success with no-till vegetables: 1) produce a dense, uniformly distributed cover crop before transplanting; 2) kill cover crops before transplanting, leaving a heavy, uniformly distributed mulch cover over the soil surface; 3) establish transplants into cover crops with minimum disturbance of surface residues and surface soil; and 4) practice year-round weed control. He outlined recommendations for achieving those objectives. Fig. 8 shows a no-till transplanter in action.

Broccoli (*Brassica oleracea* L. Italica group) transplanted with no tillage into a cover crop mulch yielded as well as conventional tillage. Fur-

thermore, weed suppression from the mulch was effective (Abdul-Baki et al., 1997; Infante and Morse, 1996).

Some research has shown that early yield of summer squash (*Cucurbita pepo* var. *melopepo*) may be reduced when using a no-tillage production system and direct seeding, but Walters and Kindhart (2002) found that there was no reduction in yield if transplants were used.

Makus (1993) transplanted cabbage (*Brassica oleracea* Capitata group), broccoli, and cauliflower (*B. oleracea* Botrytis group) into strip-tilled killed sod. Yields with broccoli and cabbage compared favorably to yields of conventionally grown plants.

Fig. 5. Single-row automatic transplanter. This prototype machine by LandTec, Inc. (Gainesville, Fla.) is based on a University of Florida design by L. Shaw. It uses spider arms to place the plants.

Fig. 6. Three-row automatic transplanter. This prototype machine was developed by Faulring Mechanical Devices (North Collins, N.Y.).

Fig. 7. Transplanter with carousel to allow the operator some flexibility in loading plants. This design allows the operator to place several plants, then stop to pick up more plants or untangle plants without missing cells.

Fig. 8. No-till transplanting of tomato. This transplanter opens a continuous furrow for transplanting rather than just dibble holes.

Yield of cauliflower was reduced 42% with conservation tillage. It was noted that the overall benefits of no-till management include less soil disturbance and preparation, better accessibility to fields during inclement weather, and reduced risk of soil erosion.

When growing on plastic mulch, transplanting is more common than direct seeding. Using transplants decreases the time to maturity for warm season crops (Orzolek, 1996). Also, it is easier to justify the cost of transplanting when the grower is already using an expensive plasticulture system.

CURRENT DEVELOPMENTS—SEEDING AND TRANSPLANTING IN HIGH TUNNELS. A small mechanical transplanter for use in the limited space available in high tunnels is being developed (Lamont et al., 2003). Many of the smaller seeders and transplanters de-

signed for field work will also work well in high tunnels.

Discussion

We are likely to see more precision in both planting and transplanting. Precision will improve in terms of both seed/plant spacing and depth control. We are also likely to see increased emphasis on automated transplanting as good field labor becomes less available. As with most other horticultural mechanization efforts, development of automated equipment will be driven by labor shortages rather than as a means of displacing laborers.

The most important factor in the development of improved seeding and transplanting equipment is continuing close cooperation between horticulturists and agricultural engineers. Often changes in cultural practices (e.g., tray

standardization) and even cultivars must accompany engineering design efforts to achieve a mechanized system that functions effectively and meets the needs of growers. Horticulturists and agricultural engineers have a long history of effective cooperation and this should continue.

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