

Transplant Age in Vegetable Crops

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ADDITIONAL INDEX WORDS. *Lycopersicon esculentum*, *Capsicum annuum*, *Solanum melongena*, *Physalis ixocarpa*, *Citrullus lanatus*, *Cucumis melo*, *Brassica oleracea* var. *italica*, *Brassica oleracea* var. *capitata*, *Brassica oleracea* var. *botrytis*, *Brassica campestris* ssp. *pekinensis*, *Brassica napus* ssp. *oleifera* var. *napus*, *Allium cepa*, *Allium porrum*, *Lactuca sativa*

SUMMARY. The research reviewed here represents the majority of the information available on transplant age to date. When the results of these studies are distilled down to the "ideal" transplant age for setting of a specific crop, we generally arrive at the recommendations found in the 1962 edition of *Knott's Handbook for Vegetable Growers*. The conflicting results in the literature on transplant age may be due to the different environmental and cultural conditions that the plants were exposed to, both in the greenhouse and in the field. The studies did reveal that the transplant age window for certain crops might be wider than previously thought. Older transplants generally result in earlier yields while younger transplants will produce comparable yields, but take longer to do so. Our modern cultivars, improved production systems, and technical expertise enable us to produce high yields regardless of transplant age. The data, in general, support the view that if a vegetable grower requires resets after an catastrophic establishment failure (freeze, flood, etc.), they need not fear the older plants usually on hand at the transplant production facility.

The effect of transplant age on yield is an issue often broached by growers of horticultural and agronomic crops in an effort to maximize production potential. Despite general interest in this area, the literature is surprisingly sparse. For example, *Bedding Plants IV* (Holcomb, 1994), a highly regarded manual on the culture of bedding plants as greenhouse crops, makes only passing reference to transplant age, usually from a postharvest shelf-life standpoint.

Agronomic interest in transplant age is most prominent in rice (*Oryza sativa* L.), a bare-root transplanted crop of major economic importance. Transplant age studies have also been conducted on tobacco [*Nicotiana tabacum* L.] (Greenfield and Paterson, 1994; Tancogne, 1991), cotton [*Gossypium hirsutum* L.] (Abou-Zeid et al., 1995; Sherief et al., 1995), rape [*Brassica napus* L. ssp. *oleifera* var. *napus* L.] (Gupta, 1994), and forest species (Battaglia and Reid, 1993; Chaney and Byrnes, 1993).

The largest volume of literature on transplant age is on vegetables. *Knott's Handbook for Vegetable Growers* (Lorenz and Maynard, 1988) and various extension bulletins (e.g., Vavrina, 1995) suggest ages for field planting of numerous vegetable transplants (Table 1.) These recommendations are generally based on years of horticultural observations and research. But the scientific investigation of vegetable transplant age is far from complete.

Table 1. Times required for growing plants for field transplanting.^z

Vegetable	Time (weeks)
Broccoli	5-7
Brussels sprouts	5-7
Cabbage	5-7
Cauliflower	5-7
Celery	10-12
Corn, sweet	3-4
Cucumber	3-4
Eggplant	6-8
Lettuce	5-7
Muskmelon	3-4
Onion	10-12
Pepper	6-8
Summer squash	3-4
Tomato	5-7
Watermelon	3-4

^zTable adapted from Lorenz and Maynard, 1988.

McKee (1981) provided a brief review of studies conducted on transplant age. He referenced work by Loomis (1925) and Dullforce (1954), noting that almost all vegetables can be transplanted as early seedlings with little effect on growth, but with increasing age, this situation changes. He stated "The later the transplant check [i.e., cessation in growth] occurs in the ontogenetic development of the plant, the more serious the effect in terms of its normal development. Following transplanting, older plants have only a limited time for the readjustment of their vegetative development before the initiation of reproductive growth or the maturation of the vegetative phase." (p. 270).

How does the transplant producer and vegetable grower view age? As a general rule, vegetable growers prefer young, actively growing transplants. While the traditional time frame for vegetable transplant production (4 to 6 weeks) is generally adhered to by the producer, a delay in the vegetable growers' planting schedule results in aging transplants. Additionally, the transplant producer may tend to slow plant growth in an effort to stay within height constraints often dictated by the vegetable grower. Finally, in the event of a catastrophe (freeze, flood, etc.) vegetable growers demand transplants to replant, regardless of age. When transplants are thought to be too old, concerns are raised about their subsequent growth and yield potential.

This paper will review the litera-

ture on vegetable transplant age and its effect on field performance. The focus of this review will be on data found in journal articles and abstracts. It also recognizes that both greenhouse and field practices (e.g., cultivar, irrigation, fertilization, etc.) and the environment affect transplant establishment and subsequent yield, but it is not the intent of this article to address these practices. A summary of transplant age research on 15 vegetable crops is presented.

Solanaceae

TOMATO (*Lycopersicon esculentum* MILL). A review of the literature on tomato transplant age has shown that little can be distilled from the 70 years of research (Vavrina and Orzolek, 1993). A revised summary table from that work (Table 2) shows that lack of standardized methods, multiple cultivars, processing versus fresh market types, bare-root vs. containerized, various container cell sizes, superimposed studies, postharvest storage, and other aspects all led to varying results.

Vavrina and Orzolek (1993) concluded that transplant age apparently had little bearing on tomato production. Some points stressed by the authors included the following:

- 1) Young transplants (3 to 4 weeks) reduce production costs, but may not pull from the container without injury, and will need to be grown longer in the field to reach optimum yield (Hoffman, 1929; Leskovar et al., 1991; Orzolek et al., 1991).
- 2) Older transplants (7 to 9 weeks) tend to produce earlier yields (Hoffman, 1929; Liptay, 1987; Nicklow and Minges, 1962; Vavrina, 1991) but may result in more problems during the greenhouse phase (i.e., insects and diseases).
- 3) Commercial transplant guidelines (4 to 7 weeks) are very appropriate, however, if significant mortality occurs after transplanting, the use of older plants to reset fields should not reduce yield, fruit size, or earliness.

PEPPER (*Capsicum annuum* L.).

Nicklow (1963) in a study in New York state, found that pepper transplants without flower buds or with unopened flower buds produced more large fruit (early and total) than transplants with open blooms or small fruit.

McCraw and Greig (1986) used 8- and 11-week-old transplants of four cultivars in a pepper transplant age study in Kansas in 1975-76. Pooling the data from the four cultivars, they found no differences due to transplant age in early yield (number, weight) the first year, but a greater number of heavier fruit with 8-week-old transplants the following year. Three of the four cultivars tested showed that the 11-week-old plants produced more total fruit per plant than the younger transplants (12 vs. 10 fruit).

Weston (1988) conducted a study in Kentucky using containerized pepper transplants of 4, 6, 7, and 9 weeks. She found 70% more early U.S. Fancy and No. 1 fruit with 9-week-old transplants. However, total U.S. Fancy and No. 1 fruit yield and total overall yield were unaffected by transplant age.

Vavrina and Armbruster (1991) conducted a 1-year trial in Florida with transplant ages of 4, 6, and 11 weeks. They found no effect of transplant age on yield (number, weight) in three of four harvests, but a significant yield increase at fourth harvest with 4-week-old transplants. The yield effect here was due to a greater number of fruit not greater individual fruit weight. McCraw and Greig (1986), as noted above, had a similar finding with 11-week-old transplants.

Three of the studies cited here imply that pepper transplants of 8 to 11 weeks may have a yield advantage for early size and number of fruit (McCraw and Greig, 1986; Nicklow, 1963; Weston, 1988). Yet Vavrina and Armbruster (1991) offered evidence that younger transplants may eventually exceed yields produced by older plants. These researchers used different cultivars, numbers of harvests (McCraw and Greig, 3; Vavrina and Armbruster, 4; Weston, 10), and were under quite different environments, which makes comparisons among the studies difficult. Perhaps a standardization of the number of harvests for early and total yield is necessary to critically determine the impact of transplant age on pepper production. Considering the slower growth habit of pepper compared to tomato, older transplants (i.e., >4 to 6 weeks) may be advised.

EGGPLANT (*Solanum melongena* L.).

Lou et al. (1993) indicated that younger eggplant grew more vigorously after transplanting and yielded

Table 2. Yields associated with tomato transplant age studies as determined by multiple researchers.^z

Researcher	Cultivar	Transplant Age Range	Highest Yield		
			"Ideal" Age	Early (lb/plant)	Total (lb/plant)
Hoffman (1929)	---	5, 6, 9, 10	5	---	10.6
Casseres (1947)	Earliana	7, 11, 15	7	0.89	11.9
Sayre (1948) ^y	John Baer	6, 8, 10	6	3.86	---
			8	---	18.04
	John Baer	10, 12, 14	10	3.49	---
			10	---	9.87
Chipman (1961) ^y	Scotia	7-12	7	2.6	---
			8	---	8.8
	Scotia	7-12	7, 8	15.4	---
			7	---	28.5
Nicklow & Minges (1962)	Fireball	6, 8	6	---	11.2
	Fireball	4, 6, 8	4	---	2.2
	Fireball	3, 5, 7, 9	9	0.24	---
			5	---	12.9
Cooper & Morelock (1983) ^x	Traveler '76	5, 7, 9, 11	7	1.35	---
			5	---	8.0
Liptay (1987)	H-2653	4-7	7	4.20	---
			6	---	7.9
Weston & Zandstra (1989)	Pik-Red	3-6	4	2.23	---
			6	---	17.1
Leskovar et al. (1991)	Sunny	3-6	5	10.20	---
			4	---	25.5
	Sunny	2-5	4	4.11	---
			4	---	15.0
Vavrina (1991)	Sunny	3, 5, 7, 9, 11	9	8.33	---
			9	---	11.9
Orzolek et al. (1991)	Sunny	3, 4, 7, 9, 11	4	---	6.9
	Colonial	5, 7, 9, 11, 13	13	---	10.1

^zTable adapted from Vavrina and Orzolek, 1993.^yPlant populations not indicated; therefore, yields given in tons/acre.^xPlant populations determined through personal communication.

greater than older seedlings in China. Hotta et al. (1993) in Japan determined that 40-d-old eggplant seedlings were the most successful in summer trials. Harmon et al. (1991) tested 4-, 5-, 6-, and 7-week-old eggplant transplants in Kentucky. They suggested that transplants ≤5 weeks old produced only minimal yields, while the earliest yields were obtained with 7-week-old plants in large cells (>30.7 cm³).

The information available from these studies did not define ideal eggplant transplant age. However, the data supported a 5- to 7-week-old transplant, similar to tomato.

TOMATILLO (*Physalis ixocarpa* BROTT.) Pena-Lomeli et al. (1991) in Mexico used three cultivars of tomatillo transplants of 2, 3, 4, 5, and 6 weeks of age. They found the 3-week-old transplants had the highest yields across cultivars. Direct-seeded tomatillo out yielded the 5- and 6-week-old transplants.

Cucurbitaceae

WATERMELON (*Citrullus lanatus* (THUMB.) MATSUM & NAKAI). Vavrina et al. (1990, 1993) in Florida reporting on four years of data, showed that watermelon transplant age did not effect either early or total yield. Transplants of 3, 5, 7, 9, 11, and 13 weeks of two cultivars were evaluated in multiple locations. The authors suggested that in the event of a crop loss, age of the watermelon resets need not be a consideration.

SQUASH (*Cucurbita pepo* L.). NeSmith (1993) compared 1-, 2-, 3-, 4-, and 5-week-old summer squash (yellow crookneck and zucchini) transplants in greenhouse and field studies in Georgia. He found no difference in early or cumulative yield due to transplant age in yellow squash, but slightly higher cumulative yields with 4-week-old zucchini transplants. He advocated 3-week-old transplants, which agrees with the recommendations in Knott's

Handbook for Vegetable Growers (Lorenz and Maynard, 1988). NeSmith stated further that a 3-week-old transplant could be held for 10 d before planting, if necessary, without subsequent yield loss.

MUSKMELON (*Cucumis melo* L.). NeSmith (1994) also designed a muskmelon transplant-age trial using plants 2, 4, 6, and 8 weeks old. He found age had no effect on either early or total yield.

These research data imply that transplant age does not adversely influence yield in cucurbits. Commercially, 3- to 4-week-old transplants are used for general cucurbit production. However, findings here support the idea that cucurbits can be held beyond this time frame without fear of yield loss, in the event of poor planting conditions.

Brassicaceae

BROCCOLI (*Brassica oleracea* L. VAR. *ITALICA* PLENCK.). Olson and Lo-

cascio (1990) ran four experiments in Florida with broccoli transplants of 3, 4, 5, and 6 weeks of age. In two of the four trials, age had no effect on yield. In the remaining two trials, the 6-week-old plants yielded the most in one trial and the least in the other trial.

Jones et al. (1991) studied broccoli transplant age (specified only as 3 to 7 weeks), in spring and fall crops for two years in Kentucky. This work found transplants of 5 weeks or older produced higher early fall yields in one of the two years. However, age had no effect on spring early or total yield.

In a study that stretched the limits of transplant age, Lamont (1992) compared broccoli transplants of 31 and 29 weeks to plants of 2 and 6 weeks of age, respectively, in trials in North Carolina. He found minor statistical differences in head weight and diameter in a spring trial only, but considered the differences too small to be of concern to the consumer.

Damato et al. (1994) used three cultivars of broccoli in a study with transplants 5, 6, and 7 weeks old for fall production in Italy. These authors found a linear decrease in individual head weight with increasing age, but treatment effect on head weight was not significant when tested via mean separation. Time to first harvest increased significantly with increasing age, however the incidence of hollow stem lessened with increasing age in this study.

These studies sufficiently cloud the issue of transplant age in broccoli. Jones et al. (1991) suggest older is better, Damato et al. (1994) indicate younger is better, Lamont (1992) implies age makes no difference, and Olson and Locascio's (1990) results confirm each of the other researchers work. Neither Olson and Locascio, Lamont, nor Jones et al. addressed time to harvest, an important factor to growers. However, it appears more work is necessary before recommendations for broccoli transplant age can be made.

CABBAGE (*Brassica oleracea* L. VAR. *CAPITATA* L.). Jones et al. (1991) found that transplant age did not influence cabbage early or total yield in the spring of their 2-year study in Kentucky.

CAULIFLOWER (*Brassica oleracea* L. VAR. *BOTRYTIS* L.). Salter and Fradgley (1969a) found if they delayed using bare-root-raised cauliflower transplants

by 14 days, time to maturity was unaffected, but marketable yields tended to decline (Salter and Fradgley, 1969b).

Wurr et al. (1986) conducted two experiments with cauliflower in England; the first study compared 5- and 6-week-old transplants to 7- and 8-week-old transplants while the second compared 5- and 7-week-old transplants to 6- and 8-week-old transplants. They determined transplant age had only a minor effect on time to 50% maturity (old plants matured 3 days later than young plants in one of two years), but transplant age had no effect on yield (Wurr et al., 1988).

Jones et al. (1991) found that containerized cauliflower transplants of ≥ 5 weeks produced higher early and total yields in one of two fall trials and higher early yields in the spring (in general).

In a 3-year trial in Poland, Lewandowska (1992) demonstrated higher yields of better quality cauliflower with younger transplants (age unspecified). The study involved three cultivars and transplants of 3, 4, 5, 6, and 7 weeks of age. Lewandowska further noted that as transplant age increased, so did the time to early and mid harvest.

The data supplied by these cauliflower studies suggest more may be at work here than transplant age (e.g., cultivar, season, etc.). Slater and Fradgley (1969a) used bare-root plants, while Wurr et al. (1986) used containerized plants. The data from Jones et al. (1991) and Lewandowska (1992) were simply abstracts. Therefore, more information is necessary concerning cauliflower transplant age.

CHINESE CABBAGE [*Brassica rapa* L. SSP. *PEKINENSIS* (LOUR.)]. Kratky et al. (1982) in Hawaii found no significant differences in time to maturity, individual head weight, and total yield from Chinese cabbage transplants of 3, 4, 5, and 6 weeks of age.

RAPE (*Brassica napus* SSP. *OLEIFERA* VAR. *NAPUS*). In a 3-year study in India with fall-planted rape, Gupta (1994) showed that rape seedling age influenced seed yield. Of the 30-, 40-, 50-, and 60-d-old transplants, the highest yields were obtained from the 60-d-old plants.

Alliaceae

ONION (*Allium cepa* L.). Vachhani and Patel (1988, 1989) in India used red onion transplants from 4 to 10

weeks old and found yields increased with increasing age to 7 weeks. Yields then gradually decreased with older plants.

Lujan-Favela (1992) in Mexico, compared planting date and transplant age with a white Grano cultivar, showing the highest yields from 7-week-old transplants set in mid-September. Lujan-Favela correlated yield with transplant size suggesting larger was better.

Wojtaszek et al. (1993) grew 30-, 40-, and 50-d-old onion transplants in peat blocks (5 seed per block) for spring onions in Poland. They found no effect of age on marketable yield.

Herison et al. (1993) in Michigan used three cultivars of containerized Spanish-type onions, 8, 10, and 12 weeks of age. Although bulbs essentially matured at the same time, the 10- and 12-week-old transplants yielded larger bulbs. This response was positively correlated with larger plants at transplanting.

Yield response in onions may be more the result of plant size than age as both Herison et al. (1993) and Lujan-Favela (1992) suggested. Herison et al. (1993) noted higher N rates during transplant production resulted in larger seedlings (regardless of age) and greater yields. Most onion transplants are field grown due to the population density required per unit area. Wojtaszek et al. (1993) and Herison et al. (1993) conducted studies with containerized plants but Vachhani and Patel (1988) and Lujan-Favela (1992) gave no indication whether their studies involved containerized or bare root transplants.

LEEK (*Allium porrum* L.). Kunicki (1993) in a 3-year study in Poland with leek transplants of 11, 13, and 15 weeks of age, found no effect of age on crop height or quality.

Asteraceae

LETTUCE (*Lactuca sativa* L.). Boa et al. (1979) suggested a minor effect of transplant age on butterhead lettuce, finding older transplants tended to produce lighter heads.

Wurr et al. (1987) conducted seven experiments over 3 years in England on the influence of plant raising and transplant age on crisp (Iceberg) lettuce. Finding inconsistent results, they concluded that the plant age (13, 19, 25, 32 d) affected mature head weight and suggested that younger transplants (<25 d) minimized varia-

tion in head weight across seasons (i.e., product consistency.)

The studies reviewed above represent the majority of the research on transplant age found in the literature today. Yet with all this work, we still fall short of an ideal transplant age. When the results of these studies are distilled to determine a satisfactory range for an individual crop, we generally arrive at the recommendations laid down in *Knott's Handbook for Vegetable Growers* (Knott's, 1962). The conflicting results in the literature on transplant age are likely due to the different environmental and cultural conditions that the plants were exposed to in the greenhouse and in the field.

Certainly, even under the most controlled experimental conditions, older plants are exposed to greater levels of hardening and water stress. Root pruning, which may be excessive in bare-root production, and is encouraged by the air-pruning Speedling system, will differ in magnitude among plants of varying ages. Such factors result in hormonal changes that influence plant growth, and as McKee (1981) suggested, there may be a point beyond which normal growth does not occur.

Yet these studies revealed that the transplant age window for certain crops may be wider than we had previously thought. Perhaps our modern cultivars, production systems, technical expertise, or a combination of these factors enable us to produce high yields regardless of transplant age. Or perhaps transplant age may just not be critical at all. Transplant producers will continue to provide their clientele with quality transplants of a particular age as dictated by their production practices. Vegetable growers, in the event of catastrophic loss, will not fear "older" plants, knowing yields will not suffer.

Research on vegetable transplant age provides a valuable service, yielding new information while building on the existing literature foundation. Several observations noted while reviewing these studies should help in developing a stronger database in the future:

ABSTRACT. Published abstracts should provide full, clear, and concise information, especially for work compiled in an abridged form (e.g., proceeding papers), obscure source, or

where a translated summary is requested. A translated abstract may be our only opportunity to benefit from information contained in a publication from another culture.

STANDARDIZATION. Realizing the impact of aspects other than transplant age on transplant growth (cultivar, cell size, fertilization, water quality, etc.), production practices should be more standardized across studies. Qualified commercial operations might be enlisted for the actual growing of test seedlings. Additionally, replications of and comparisons with established work should occur.

AGE RANGE. Efforts should be made to broaden experimental time frames. Researchers are often timid in their approach, limiting studies to 3, 4, 5, and 6 weeks. If Lamonts' (1992) results were not significant for transplants varying in age from 2 weeks to 6 months, than what can we hope to learn from short time-frame studies?

YIELD ASPECTS. All studies should incorporate at least time to maturity, early yield, and total yield, and include fruit size and/or grade characteristics. Some standardization in number of harvests (for multiple-harvest crops) and determination of earliness is also suggested.

CULTIVAR. At least two cultivars should be included to distinguish if genome plays a role.

STATISTICAL SIGNIFICANCE VS. COMMERCIAL REALITY. Researchers should give consideration to distinguishing between significant results and their application to commercial production. Small significant differences may not be of great commercial importance.

HELPFUL HINTS. In addition to transplant age effects on yield, secondary horticultural findings of value often result from the research. Examples of useful information gained from the studies reviewed here include: younger tomato transplants must be grown in the field longer to reach optimum yield (Hoffman, 1929; Orzolek et al., 1991), onion transplants of various ages essentially mature at the same time (Herison et al., 1993), pepper transplants without flower buds or with unopened flower buds produce more large fruit (early and total) than transplants with open blooms or small fruit (Nicklow, 1963), and watermelons set fruit synchronously regardless of transplant age (Vavrina et al., 1993).

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