Paperpot Transplanting Systems—Overview and Potential for Vegetable Production

J.G. Robb¹, J.A. Smith²,
R.G. Wilson³, and C.D. Yonts⁴

Additional index words. equipment, economics, onion (*Allium cepa*), sugar beet (*Beta vulgaris*), multidisciplinary

Summary. The Paperpot system provides a relatively flexible approach to commercial transplanting of crops. Around the world, most of the research and application of this system has been on sugar beets. Compared to traditional hand-transplanted, field-grown, bare-root onions, there are several potential advantages of the Paperpot system, including reduced labor requirements, accuracy of placement, and fewer imported insect and disease problems. Comparison of three transplanters—carousel, BST, and chain-type—indicated the chain-type transplanter had lower labor inputs and a higher transplanting capacity than the other models. The BST transplanter was capable of placing 65% of the plants within a 3- to 5-inch plant spacing. The chain-type and carousel deposited 36% and 14%, respectively, within this same spacing. Yield was higher when onions were transplanted with the BST machine. This was attributed to the more-accurate placement of the onion plants. A four-row BST transplanter was capable of transplanting 0.4 acres/h of onions in field-scale trials.

Transplanting, in contrast to direct field seeding, involves taking a plant from a greenhouse or plant-bed environment and reestablishing it in a field environment. For commercial agriculture in the United States, research and application of transplanting have focused on tobacco (*Nicotiana tabacum* L.), sugar beet (*Beta vulgaris* L.), and several vegetable crops. Although mechanical transplanting technology has advanced in the past 20 years, hand-transplanting of individual onion plants is still the normal practice in many areas.

Several approaches to the automation of field transplanting have been proposed and developed. Huang and Splinter (1968) presented advantages of mechanical transplanting and discussed the application of an automated field transplanter for tobacco. More recently, Suggs et al. (1987) evaluated two proprietary transplanters and constructed one for use in tobacco and vegetables. Brewer (1988) provided a review of various approaches to automated transplanting. These reviews suggest that automated field transplanting systems can offer technological benefits to commercial producers of vegetable crops.

A complete transplanting system involves many components, from seeding to post-field transplanting cultural practices—not just the development of an adequate container and/or transplanter. It is important that the system be adaptable to the specific crop, location, farm size, soil characteristics, etc. Profitability involves a number of components, including equipment selection, greenhouse production costs, transplant production costs, labor requirements, and the prices received for early produce.

Paperpot system

Researchers and private industry in Japan developed a complete sugar beet transplanting system for field-scale use in the 1960s (Nippon Beet Sugar Mfg. Co., 1981). This method, known as the Paperpot system, incorporates a uniquely designed paper container (tube or “pot”), filling and seeding equipment for the container, seedling-raising techniques, transplanting equipment, and field cultural practices. In 1985, 96%, or 1,782,000 acres (72,100 ha) of the total sugar beet production area in Japan used the Paperpot system (Masuda, 1986).

Paperpot container. Masuda and Kagawa (1963) developed the Paperpot system. Individual paper tubes, made of a mixture of paper and other fibers that decompose, are bonded together using water-soluble glue to form a “set.” Individual tubes are designed to be transplanted with the plant and are not reusable, as are many other containers. Paperpots are not produced in the United States and have been imported indirectly from Japan through a Finland-based firm [manufactured by the Nippon Sugar Beet Mfg. Co., Ltd., Obihiro, Hokkaido, Japan, and distributed by Lannen Tehta Oy, Sakyla, Finland]. The Finnish firm has a licensed agreement controlling Paperpot marketing rights in North America and also has produced Paperpots.

Paperpots have been developed in various sizes and types, as shown in Fig. 1. The Paperpot has been used primarily for sugar beets, using a group of individualized containers (tubes), called sets. Each set contains 1400 individual tubes (Fig. 1, top). The sugar beet Paperpot set opens to dimensions of 12.2 inches by 46 inches. Individual tubes are 5.1 inches long with a diameter of 0.75 inch. Several grades of paper are available for vegetable and forestry applications. The heaviest grade is used in forestry, where rapid breakdown of containers is not desired. Sets are folded compactly for shipping and are stretched open on a dibble board (Fig. 1, top) or in a plastic tray with clips (Fig. 1, right) that accommodate other styles of Paperpots.

Two basic designs have been used for Paperpot containers. The most common, or “standard,” Paperpot is comprised of the individual tubes held together by an adhesive to form a set. When the set is filled, seeded, and placed in the greenhouse, water dissolves the adhesive over time and individual tubes are no longer bound to each other and separate easily. The chain-type Paperpot, or “chainpot,” is a more-recent development and has been a component of an “automatic” transplanting system that mechanically separates and plants each container. When the glue breaks down in the chain-type Paperpot, individual tubes still are linked together by perforated paper, forming a continuous chain, or a bandoleer, of 1400 tubes.

Seeding containers and growing plants. Tubes in the Paperpot

Panhandle Research and Extension Center, University of Nebraska, 4502 Avenue I, Scottsbluff, NE 69361.

Journal Series No. 9520, Agricultural Research Division, Univ. of Nebraska, Lincoln. Mention of trade name(s) is for readability purposes only.

¹Former Farm Manager Specialist.

²Machinery Systems Engineer.

³Weed Specialist.

⁴Irrigation Engineer.

Fig. 1. *Examples of Paperpots.*

container sets are filled mechanically with a growing medium, then seed is dropped into each tube, and a thin layer of medium is placed over the seed. Various types of medium have been used, ranging from all soil to a complete commercial plant-growing mix. Medium selection is based on the crop, the growing conditions in the greenhouse, disease concerns, medium cost, and even the operation of the transplanter. A mix of 85% field soil plus 15% peat typically is used for sugar beets in Japan. Vegetables transplanted in Paperpots in Europe generally use a soilless mix.

Specially designed equipment is necessary for filling and seeding the Paperpot. The small-diameter, relatively long Paperpot tubes present two problems for filling and seeding. First, the sets must be expanded to a consistent size so the individual tubes will match the vacuum seeder's head configuration. Second, because the tubes are relatively small in diameter and long, it is difficult to uniformly and adequately fill each tube in the set. Problems from inadequate or nonuniform filling include poorly developed root systems when medium voids exist within the containers, and tubes without plants.

Equipment for filling and seeding the Paperpot containers has been designed by several Japanese firms. This equipment has different capacities and labor requirements, but the sequence of operations is generally the same. The sets are expanded, turned upside down, and secured on a dibble board. Medium is added and the set is inverted. The dibble board is removed and seed is dropped into the dibble holes, which align with individual tubes. A thin layer of medium is placed over the seed, and the set is ready to be moved to the growing area, generally a greenhouse.

The greenhouse phase of the Paperpot transplanting system is perhaps the most-important step in the process to achieve success. A healthy, properly developed seedling of the correct size in every tube of the set is the key to both optimal transplanter performance and stand establishment in the field. The plant tops must be the correct size and the tube material must be in the proper condition for the transplanter to operate efficiently. Details for growing sugar beet seedlings in Paperpots have been developed by Nippon Beet Sugar Mfg. Co. (1981).

Transplanters. The first transplanters designed specifically for appli-

cation with the Paperpot were developed in Japan for sugar beet production. Later, Paperpot transplanters were developed in Finland, and adaptations have occurred in the United States and Europe.

Transplanters for Paperpots can be categorized into three types, varying in concept and level of mechanization. The first, and most labor-intensive, is termed the "carousel" type. It requires handfeeding the individual Paperpot tubes with plants into a turret. The tubes are released from this turret, and are fed by gravity into an opening in the soil.

The second type is exemplified by a specific model, the "BST," developed by Nippon Beet Sugar Mfg. Co. With this machine, a hand-operated gripping device grasps up to 35 individual Paperpot tubes. Thus, up to 35 individual containers are transferred at one time to the machine. The transplanter separates the individual containers, eliminates containers without plants, and compensates for any rejected, empty containers. The transplanter mechanism advances the container and places seedlings into an open furrow. The container is released after soil is pressed around the container. Only a narrow range of Paperpot

diameter and length can be used with this transplanter.

A third type of transplanter for Paperpot sets is described generally as "automatic" or "chain-type." This container system and transplanter was developed by Nippon Beet Sugar Mfg. Co. to reduce the amount of hand-feeding in the transplanter operation. Each set must be started manually into the machine. The transplanter mechanism advances the chainpot bandoleer and separates individual tubes without manual input. After separation from the bandoleer, the individual tubes are fed by gravity into the opened furrow.

Paperpot for vegetables

In 1984, studies were initiated at the Univ. of Nebraska to evaluate the applicability of this transplanting system for vegetables, such as onions, cole crops, peppers (*Capsicum annuum* L.), and sweet corn (*Zea mays* L. var. *saccharata*). By 1986, research studies focused on onions, with limited work on peppers and broccoli (*Brassica oleracea* L.).

While the Paperpot system technique has been used in Europe on cole crops, North America has had only a limited application of the Paperpot system for vegetable production. Suggs et al. (1987) evaluated a transplanter for use with the Paperpot system for vegetable production and proposed some modifications to an automated transplanter (Suggs et al., 1989).

Application to onions. Transplanting of onions is used commercially in conjunction with direct-seeding for three basic reasons in western Nebraska and other areas. First, it changes the effective field-growing season, allowing for an earlier harvest, which, in some areas, increases success with double-cropping, gains an early crop market window with a price premium, and/or allows grading/packaging equipment to be used over a longer period of time. Second, yield can be increased compared to direct-seeding, especially when the growing season is limited. Third, improved quality (size) can result from transplanting.

In western Nebraska and Colorado, storage onions are grown at high field populations (e.g., 111,000 plants/acre). They are planted in the early spring, irrigated through the growing season, and harvested in late summer through early fall. When transplanters are used, seedlings are field-

grown in other states (e.g., California, Arizona). Bare-root seedlings are harvested, bundled, and boxed, then transported to the grower and often are stored before transplanting. Transplanting is done by groups of laborers walking through the field and pressing seedlings into the soil by hand. Often a field implement is used prior to transplanting to make shallow impressions where seedlings are to be located. The field is rolled after transplanting to help firm the soil around the seedlings.

Onion transplant research.

Three types of transplanters were evaluated for onion transplanting using Paperpots.

The carousel type was a two-row model RT-2 manufactured by Lannen Tehta Oy, Finland. This model used a nine-cell rotating carousel for plant loading. A series of support wires engaged the plant in the opened furrow to hold it upright until soil flowed around it. The work rate of the machine was limited by the speed with which one person per row could transfer seedlings into the carousel.

The BST transplanter was a four-row model operated with one person per row transferring groups of 35 containers to that row.

The chain-type transplanter was a two-row model manufactured by Lannen Tehta Oy and modified for specific soil conditions by the Univ. of Nebraska. Modifications were made to the chute that delivered containers from the separation mechanism to the open furrow, to the furrow-opening device, and to the press wheels. This unit also was altered to include a common drive for both rows. If the containers were conditioned properly for transplanting, one person could monitor two rows.

The carousel and BST transplanters used the standard Paperpot BH-213, designed for sugar beets. The chain-type transplanter used the chain-type C-213 Paperpot. All Paperpots were filled with a medium developed by the Univ. of Nebraska for sugar-beet transplanting. This mix was a combination of about 45 peat : 15 sand : 20 vermiculite : 20 styrofoam beads (by volume). The Paperpots were filled and seeded by a filling and seeding line designed by Gleason Industries (Clackamas, Ore.). This line consisted of a mixer, flat filler, rollover for inverting the filled sets, a plate-type vacuum seeder, and top-dresser for

applying growing medium over seeds, along with connecting conveyors. Performance of this equipment was excellent for filling and seeding the small-diameter, long containers up to a rate of two Paperpot sets/min.

The sets were placed in the greenhouse for a period of 12 weeks to grow and condition the onion seedlings. The onion tops were ≈ 10 inches long at transplanting. This length was not compatible with the chain-type transplanter, so the tops were trimmed to 4 inches. The tops were not trimmed for the carousel and were both trimmed and not trimmed for the BST transplanter.

Transplanter performance was measured by labor input, plant spacing accuracy, transplanting rate, and onion bulb yield. Table 1 shows the machine labor inputs and output of plants for the various transplanters. The chain-type transplanter had lower labor input and transplanted more acres per hour per row than the BST and carousel transplanters.

Transplanters were set to transplant onions at a 4-inch spacing between plants. The BST transplanter placed $\approx 55\%$ of the plants within a 3- to 5-inch plant spacing (Fig. 2). If onion tops were trimmed to a length of 4 inches, the BST transplanter deposited 65% of the plants within a 3- to 5-inch plant spacing. Removing ≈ 6 inches of the onion top reduced the number of tangled plants and allowed plants to move through the transplanter more uniformly. The chain-type and carousel transplanters deposited 36% and 14%, respectively, of the plants within a 3- to 5-inch plant spacing. If transplanter spacing performance is compared relative to frequency mode, instead of on the basis of target plant

Table 1. *Example of transplanter labor requirements and plant output using data from a 1988 Univ. of Nebraska study.*^z

Transplanter	Persons/ transplanter per row	Output per row (acres/h)	
		In tests	Potential ^y
Carousel	2	0.10	0.12
BST	2	0.12	0.23
Chain	1	0.13	0.17

^zOutput reflects rate of work when the machine is actually transplanting onions at a 4-inch plant spacing and does not account for field efficiency (see text).

^yThe column "potential" indicates, in our opinion, a realistic output on a larger-scale situation with experienced workers and properly conditioned containers.

Fig. 2. Onion plant spacing performance of carousel, chain (automatic), and BST transplanters in research plots. Trimming of the onion seed tops was required for operation of the chain transplanter, not for the carousel transplanter, and was optional for the BST transplanter. Spacing measurements were taken between 50 plants in each of six replicated plots for each treatment.

spacing, the BST transplanter still had substantially better performance.

Total onion bulb yield was highest in plots where the BST transplanter was used (Table 2). Onion yields were similar in areas transplanted with the chain-type and carousel transplanters. The yields of onion bulbs with a size of 3 to 4 inches were greatest in areas transplanted with the BST transplanter. Improved onion yields with the BST transplanter are attributed primarily to the more-accurate onion placement, depth control, and spacing between plants.

Onion transplant field trials.

The BST machine was used also in a field-scale evaluation to transplant onions near Greeley, Colo., in 1989. Full field-length strips were transplanted with the BST machine, and the remainder of the field was transplanted by experienced hand labor. The grower desired a 4-inch in-row plant spacing. The transplanter was configured to transplant two beds per pass. Beds were spaced on 34-inch centers, with two rows spaced 11 inches apart on each bed. The machine was

operated at a field speed of 0.45 mile/h, which produced 120 plants/min per row. This is equivalent to 0.4 acre/h for a four-row BST machine. Observed field efficiency [ratio of effective field capacity (actual rate of performance of land or crop processed in a given time, based on total field time) to theoretical field capacity (rate of performance obtained if a machine performs its function 100% of the time at a given operating speed using 100% of its theoretical width), expressed as a percentage] was estimated to be 60% in a field that was 600 ft long. The low field efficiency was caused by loading plants on the machine at one end of the field and turning at both ends of the field. Experienced operators and improved field efficiency could substantially improve output capacity of this BST machine. Figure 3 compares the in-row plant spacing of the BST transplanter with experienced hand labor. The central tendency of spacings with the BST were nearer to the

Table 2. Example of onion bulb yield from different Paperpot transplanters. Data taken from a 1988 Univ. of Nebraska transplanter study. Onion variety was Armada.

Transplanter	Onion tops trimmed	Onion bulb yield (no. 50-lb bags/acre)				Total
		>4 inches	3-4 inches	2-3 inches	<2 inches	
Chain	Yes	420	690	90	5	1205
BST	Yes	710	990	120	10	1830
BST	No	590	910	150	10	1660
Carousel	No	820	430	50	5	1305
LSD ($P = 0.05$)		280	230	100	10	240

Fig. 3. Onion plant spacing performance (1989) of BST transplanter using Paperpot containers compared with commercially grown onion sets transplanted by experienced hand-labor in the same field. Spacing measurements were taken between 20 plants at six locations selected at random within each treatment area.

desired 4-inch spacing than hand-transplanted. In addition, the BST had less dispersion in plant spacing relative to the mode.

Economic aspects. Because three major stages are used in the Paperpot transplant system, onion production costs are summarized for these stages. The first stage includes all inputs and equipment associated with seeding, including the cost of the Paperpot containers, growing media, seeding line equipment (depreciation, interest, repairs, etc.), and labor. For the seeding line stage, Paperpot containers are the largest cost item. Transplant onion cost per acre will decline as overhead costs (equipment, property taxes, etc.) are allocated over more acres.

The second stage involves the actual growing of the onions in the greenhouse (facilities, labor, fertilizer, etc.). The cost of growing onion seedlings in greenhouse facilities can be reduced if other crops can make use of the facilities during different times of the year. Using the greenhouse for one crop (onions) resulted in a total cost for the greenhouse stage of almost \$198/acre. Total cost for this second stage declined to about \$152/acre when two crops shared the greenhouse facility.

Field-transplanting is the third stage of this production system. Total

field-transplanting costs include machinery (transplanter, tractor, trucks), labor, and fuel. Table 3 summarizes total field onion transplanting cost results and prospects using the BST machine for transplanting in the field. It is estimated that experienced operators and Paperpot containers conditioned for good handling would almost double the machine field speed. If the field speed could be increased or field efficiency increased significantly, associated costs would decline dramatically (Table 3). By relatively quick adjustments, the transplanter can be adapted for use for another crop. Row spacing differences also are addressed easily. These considerations further reduce the total cost of transplanting.

The costs summarized here are based on Paperpot transplanting research and demonstrations conducted by staff of the Univ. of Nebraska Panhandle Research & Extension Center. Summing the costs of these three stages of the Paperpot transplanting system

Table 3. Transplanting costs per acre for onions with different transplanter coefficients and one or two crops using the BST transplanter.

Speed (miles/h)	Field efficiency	
	60%	75%
	One crop	Two crops
0.45	\$365	\$302
0.90	\$189	\$152

provides a basis for comparing the system with traditional field-grown, hand-transplanted onions. The Paperpot system for onions currently would cost about \$832/acre [based on \$480/acre, \$200/acre and \$152/acre for the seeding line, greenhouse, and field transplanting stages, respectively]. Detailed cost studies for the traditional system have not been developed; growers involved consider this information proprietary. General discussion with growers indicates that, based on 1989 conditions, the cost of the Paperpot system would probably need to be reduced by at least \$130/acre to be competitive with present systems.

Several potential options exist to reduce the cost of the Paperpot system for onions, besides reducing the cost of the Paperpot container. One option is to use more than one seed per container, which can reduce significantly seeding line and greenhouse costs. This option needs to be evaluated carefully in terms of the impact on onion quality and field cultural practices. There also may be benefits to the Paperpot system for weed, insect, and disease control compared to traditional field-grown transplants that could improve the overall economics of the system. For example, placement of chemicals in the containers prior to transplanting.

Conclusions

Paperpots. The cost of imported Paperpot containers more than doubled between 1984 and 1989. Most of the cost increase was due to changes in currency exchange rates between the United States and Japan. Paperpots are a patented product and no production capability is available in the United States. Cultural practices in the greenhouse, such as watering frequency and amount and fertilizer application, can influence container breakdown, which can significantly influence transplanter performance.

Transplanters. Modification of automated transplanters will be necessary for further acceptance of the Paperpot system in the United States. The BST transplanter is currently in production in Japan and is an excellent machine. The "U.S. version" should use heavier construction consistent with current farm equipment; a common, positive drive, particularly for closely spaced crops; a convenient plant storage rack; and should be adaptable to narrow row spacing. For vegetables in Paperpots, the BST machine provides the best initial prospect for semi-automation of field transplanting.

The chain-type transplanter has

the potential to substantially reduce the labor required during transplanting, but must have further design/development before it will be accepted. Blending the design concepts of the BST and chain-type Paperpot transplanters should result in improved automation for U.S. growers.

Other system components. The viability of the Paperpot system for vegetable transplanting also will depend on reducing the per-unit cost (\$/transplant) contributions of other system components. For example, increased transplanting capacity and reduced labor input with a relatively low capital investment can improve the overall economics of the system. If several types of vegetables, using different sizes of containers, are to be processed through the seeding line to help spread investment cost over more transplants, appropriate flexibility must be designed into the machinery.

Another important system constraint is the handling and transportation of seeded Paperpot containers. Enhancement should focus on reducing labor requirements and minimizing damage to Paperpots. Damage to Paperpots impedes transplanter performance, especially for chainpots.

Literature Cited

- Brewer, H.L. 1988. Experimental automatic feeder for seedling transplanter. *Applied Eng. in Agr.*, 4:24-29.
- Huang, B.K. and W.E. Splinter. 1968. Development of an automatic transplanter. *Trans. ASAE* 11:191-194.
- Masuda, A. 1986. Latest development in sugar beet transplanting techniques in Japan. *Proc. 49th Winter Congr., Intl. Inst. for Sugar Beet Research, Brussels, Belgium*. p. 201-221.
- Masuda, A. and K. Kagawa. 1963. Agronomical techniques to develop superior seedlings of sugar beet through the "paper tube transplanting system", growth responses of seedlings to the concentration of fertilizers. *Jpn. Bul. Sugar Beet Res. Suppl.* 4: 7-14.
- Nippon Beet Sugar Mfg. Co. 1981. The Paperpot transplanting method of sugarbeet. Research Center, Nippon Beet Sugar Mfg. Co., Obihiro, Japan.
- Suggs, C.W., T.N. Thomas, D.L. Eddington, H.B. Peel, T.R. Seaboch, and J.W. Gore. 1987. Self-feeding transplanter for tobacco and vegetable crops. *Applied Eng. in Agr.*, 3:148-152.
- Suggs, C.W., D.L. Eddington, T.R. Seaboch, and H.B. Peel. 1989. Automatic feeding transplanter. *Amer. Soc. Agr. Eng., St. Joseph, Mich. ASAE Paper* 89-1083.