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Vegetable Transplant Nutrition

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SUMMARY. The first objective of this paper is to review and characterize the published research in refereed journals pertaining to the nutritional practices used to grow vegetable transplants. The second objective is to note those studies that indicated a direct relationship between transplant nutritional practices and field performance. The third objective is to suggest some approaches that are needed in future vegetable transplant nutrition research. Even after review of the plethora of available information in journals, it is not possible to summarize the one best way to grow any vegetable transplant simply because of many interacting and confounding factors that moderate the effects of nutritional treatments. It is, however, important to recognize that all these confounding factors must be considered when developing guidelines for producing transplants. After thorough review of this information, it is concluded that transplant nutrition generally has a long term effect on influencing yield potential. Therefore, derivation of a nutritional regime to grow transplants needs to be carefully planned. It is hoped that the information that follows can be used to help guide this process.

Vegetable transplants have been used for decades and the advantages for their use are well-documented (Dufault, 1993). The character (size and age) of transplants has changed tremendously since the early 1930s, as well as the methods used to produce them. Prior to standardized trays, all sorts of containers were used such as clay pots, peat pots, paper bands, wood veneer bands and tin cans (Ware, 1937). Field soils were used to grow transplants and often, composts were developed years in advance to produce a soil that was more fertile for transplant growing (Work, 1945). In many cases, the resulting transplants were very large and unwieldy. Regulation of the nutrition was not a major consideration during the production phase since field soils naturally provided nutrient release.

Since the early 1930s, the use of transplants and the transplant industry have both grown dramatically necessitating more efficient greenhouse utilization and the use of smaller transplants. Today's transplants bear little resemblance to the transplants of the past, with most present day transplants are grown in standardized trays with soilless media using nutritional methodologies that are completely different from past practices. The necessity of scheduling the delivery of transplants to commercial growers required that all phases of transplant production be strictly controlled, especially the growth rate of transplants. The most effective way of controlling transplant growth is to moderate the nutritional regimes used to grow them.

In the past 20 years, there has been an abundance of vegetable transplant nutrition research published on a wide array of crops which has attempted to define nutritional methods that moderate growth effectively. The first objective of this paper is to review and characterize the published research in refereed journals pertaining to the nutritional practices used to grow vegetable transplants. The second objective is to note those studies that indicated a direct relationship between transplant nutritional practices and field performance. The third objective is to suggest some approaches that are needed in future transplant nutrition research.

Goals of commercial vegetable transplant nutrition

Selection of a nutritional regime to grow a specific vegetable transplant crop depends on the desires of the transplant grower and the farmer who buys the transplants. The transplant grower needs to produce a plant that is visually appealing and of acceptable quality to his customer. Further, the transplant grower must control the growth of the transplants to insure that the plants are at the desired size and age for field planting and for shipment to the market or farmer. In some cases, farmers often dictate the height, color, size, etc., of the desired transplant and with those specifications, the transplant grower must produce the desired transplants before they will be deemed acceptable. The farmer, on the other hand, uses transplants because he usually wants earlier production and greater total yields compared to direct seeding.

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In commercial transplant production, the nutritional regimes used to grow transplants can generally be altered to modify the production scheduling and shipping quality requirements. Finished transplants tend to be small in order to pack hundreds together in shipping boxes. These transplants must be "pulleable" from growing trays with good root systems that are not injured in the removal process. Transplants should be mildly hardened to prepare the plants for rigors of shipping, but should also be visually attractive to the farmer. The transplants should have the ability to be held for a short time upon delivery in case the fields cannot be planted immediately. Lastly, transplants need to be pest free. For the transplant grower, delivering the transplants to the farmer is a terminal process.

Commercial production of transplants needs to be as pragmatic as possible. Complex nutritional practices are only justified if the subsequent transplants perform better in the field. Performance includes improvements in stand establishment coupled with enhancements in one or more attributes of earliness, uniform maturity, yield quantity and quality, and postharvest holding superiority. Much of the published research describes changes induced by certain nutritional practices upon seedling growth only, but, unfortunately, field trials are lacking. This research has merit since transplant growers are very concerned that the marketable product is visually appealing and acceptable to the commercial vegetable grower. However, if long term effects of transplant nutrition are not demonstrated in some improvement of field performance, the most basic fertility plan should be chosen.

Characteristics of published vegetable transplant nutrition research

Thirty-eight papers were found in the literature on transplant nutrition that dates back as early as 1940. In those papers, 46 separate experiments were conducted on many crops to include: asparagus, broccoli, cabbage, cantaloupe, cauliflower, celery, lettuce, onion, peppers, tomatoes, and watermelon. The most popular crop studied was tomatoes with 33% of all work devoted to fresh and processing tomatoes. Celery was second in popularity with 17% of all publications, followed by pepper (13%), lettuce (11%), broccoli (7%), asparagus, cauliflower, and watermelon (4% each), and cabbage, muskmelon, and onion (2% each).

The major nutrient studied in all these transplant nutrition reports was nitrogen (N) with sources of N a very popular topic of the research studies. The most commonly recommended source and ratio was a 2:1:2 ratio of nitrate-N/ammonia-N/urea on seven different crops, followed by calcium nitrate on six different crops. Five crops were produced with a 2:1 ratio of nitrate-N to ammonia-N. The following tabulation relates to published research using various N sources along with the number of vegetable crops included in these studies: urea alone (5), potassium nitrate (5), urea/nitrate-N/ammonium-N 3:2:1 (4), sodium nitrate (3), nitrate-N/ammonium-N 2:1 (2), nitrate-N/ammonium-N 3:1 (2), ammonium phosphate (2), nitrate-N alone (1), and even Osmocote (1). The second most commonly studied nutrient was phosphorus with 14 studies evaluating different rates of N with P. Six studies included experimental potassium rates included with nitrogen rates. Lastly, 3 studies examined calcium used with N rates.

Most of the published transplant nutrition work evaluated a range of experimental N rates only. In pooling all this data across all crops, the most commonly recommended N rate for vegetable crop transplant production ranges between >300 to 400 ppm; however, all of these reports except one study, were from Canadian researchers (suggesting a location effect). About 40% of the papers reviewed recommended this high N rate. Twenty-three percent of all research papers recommended >200 to 300 ppm N. Recommendations for lower rates dropped to 17% for >100 to 200 ppm N, 10% for either >50 to 100 ppm or 0 to $\leq$50 ppm N. Within each of these groups, there are no trends in recommending the same N rate for an individual crop across all the studies. For example, some studies recommended up to 400 ppm N for pepper, tomato, lettuce, while other studies recommended 50 to 100 ppm N for the same crops.

The diversity of plant response in the reviewed literature makes distillation, recommendation and adaptation difficult on a commercial basis. Examination of this literature leaves one confused about what specifically is required to produce an acceptable transplant with high yield potential. Clear cut, straightforward application of these guidelines is confusing because of the great diversity of conditions that the research was conducted under. Confounding items include differences due to

1) Crops
2) Cultivars within the same crop
3) Microclimatic diversity of greenhouse environments used in research
4) Fertilizer sources and concentrations, i.e., nitrate, ammonium, urea, and other nutrients used such as secondary and even trace elements
5) Interaction of other factors studied, for example CO_2 enrichment, nutrient ratios, application timing, container type and size, supplemental lighting, etc.
6) Interaction between nutrients and growth media, affecting cation exchange capacity, pH, salinity, etc.
7) Geographical research location and microclimatic diversity of field environment transplant subsequent yield performance was evaluated.
8) Application frequency resulting in differences in total application of an element.

Whereas much of the published research on transplant production recommends high N levels, these rates increase transplant size especially in southern-grown locations. In some vegetable production regions, the industry may reject large transplants due to difficulty in transplanting with commercially available transplanting units and the greater incidence of transplant shock in the field.

A dilemma exists in that much of the published research also indicates a long term advantage from using high N rates on increasing early yields than at lower rates. Out of the published studies that took nutritionally conditioned transplants to yield, 76% indicated greater earlier or total yields (Table 1), with only 24% reporting no significant difference in yield. It is also uncommon for total yield of a sequentially harvested vegetable crop to be enhanced by transplant nutrition, but 8% of these studies reported greater total yield. The process of deciding the value and application of published transplant nutrition research is confounded further by the fact that these very large transplants invariably were hand planted with lots of care, versus the real world abuse that commercial transplants are exposed to. Therefore, it is indeed difficult to judge the merits of these recommended regimes from published research and adapt them commercially without more testing of high N transplants and controlled mechanical transplanting stresses.

Comparative vegetable transplant nutrition research on individual crops

ASPARAGUS (*Asparagus officinalis* L.). In the two studies conducted on asparagus transplant nutrition (Adler et al., 1984; Precheur and Maynard, 1983), the experimental approaches were different. Adler et al. (1984) evaluated N-P-K rates on Green Giant cultivar in a greenhouse transplant quality, study using N from urea at 0 to 200 ppm, P from phosphoric anhydride at 0 to 20 ppm and K from potassium chloride at 0 to 200 ppm. They evaluated the effect of transplant nutrition on shoot and root weights and number, plant height and bud number on seedling crowns and found that 100 ppm N-K with 20 ppm P was sufficient for quality asparagus transplant production, but this work was riot taken to the field. Precheur and Maynard (1983) assessed ratios of nitrate-N to ammonium nitrate at 100%, 75%, and 50% at 15 meq$\cdot$L^{-1} using calcium nitrate, potassium nitrate and ammonium sulfate as N sources. Optimal 'Rutgers Beacon' transplant growth occurred with 75% nitrate-N and 25% ammonium nitrate and calcium carbonate at 1% (w:w) in a sand media, reduced ammonium toxicity.

BROCCOLI (*Brassica oleracea* L. VAR. *itatica*). Three Canadian Studies have been contributed to our understanding of broccoli transplant nutrition. Tremblay and Senecal (1988) surveyed different N and K rates on 'Emperor' broccoli. The study compared N at a 3:2:1 ratio of urea, nitrate-N, and ammonium-N at 150 and 350 ppm N, and K from potassium hydroxide and potassium sulfate at 200 and 350 ppm. In this greenhouse study, they evaluated shoot and root weights, leaf area and growth ratios and reported that N at 350 ppm with 200 ppm K promoted transplant growth. In 1991, Masson et al. (1991a, 1991b) grew transplants with N from a 2:1:2 ratio of nitrate-N, ammonium-N and Urea at 100 to 400 ppm N and they also exposed these transplants to either artificial light at 10 µmol$\cdot$s$^{-1}\cdot$m^{-2} or natural light. They found that 400 ppm N increased transplant growth but decreased root growth and artificial light increased shoot and root growth. Broccoli transplants grown with 400 ppm N yielded heavier heads than those transplants grown at lower

Table 1. Lowest N rate in transplant nutrient solutions recommended in published research to increase vegetable crop yield[z]

Crop	Yield	Recommended N rate	First author and year
Boccoli	T	400 ppm	Masson, 1991
Cabbage	E	1030 ppm	Babb, 1940
Cantaloupe	E	250 ppm	Default, 1986
Cauliflower	E	1030 ppm	Babb, 1940
Celery	T	300 ppm	Masson, 1991b
Celery	T	350 ppm	Tremblay, 1989b
Celery	T	400 ppm	Tremblay, 1987
Lettuce	T	200-600 ppm	Kratky, 1981
Lettuce	T	400 ppm	Masson, 1991b
Onion	T	150-250 ppm	Herison, 1993
Pepper	E	5m*M*	Bar-Tal, 1990b
Pepper	T	240 g N/m^3	Knavel, 1977
Tomato	E + T	8-15 m*M*	Basoccu, 1995
Tomato (Processing)	T	10 m*M*	Garton, 1990
Tomato (Processing)	E	100-200 ppm	Liptay, 1993
Tomato	E	300-400 ppm	Masson, 1991b
Tomato	E +T	200 ppm	Melton, 1991
Tomato	E	75 ppm	Vavrina, 1994
Tomato	E	400 ppm	Weston, 1989

[z] E=Early Yield; T=total yield.

Table 2. Vegetable transplant nutrition research on celery[z]

Cultivar	Reference	N rates & source	Other factors studied	Location, conclusions and recommendations
'Utah 527OR'	Dufault, 1985	10, 50, 250 ppm from urea	P anhydride at 5, 25, 125 ppm, K from KCl at 10, 50, 250 ppm	Greenhouse. Shoot & root growth increased with N rate. Shoot growth, but not root growth increased with P rate. K had no effect. Suggested 250N-125P-10K ppm for quality growth.
'Utah 527OR'	Dufault, 1985	1.25, 2.5, 5.0, 7.5, 10.0, 20.0 g kg^{-1} Osmocote media (1.5 vermiculite: 1.5 Perlite: 7 peat)	P at 1.25, 2.5, 5.0, 7.5, 10.0 g kg^{-1} media from Osmocote	Greenhouse., Shoot growth increased from 1.25 to 10 g?k-1 media, but decreased from 10 to 20 g?kg^{1} media. Increaseing P rate from 1.25 to 10.0 g?kg^{1} media only decreased chlorophyll content. N rate of 1.25 & 2.5 g?kg^{-1} media produced quality transplants only in "cool" greenhouses at 14º to 24ºC.
'Florida 683'	Masson et al.,1991a	100, 200, 300, 400 ppm from 2:1:2 ratio NO_3, NH_4, urea	natural light versus artificial light at 10 µmol?s^{-1}?m^{-2}	Greenhouse. 400 ppm increased shoots growth, but decreased roots growth; supplementary light increased shoot & root growth.
'Florida 683'	Masson et al., 1991b	100, 200, 300, 400 ppm from 2:1:2 ratio NO_3, NH_4, urea	natural light versus artificial light at 10 µmol?s^{-1}?m^{-2}	* Field. Light effect was NS, but maximum yield & head wt with transp lants grown with 300 ppm N.
'Florida 683'	Tremblay & Gosselin, 1989a	150, 250, 350 ppm from NO_3, NH_4	N-NO_3 to N-NH_4 in ratios of 1:1, 2:1, 3:1	Greenhouse. Shoots, but not roots increased with N rate. A minimum 250 ppm N at a NO_3:NH_4 ratio of 2:1 suggested for adequate transplant growth.
'Florida 683'	Tremblay & Gosselin, 1989b	150, 350 ppm from NO_3, NH_4	2:1 & 3:1 ratio of NO_3:Nh_4, N-urea of 0% & 50%	* Greenhouse and field. N at 350 ppm & 2:1 ratio of NO_3:NH_4 increased transplant shoot & root wt over low N. 50% urea increased shoot/root dry matter. Marketable yield greatest with 350 ppm N with 50% as N-urea.
'Florida 683'	Tremblay & Senecal, 1988	150, 350 ppm from 3:2:1 ratio urea, NO_3, NH_4	K from KOH & K_2 SO_4 at 50, 200, 350 ppm	Greenhouse. N at 350 ppm with 200 ppm K promoted transplant shoot growth.
'Florida 683'	Tremblay et al., 1987	200, 400, 600 ppm from urea	P from H_3PO_4 at 100, 150, 200 ppm P; CO2 enrichment evaluated	* Greenhouse and field. CO_2 enrichment increased transplant shoot & root growth but not yield. N at 400 ppm increased transplant shoot growth, total marketable & side shoot wts. P did not affect transplant growth, but interacted with N to increase yield.

[z] * =denotes long term effect on yield; X=no effect

Table 3. Vegetable transplant nutrition research on lettuce[z]

Cultivar	Reference	N rates & source	Other factors studied	Location, conclusions and recommendations
'Empire' 'Florical 50011'	Karchi et al., 1992	32, 58, 175, 292 ppm from NH_4	P from liquid P_2O_5 at 58, 175, 292, 318 ppm; in N:P ratios of 1:1, 5:1, 1:5, 1:10	Greenhouse. High P and low N extended transplant root growth over longer time periods, increased root dry wt, & enhance greater root to leaf ratios. High N with low P enhanced leaf growth over root growth. Proposed that the low N & high P plants might overcome transplant shock better, resume growth earlier & yield better than high N low P plants.
'Great Lakes R-200'	Kratky & Mishima, 1981	0, 200, 600, 1800 ppm N-P-K fertilizer (13-11-21) applied as a foliar feed	6 different media; N-P-K starter granular fertilizer at 0, 4, 8, 16, 32 g/liter media	**X** Greenhouse and field. Transplant fresh wt greatest with 1800 ppm N-P-K solutions with 0-4g preplant granular fertilizer/liter. Foliar of 600 to 1800 ppm

				N-P-K cause excessive succulence. But total salable wt & head wt not affected by any media. Salable heads decreased with 16-32 g/liter preplant fertilizer. Recommended 200-600 ppm foliar 13-11-21 plus 4-8 g 8-14-17/liter preplant in media.
'Ithaca'	Masson et al., 1991a	100, 200, 300, 400 ppm from 2:1:2 ratio NO_3, NH_4, urea	natural light versus artificial light at 10 $\mu mol \cdot s^{-1} \cdot m^{-2}$	Greenhouse. 400 ppm N increased transplant shoot growth but decreased root growth; supplementary light increased shoot/root growth.
'Ithaca'	Masson et al., 1991b	100, 200, 300, 400 ppm from 2:1:2 ratio NO_3, NH_4, urea	natural light versus artificial light at 10 $\mu mol \cdot s^{-1} \cdot m^{-2}$	* Field. Light effect was NS. Head wt & density, not circumference, increased with transplants grown with 400 ppm N.
'Ithaca'	Temblay & Senecal, 1988	150, 350, ppm from 3:2:1 ratio urea, NO_3, NH_4	K from KOH & K_2SO_4 at 50, 200, 350 ppm	* Greenhouse. N at 350 ppm with 350 ppm K promoted shoot growth.

[z] *=denotes long term effect on yield; **X**=no effect

N rates, but artificial light had no long term effect on yield status.

CABBAGE (*Brassica oleracea* L. VAR. *capitata*). Only one transplant nutrition study on cabbage was found, dating back to 1940. Babb (1940) grew 'Golden Acre', 'Early Jersey' and 'Wakefield' transplants with various solutions of N (from nitrate of soda), P (from superphosphate), and K (from muriate of potash) and reported that transplants grown with N or complete nutrient solutions yielded earlier than those unfertilized. Total yield and quality, however, were unaffected by transplant nutrition.

CANTALOUPE (*Cucumis melo* L.). The only known study on cantaloupe appraised the long-term effects of N from urea at 10 to 250 ppm N, P from phosphoric anhydride from 5 to 125 ppm P, and K from potassium chloride from 10 to 250 ppm Kon 'Magnum 45' cantaloupe (Dufault, 1986). Transplant shock (incidence of leaves with necrotic lesions counted 10 d after transplanting) increased with increasing transplant N-P-K rates, but plants conditioned with high N-P-K, vined, flowered, set fruit and yielded earlier than plants conditioned at lower N-P-K rates. Midseason and total yields were unaffected by N-P-K transplant conditioning and 250N-125P-250K was recommended for cantaloupe transplant production.

CAULIFLOWER (*Brassica oleracea* L. VAR. *botrytis*). Babb (1940) included 'Danish Giant' cauliflower in his evaluation of transplant nutrition using the same methodology reported above on cabbage. He reported that transplants grown with only K or P solutions or complete nutrient solutions yielded earlier than those fertilized with N. Nitrogen during transplant production lowered total yield, but K, P and complete nutrient solutions had no effect on total yield.

CELERY *(Apium graveolens* L. VAR. *dulce).* There are eight transplant nutrition publications available on celery, with six of the eight contributed by Canadian researchers (Table 2). The first study evaluated the N-P-K nutrient needs for high quality 'Utah 5270R' celery transplants (Dufault, 1985). Nutrient solutions contained N from urea at 10 to 250 ppm and K from potassium chloride at 10 to 250 ppm, and P from phosphoric anhydride at 5 to 125 ppm. Shoot and root growth increased with N rate, but only shoot growth and not root growth increased with P rate. K had no effect on transplant growth. Dufault (1985) recommended 25ON-125P-10K ppm for quality transplant growth. In a later study, Dufault (1987) grew the same celery cultivar with Osmocote as the N-P nutrient source. Osmocote (containing only N) from 1.25 to 20 g?kg^{-1} (Osmocote : media) were combined with Osmocote (containing only P) from 1.25 to 10.0 g?kg^{-1} (Osmocote : media). It was possible to grow quality celery transplants with Osmocote with as little as 2.5 g N Osmocote/kg media in greenhouses kept consistently cool at 14 to 24 ^{o}C.

From 1988 to 1991, Canadian researchers defined the N rates, sources and ratios, the K rates, light requirements, and the value of CO_2 enrichment on 'Florida 683' celery (Masson et al., 1991a, 1991b; Tremblay and Gosselin, 1989a, 1989b; Tremblay and Senecal, 1988; and Tremblay et al., 1987) (Table 2). Generally, N rates at 350 to 400 ppm optimized celery transplant growth. Three of the six studies on transplant nutrition were taken to the field and all three field studies reported long-terrn effects of transplant nutrition on increasing yield and celery stalk weight.

LETTUCE (*Lactuca sativa* L. VAR. *capitata*). Kratky and Mishima (1981) studied the use of a complete foliar N-P-K transplant solution of 13N-1IP-21K from 0 to 1800 ppm in conjunction with 0 to 32 g?L^{-1} of preplant-incorporated 8N-14P-7K on Great Lakes R-200 cultivar (Table 3). Foliar nutrition of $\geq$600 ppm caused excessive succulence and lower N-P-K nutrient regimes from 200 to 600 ppm were recommended. Granular starter fertilization applied preplant in the media subsequently increased marketable head weight and they recommended foliar application of 200 ppm 13N-11P-2lK plus 4 to 8 g of 8N-14P-7K g fertilizer/L of media or 600 ppm 13N-11P-2lK plus 4 g?L^{-1} 8N-14P-7K g fertilizer/L of medium.

Canadian researchers from 1988 to 1991, similar to celery, defined the N rates, sources and ratios, the K rates, and light requirements of 'Ithaca' lettuce (Masson et al., 1991a, 1991b; Tremblay and Senecal, 1998) (Table 3). Generally, lettuce transplant growth was optimized with 400 ppm N. Only one of the three studies was taken to the field and Masson et al. (1991b) reported that 400 ppm N had long-term effects on increasing lettuce head weight and density.

Karchi et al. (1992) studied the transplant nutritional needs of Empire and Florical 50011 lettuce cultivars using N from ammonium-N at 32 to 292 ppm, P from phosphoric acid at 58 to 318 ppm in varying N-P ratios of 1:1, 5:1, 1:5, and 1:10 (Table 3). High N with low P stimulated leaf growth over root growth with low N and high P enhancing root growth. Even though this work was not taken to the field, they proposed that conditioned transplants may mature earlier and because of greater root growth, they may overcome transplant shock better than plants with succulent leaf growth.

ONION (*Allium cepa* L.). Only one study was found on the effect of transplant nutrition on onion. Herison et al. (1993) compared various factors to include: N rates from urea from 75 to 225 ppm, one to three seeds per cell, and transplant age varying from 10- to 12-week-old on 'Sweet Savannah', 'Yula', and 'Vega' onions. Long term beneficial effects of transplant nutrition were reported with bulb fresh weight optimized with 150 to 225 ppm N in 10- to 12-week-old transplants.

PEPPER *(Capsicum annuum* L.). As early as 1977, Knavel established that the N level at which certain bell pepper cultivars are grown has a strong influence on yielding capacity (Table 4). Tremblay and Senecal (1988) determined that shoot growth of 'Bell Boy' pepper, increased with high N and low K 'Maor' bell peppers yielded earlier after conditioned during the transplant production phase with relatively low N-P solutions (Bar-Tal et al., 1990b). Bar-Tal et al. (1990a) stated that using N-P together significantly affected the uptake of each other nutrient suggesting synergism.

Transplant nutrition affects seedling carbohydrate status which subsequently may affect their growth rate soon after transplanting. Aloni et al. (1991) established that nutrient solutions deficient in N, inhibited the shoot growth of 'Maor' bell pepper and that at least 100 ppm allowed faster post transplant establishment and earlier flowering than those grown at low N (Table 4).

Improved field performance with transplant nutrition does not always produce consistent results. Although transplant root and shoot growth were affected by different N-P regimes ranging from 25 to 225 ppm N and 15 to 60 ppm P, earliness and total yield of 'Gatorbelle' peppers were unaffected by transplant nutrition and the lowest rate of 50 N to 15 ppm P can be used (Dufault and Schultheis, 1994) (Table 4).

TOMATO *(Lycopersicon esculentum* MILL.). Fourteen transplant nutrition studies have been published on the nutrient requirements for processed and fresh market tomatoes since 1940 (Table 5). Eight of ten published studies indicated that transplant nutrition increased some component of yield and in some cases, reduced yield (Babb, 1940; Liptay et al., 1992). Similar to bell peppers, improved field performance with transplant nutrition is not always consistent with tomato. For example, earliness was improved with low N rates at 15 mM N (Basoccu and Nicola, 1995; Garton and Widdcrs, 1990) and 75 ppm N (Vavrina and Hochmuth, 1994), but conversely, some researchers found that moderate N (200 pprn N) versus high N rates (300 to 350 ppm N) were advantageous (Liptay and Nicholls, 1993; Melton and Dufault, 1991b). Lastly, earlier yields were reported with 400 ppm N (Masson et al., 1991b). Weston and Zandstra (1989) felt that moderate to high N (16 to 28 mM was needed to increase the internal plant tissue N status for improving posttransplanting seedling growth. Determining recommendations for tomato transplant nutrition are confounded by varietal and climate variations, once over harvesting for processing cultivars versus sequential for fresh market cultivars, and a plethora of diverse experimental conditions used to conduct the research.

WATERMELON *(Citrullus lanatus).* High rates of nitrogen have been reported to increase transplant growth of seeded 'Crimson Sweet' (Lamb et at., 1993) and seedless 'Queen of Hearts' (Schultheis and Dufault, 1994). Only the later study was taken to the field and they found no advantage to nutrient conditioning with either cultivar using transplant nutrient solutions (from calcium nitrate) from 25 to 225 ppm N and P from 5 to 45 ppm (calcium phosphate).

Approach to future vegetable transplant nutritional research

LOW N RATES. It is apparent that the future approach to vegetable transplant fertility research should mimic what the industry needs and demands. The requirements of transplant growers have already been outlined, and in general, smaller transplants are used and desirable. For greater greenhouse space conservation and efficiency and for greater ease in shipment and transplanting, the smaller transplant makes sense. In order to produce these plants, low N-P-K levels are necessary especially in southern locations where ambient outside temperatures favor plant growth and transplant nutrition is a major growth control method. Therefore, research should still probe what the long-term effects of low N-P-K rates are on earliness and total yield and quality. Since the body of information from research has indicated strongly that high N rates are advantageous, it is wise to include three types of controls: 1) a very low N control and 2) a high N control. If possible, field testing of any nutrient regime should include 3) a locally grown commercial control of same chronologic age and cultivar. Weston and Zandstra. (1986) indicated in their work the superiority of locally grown plants versus plants grown in distant locations. As with all cultural research, it is essential to include more than one cultivar since previously published research has indicated a wide diversity of responses among different cultivars within the same genus and species.

Table 4. Vegetable transplant nutrition research on bell pepper[z]

Cultivar	Reference	N rates & source	Other factors studied	Location, conclusions and recommendations
'Maor'	Aloni et al., 1991	0, 30, 100, 200 ppm N from KNO_3	none	Greenhouse. N at 0-30 ppm inhibited shoot growth. Root growth had a negative relation with N supply. Transplants grown with 100 ppm N grew faster post-transplanting & flowered earlier. Carbohydrate status of young pepper transplants influenced their post-transplant recovery. Optimal N supply at 100 ppm N is essential for full recovery after transplanting.
'Maor'	Bar-Tal et al., 1990a	1.0, 6.0 m*M* N from NO_3:NH_4 in a 3:1 ratio	0.01, 0.03 m*M* P of unknown source	Greenhouse. As N & P rate increased from low to high, the uptake in transplant of N two-fold & P 5 to 6 fold. Uptake of N & P were found to depend each other's uptake.
'Maor'	Bar-Tal et al., 1990b	1, 5, 10, 15 m*M* N from NO_3:NH_4 in a 1:1 ratio	0.1, 0.5, 1.0 m*M* P of unknown source; root volumes of 5, 15, 35, 65, 700 cm^3 per plant	* Greenhouse and field. Transplants with >160 mg top dry wt had highest growth rate even after 4 weeks post transplanting. The higher growth rate increased earlier pod yield, but not total yield. The optimal nutrient solution was 5 m*M* N & 0.5 m*M* P.
'Gatorbelle'	Dufault & Schultheis, 1994	25, 75, 225 ppm N from $Ca(NO_3)_2$	5, 15, 45 ppm P from $Ca(H_2PO_4)_2$; field planted in South & North Carolina locations	**X** Greenhouse and field. N with P affected shoot wt, leaf area, root wt, seedling ht & leaf no. N & P rates did not affect recovery from transplant shock, earliness, yield or quality. No advantage of a nutritional treatment over another. As little as 50 ppm N & 15 ppm P produced quality 'Gatorbelle' transplants.
'Yolo Wonder-L'	Knavel, 1977	180, 240, 300, 360 g N/m^3 (unknown source) 1:1 Peat: vermiculite media	transplanted in field with 100, 155, 210, 265 kg N/ha	* Grenhouse and field. Transplants grown with 240 or 300 g N/m^3 then field grown with 155 kg N/ha yielded more pods than all other treatments. Growing transplants with 360 g N/m^3 yielded less than those grown with 240 or 300 g N/m^3. The N level for transplants has a strong influence on pepper yield potential.
'Bell boy'	Tremblay & Senecal, 1988	150, 350 ppm N from 3:2:1 ratio urea, NO_3, NH_4	K from KOH & K_2SO_4 at 50, 200, 350 ppm	Greenhouse. N at 350 ppm with 50 ppm K promoted transplant shoot growth.

[z] *=denotes long termeffect on yield; **X**=no effect

Table 5. Vegetable transplant nutrition research on tomato[z]

Cultivar	Reference	N rates & source	Other factors studied	Location, conclusions and recommendations
'Bonny Best' 'Penn State Earlianna'	Babb, 1940	1030 ppm N from nitrate of soda (calculated by Dufault)	superphosphate at 4150 ppm P, K from muriate of potash at 2249 ppm K. Each N-P-K source applied separately & all together.	**X** Field. In this 2 yr study, in first year, transplants grown with N yielded less than those fertilized with P or K or complete fertilizers. Total yield at end of season was NS. In 2nd yr, transplant nutrition was NS.
'Camone'	Basoccu & Nicola, 1995	4, 8, 15, 30, 60 m*M* N of unknown source	supplemental light & natural light treatments	***** Greenhouse and field. As N rate increased, transplant ht, stem & root dry wts decreased. Leaf area was maximal at 15 m*M* N. Root: shoot ratio was highest at lowest N rate. Transplants grown at 8 to 15 m*M* N with naturqal light yielded more early fruit but total yields were unaffected by transplant nutrition.
'Break O' Day'	Brasher, 1941	unknown	10 days prior to planting, plants hardened with 1)strong K soln, 2)left tender 3)weak N soln	Greenhouse. Hardening delayed early growth & reduced early production. Temder plants superior to hardened plants. "Any method used which results in stunting or hardening young tomato plants permanently slows up their field performance, probably decreasing

				the yield roughly in proportion to the severity of the hardening treatment".
Processing 'H-2653'	Garton & Widders, 1990	10, 20 m*M* N from $NH_4H_2PO_4$, KNO_3, $Ca(NO_3)_2$, or NH_4NO_3 to 4-5 wk-old seedlings for 5 or 10 days before planting in the field	2, 5 m*M* P from $Na_4H_2PO_4$, or $NH_4H_2PO_4$ applied to 4-5 wk-old seedlings for 5 or 10 days before transplanting	***** Greenhouse and field. Plants fertilized with low NP yielded equal to or greater than seedlings cultured with higher fertility. Suggested to initially use lower NP rates to avoid excessive vegetation. Before transplanting, use higher NP rates to increase tissue mineral nutrient status to a higher level. "Lower nutrient status of these seedlings even predisposes the root system to take up NP more rapidly during application of higher NP just before tranplanting".
(bareroot transplants) 'H-1350'	Jaworski & Webb, 1966	20, 60 lbs N/acre commercial fertilizer	10 & 90 lbs P/acre; field grown then dug & transplanted	***** Field. NP levels used to produce bareroot transplants is related to fruit yield. A high N (60 lbs/acre) with low P (10 lbs/acre) reduced yields in contrast to those grown with 60N-90P lbs/acre.
Processing 'TH-318'	Liptay & Nicholls, 1993	0, 50, 100, 200, 350 ppm N of unknown source	none	***** Greenhouse and field. Using high N enhanced transplants capacity for root growth in the field. Higher N in seedling tissues at transplanting may be used immediaely for growth than that available in the soil. There is also a good correlation between stem strength & survivability in the field Suggested that 100 to 200 ppm N be used to grow tomato seedlings.
Processing 'TH-318'	Liptay et al., 1992	100, 200, 350 ppm N of unknown source	Ten nutrient soln varying in N, P, K, & Ca; 25, 50, 200 ppm P; 50, 75, 100, 200 250 ppm K; 100 200 ppm Ca.	**X** Greenhouse and field. Root growth was greatest with 350 ppm N but these plants survived poorly because of unhardened nature. Increasing K levels decreased root growth, but did not affect yields. 50 to 100 ppm N depressed early yield, but total yields were the same for all N rates. Recommended 100 to 200 ppm N to improve survival. K at any level did not have reduce plant performance.
'Springset'	Masson et al., 1991a	100, 200, 300, 400 ppm N from 2:1:2 ratio NO_3, NH_4, urea	Natural light versus artificial light at 10 *u*mol?s $^{-1}$?m^{-2}	Greenhouse 400 ppm N increased shoots & roots; supplementary light increased shoot & root growth.
'Springset'	Masson et al., 1991b	100, 200, 300, 400 ppm N from 2:1:2 ratio NO_3, NH_4, urea	natural light versus artificial light at 10 *u*mol?s $^{-1}$?m^{-2}	* Greenhouse and field. Earliness, but not total yield, increased with supplementary light. Transplants grown with 300 to 400 ppm N yielded earlier. Earlier yields increased with N rate but not total yields.
'Sunny'	Melton & Dufault, 1991a	25, 75, 225 ppm N from $Ca(NO_3)_2$	5, 15, 45 ppm P from $Ca(H_2PO_4)_2$, 25, 75, 225 ppm K from K_2SO_4	Greenhouse. Transplant shoot root growth increased with increasing N rate. P at 45 ppm increased shoot growth & K had negligible effects. Production of quality transplants requires at least 225 ppm N & 45 ppm P & 25 ppm K.
'Sunny'	Melton & Dufault, 1991b	100, 200, 300 ppm N from $Ca(No_3)_2$	10, 40, 70 ppm P from $Ca(H_2PO_4)_2$ & low temperature (36°F) before transplanting	***** Greenhouse and field. Low temperature stress before transplanting did not effect earliness, yield or quality. N at 50 to 100 ppm is deficient & may reduce yield potential compared to 200 ppm. Earliness improved with transplants grown with 200 ppm versus 50 to 100 ppm. Total yield increased with tranplants conditioned with =100 ppm versus 50 ppm. Suggested 200 ppm N & 10 ppm P be used to grow tomato transplants
'Allstar'	Vavrina & Hochmuth,	0, 15, 30, 45, 60, 75 ppm N from	nutritionally conditioned transplanted planted in	* Greenhouse and field. Earliness & yield not affected from transplants conditioned

	1994	NH_4NO_3	Florida & Pennsylvania	with =30 ppm not affected in FL, but in PA, transplants conditioned with 75 ppm yielded earlier, but 45 ppm induced greatest total yields of all nutritional treatments.
'Pik-Red'	Weston & Zandstra, 1989	100, 200, 400 ppm N from KNO_3	15, 30, 60 ppm P from superphosphate (20.4%)	***** Greenhouse and field, Largest transplants produced with 400 ppm N-30 ppm P. Transplants fertilized with 400 ppm N & 30 ppm P produced the greatest early & total yields.
'Ohio 7870'	Widders, 1989	4, 16, 28 m*M* N from $NH_4H_2PO_4$, KNO_3, $Ca(NO_3)_2$, or NH_4NO_3 application began 8 days before planting	0.5, 4.0, 8.0 m*M* P from $Na_4H_2PO_4$, $NH_4H_2PO_4$, KH_2PO_4, application began 8 days before transplant	Greenhouse and field. Relative shoot growth rates declined during first 3 days after transplanting, but increased to a maximum by 10 to 14 days after transplanting. These low relative growth rates need cultural strategies to promote vegetative & root growth to enable the plant to acquire nutrients & water. Internal plant tissue N status is important for improving post-transplanting seedling growth. N from 16 to 28 m*M* accelerated seedling ralative growth during intial 5 days post-transplanting

[Z] *-denotes long term effect on yield; **X**=no effect

FIELD TRANSPLANT ACCORDING TO LOCAL COMMERCIAL STANDARDS. All transplant research should be field planted using the same commercial procedures practiced in the region that the study is conducted. Hand planting may effectively mask the potential pitfalls of certain high N rates. However, from the scientific integrity standpoint, the range of variation possible with mechanical transplanting may not be controlled which can effectively add more experimental error confounding the analysis. Therefore, an additional treatment of hand planting versus hand planting with controlled, reproducible "brushing" that simulates mechanical transplanting may be appropriate for vegetable transplant research.

SEEDLING GROWTH DATA COLLECTION. Transplant research should include seedling growth analyses of foliar and root growth at the time of field transplanting. Quantitative measurements of chlorophyll content using colorimetric tests or SPAD meters are preferable to qualitative rating systems. Determination of carbohydrate status of transplants at field testing as well as their nutrient content would provide strong guidelines for comparison of the "identity" of the biochemical and mineral nutrition status of the transplants as well as the physical biomass data that is customarily collected. These guidelines would provide easy tools of comparison among researchers to contrast the results of their work over time and location and to identify disparities in their results. Another important value of all this transplant data would be to correlate seedling performance with yield to determine if any seedling growth variable can be used as an indicator of superior performance in the field (i.e., earliness, uniform maturity, stand establishment, yield, and quality). If strongly correlated, a transplant grower may strive to achieve this seedling growth indicator to increase confidence that a quality transplant has been produced.

TRANSPLANT MEDIUM ANALYSIS. In addition to seedling tissue analysis, all vegetable transplant research should include medium nutrient analysis at initiation and termination of the experiment. Since transplants arc totally con- fined to a minute reservoir of medium, knowledge of the medium mineral nutrition status would indicate and correlate with shoot and root growth and help explain why the seedling may have grown in a certain way. Also, early field performance of a transplant may be strongly dependent on the nutrient residuals left in the growing medium.

FIELD DATA COLLEC-TION AND YIELD ANALYSIS. All transplant research should include field testing that includes an indepth analysis of the manner in which sequentially harvested plants yield. In other words, are yields skewed by the treatments or do the plants mature uniformly or is the yielding pattern spread out over the entire harvest season. Field tests should also include analysis of stand establishment. Transplant shock should be qualitatively measured with simple injury ratings taken at the height of damage symptoms usually after one week post transplanting. Quantitative measurements of transpiration or photosynthesis in the field may also indicate physiological changes induced by transplant shock and nutritional treatments.

FLUCTUATING NUTRITIONAL REGIMES. Commercial vegetable transplant production is a careful orchestrated sequence of events planned to produce a crop of seedlings by a specific date for shipping. The nutritional regimes used to grow those plants can exert major control over plant size and scheduling. Much of the previous research has shown that vegetable transplants can be nutritionally conditioned to perform better in the field. However, in this research, the same controlled nutritional rates have been used consistently throughout the entire greenhouse production sequence without moderation of rate. In commercial greenhouses, nutritional regimes or concentrations may be moderated daily in response to climate and calendar. Future research should evaluate the influence of using low N-P for size control during the majority of the production sequence, but shiffing to high N-P before finishing a crop without causing any enlargement of the transplant size. This nutrient charging approach with tomatoes has been shown to be effective to lower the nutrient status of low N-P plants, predisposing the root system to take up ions more rapidly during the application of higher N-P just before transplanting (Garton and Widders, 1990). This approach avoids the excessive vegetative growth of high N-P and should not compromise fruit yield in the long run.

Conclusions

We have known for over 50 years the potential danger of nutrient stressing transplants. Brasher (1941) stated that "any method used which results in stunting or hardening young seedlings permanently slows up their field performance, probably decreasing the yield roughly in proportion to the severity of the hardening treatment." Future research should heed these observations. Together, blending our knowledge of the long term effect of vegetable transplant nutrition and the needs of the commercial transplant industry we can carefully refine our under-standing and knowledge of producing transplants efficiently for transplant growers and produce seedlings predisposed to yield optimally for the vegetable farmer.

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