Evaluation of Organic Strawberry Runner Production

Monika Walter[1], Cath Snelling[1], Kirsty S.H. Boyd-Wilson[1], Graeme Williams[2], and Geoff I. Langford[1]

Additional index words. *Fragaria*, strawberry propagation, strawberry production, plug plant, tray plant, bare-root transplant

Summary. **System requirements for organic strawberry (*Fragaria* ×*ananassa*) runner production under cover were determined during the 2001–02 and 2002–03 seasons. In the field, yield and fruit quality were assessed for organically produced runners (plug and bare-rooted transplant) in comparison with bare-rooted conventionally produced runners under organic, BioGro certified production conditions. The preferred organic production system was the enhanced suspended system, where mother plants grew on benches in the tunnel house and the first two runners were potted into growth substrate. This system produced approximately 50 plug transplants/mother plant or 200 plug transplants/m^2. The least preferred system was the nursery bed, where mother plants were allowed to produce runners that yielded approximately 100 bare-rooted runners or 100 transplants/m^2. Tunnel house production of runners (plug transplants and bare-rooted) allowed earlier planting (March vs. May) compared to field-produced bare-rooted runner plants. The earlier planting date increased yield by approximately 181 g/plant. Under organic production conditions, organically produced runners (plug and bare-rooted transplants) performed at least as well as bare-rooted conventionally produced runners. Our results show that indoor production of organic strawberry runners is possible. We also showed that organically produced runners (bare-rooted and plug transplants) perform similarly in the field compared to bare-rooted conventionally produced runners. Generally, there were no differences in yield or fruit quality among runner sources.**

Most of the New Zealand strawberry production (conventional and organic) is in open fields using an annual plastic-hill system. Cultivars grown are short-day cultivars in the north (predominantly 'Pajaro', 'Camerosa', and 'Gaviota') and day-neutral cultivars in the south (predominantly 'Seascape' and 'Sunset'). Over 90% of the New Zealand strawberry production is based in the greater Auckland region on the North Island. Fruit are produced primarily for the fresh local and export markets specifically for the Christmas season (November to January).

In New Zealand, strawberry growers (conventional and organic) obtain their planting material from conventional strawberry runner growers who produce bare-rooted transplants in the field because plug transplants are not (yet) available to commercial strawberry growers. New Zealand strawberry runner production is regulated and governed by New Zealand Berryfruit Propagators Ltd. (NZBP, Lower Hutt, New Zealand) under the Strawberry Runner Plant Scheme and follows standard field production systems similar to those described by Larsen and Shaw (1995, 2000). Briefly, the nuclear stock unit (Lincoln Nuclear Stock Unit, Lincoln, New Zealand) provides elite mother plants to runner growers, which are planted in spring (September) in fumigated elite field beds. Daughter plants are harvested in the following early winter (June) and placed in cold storage until spring (September) to be planted in fumigated runner-beds. Bare-rooted runners are then available to strawberry growers for planting in autumn (May). The main production problems conventional runner producers face are phytophthora root rot (*Phytophthora cactorum*), strawberry lethal yellow [SLY (a phytoplasma in the putative species *Candidatus* Phytoplasma australiense)] infections, and damage by aphids (Aphidiae) (NZBP, 2003).

With a worldwide move of the organic industry to produce its own seed stock, as opposed to using untreated seed from conventional production, organic strawberry-runner production will become inevitable. In New Zealand, the organic export industry requested that the New Zealand Food Safety Authority (NZFSA, Wellington, New Zealand) establish an Official Organic Assurance Programme (OOAP) to ensure that New Zealand organic products comply with the European Union Council Regulation 2092/91 (NZFSA, 2004). These standards are adopted by all New Zealand BioGro-certified growers (BioGro New Zealand, Wellington, New Zealand) (S. Mason, personal communication). Organic plant material must be available through distributors or grown on-site to satisfy certification standards, for example, in New Zealand, United States, and Canada [National Organic Program (NOP), 2004].

Organic farming systems differ fundamentally from conventional agriculture in terms of ethical principles, ecological, and nonchemical agricultural approaches (van Bueren,

Funding was received from the New Zealand Ministry for Agriculture and Forestry via allocation of a Sustainable Farming Fund grant to HortResearch, Canterbury Commercial Organic Growers, and Rolleston Prison, Department of Corrections. Thanks to the inmates at Rolleston Prison for technical assistance and trial maintenance. We are grateful to Peter Alspach (HortResearch, Motueka, New Zealand) and Chris Frampton (Christchurch School of Medicine, Christchurch, New Zealand) for statistical advice and analyses. Special thanks to Joan Davenport (Washington State University, Prosser) for her ongoing support and editorial review.

[1]HortResearch, PO Box 51, Lincoln, New Zealand.

[2]Department of Corrections, Rolleston Prison, Rolleston, New Zealand.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	mL·L^{-1}	0.1
29.5735	fl oz	mL	0.0338
0.3183	fl oz/ft^2	L·m^{-2}	3.1414
0.3048	ft	m	3.2808
0.0929	ft^2	m^2	10.7639
3.7854	gal	L	0.2642
25.4000	inch(es)	mm	0.0394
28.3495	oz	g	0.0353
7.4892	oz/gal	g·L^{-1}	0.1335
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

2002). The challenges for research in organic propagation of seed and planting material include the development of empirical knowledge and research-based information on adapting and improving cultural practices for organic seed production, development of resistant cultivars, development for protocols for organic seed health testing, assessment of disease threshold values, and designing organic seed treatments. These challenges have been further described and discussed by van Bueren et al. (2003). Due to the restriction of agrichemicals for control of weeds, pests, and diseases in organic production, high sanitation approaches and pest and disease avoidance strategies are useful. Indoor production systems allow greater control over pest and disease problems (Bish et al., 2001), particularly when using plug transplant technology (Durner et al., 2002; Lieten, 2000; Poling and Maas, 2000). Suspended indoor growing systems are well established in the strawberry industry. Descriptions and photographs thereof are available in Bish et al. (2001), Paranjpe et al. (2003), and on the worldwide web (Paranjpe, 2001). We believe suspended indoor growing systems would also be appropriate for research on organic strawberry runner production, as similar challenges exist to adhere to sanitation and certification standards.

To our knowledge, there is limited research on development of organic runner production. Scientific literature is scarce, except for a recent publication on research evaluating three organic plug mixes and organic fertilizers for transplant establishment and transplant health (Paranjpe et al., 2004). The aims of our research project were to 1) determine and evaluate the indoor system requirements for organic runner production under New Zealand conditions and 2) assess the quality of organically produced runners in comparison to bare-rooted conventionally produced runners with respect to yield and fruit quality in organic production systems. In the first year of the field evaluation the main aim was to demonstrate that organically produced plug transplants perform similarly to bare-rooted conventionally produced transplants in an organic production system. The objective in year 2 was to validate year 1 findings and to further compare organically produced plug transplants and bare-rooted transplants with conventionally produced bare-rooted transplants. In addition to the runner-origin evaluation, the effect of planting date was studied for two cultivars.

Materials and methods

The research site was certified and managed organically according to BioGro standards (BioGro New Zealand, Inc., 2001). It was located in Canterbury at the horticultural area of the Rolleston Prison, Rolleston, New Zealand (lat. 43°34′60S, long. 172°22′60E). The research was conducted over a 3-year period (2001–04) in the tunnel house for evaluation of runner production systems, and in the field for evaluation of organic transplant performance. Runner production and field evaluations were conducted concurrently as shown in the chronology of the production steps (Fig. 1).

CULTIVARS AND ORIGIN. Throughout the research, mother plants were either sourced from tissue culture (Multiflora Ltd., Auckland, New Zealand), conventional runner growers (W. McDonald, Katikati, New Zealand), the high health unit (unit for maintenance of pathogen-free, certified

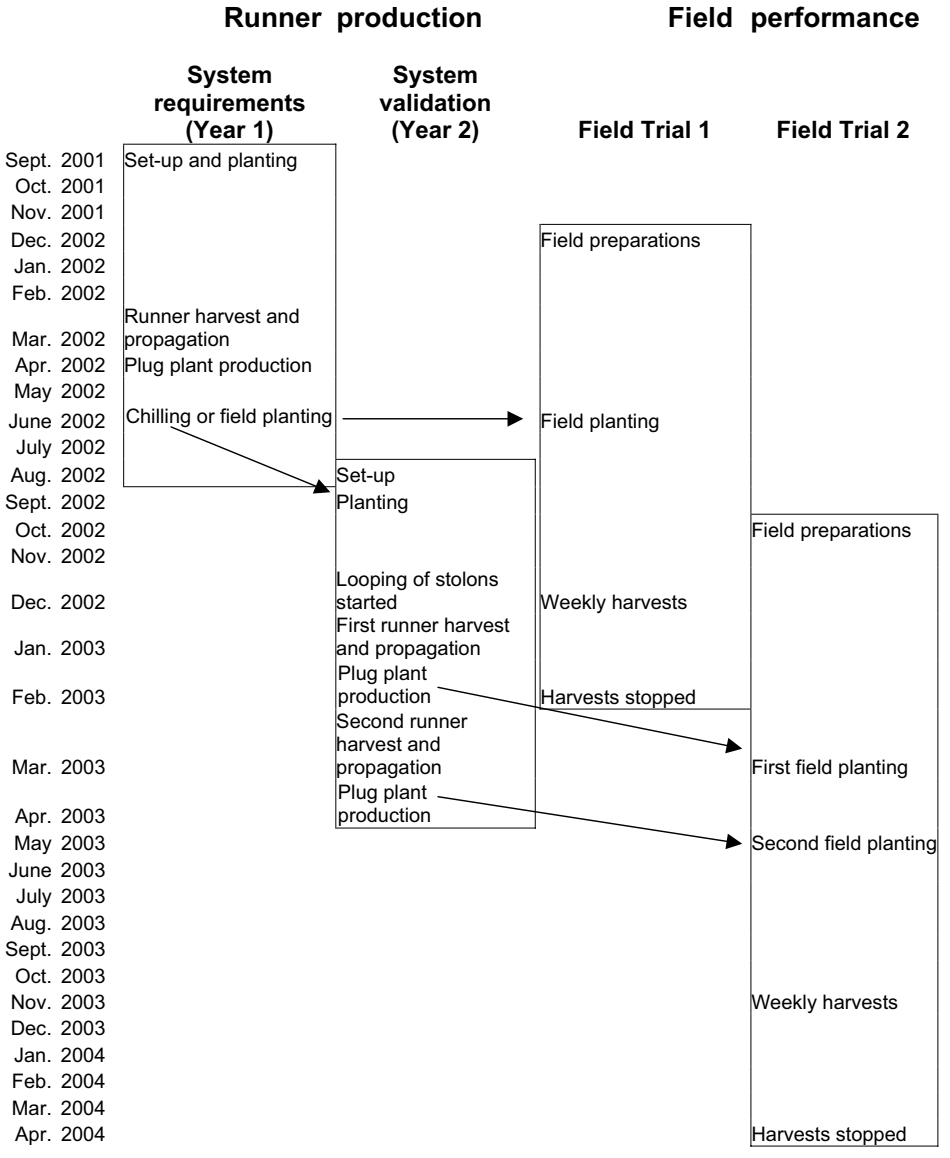

Fig. 1. Chronology of major production steps for runner production and field performance trials during Sept. 2001 to May 2004 to evaluate organic strawberry runner production under New Zealand conditions.

nuclear stock; Lincoln Nuclear Stock Unit) and/or from the trial itself (as described below). The cultivars studied in year 1 and year 2 were:

- 'Aromas', a day-neutral cultivar released by University of California, Davis; mother plants originated from Multiflora Ltd. tissue culture (year 1) or organic plug transplants from the trial (year 2).
- 'Azena', a day-neutral cultivar released by HortResearch (Lincoln, New Zealand); mother plants originated from the Lincoln Nuclear Stock Unit (year 1).
- 'Gaviota', a short-day cultivar released by University of California; mother plants originated from W. McDonald conventional runner grower (year 2).
- 'Sunset', a day-neutral cultivar released by University of California; mother plants originated from Multiflora Ltd. tissue culture (year 1) or organic plug transplants from the trial (year 2).

Runner production. System requirements for organic runner production were determined and evaluated. Studies were conducted in a tunnel house simulating a high health unit under BioGro standards. In year 1 (Sept. 2001 to Feb. 2002), the effect of container size, growth substrate, and cultivar on the number of stolons and runners produced was determined as described below in section "System requirements." In year 2 (Sept. 2002 to Mar. 2003), three selected systems then were further validated on a larger scale as described in section "System validation."

System requirements. System requirements were determined for indoor organic runner production using a two-skinned tunnel house (6 × 4.8 m), which was insect-proofed using ultraviolet (UV)-resistant nylon screen (<0.5 mm). Bare soil was covered with white hydroponic plastic. The three container sizes tested were individual planter bags [PB5 (120 × 120 × 230 mm)], and two channels: one half-round (110-mm diameter, 2 m long) polyvinyl chloride (PVC) guttering pipe and one square (100 × 100 mm, 2 m long) PVC guttering pipe. Channels were sealed with fitting end closures and suspended on 1-m-high shelves, while the PB5 bags were placed on a double freezer shelf (2 m × 150 mm × 1 m). All shelves allowed for east–west exposure and were sloped (approximately 5°) for leachate collection.

Two growth substrates were tested and their properties determined by Celentis Analytical (Hamilton, New Zealand). Compost nutritional analyses and methodology are presented in Table 1. The soilless mixes were produced on site using two techniques. "Cold compost" was produced using temperate composting of mixed vegetable crop residue (crop residue), horse manure, and comfrey (*Symphytum officinale*), whereas "hot compost" was produced by windrow composting (55 °C) of crop residue, horse manure, sawdust, and poultry wastes. The hot compost was also amended (1:1, v/v) with vermicast [produced on site, based on pea (*Pisum sativum*) straw and crop residues amended with dolomite].

The effect of growth substrate and container size was studied for the day-neutral cultivars Azena and Aromas (Table 2). PB5 bags and channels were filled with the growth substrates and strawberry plants planted in spring (27 Sept. 2001). Plants were watered daily by hand according to plant requirements. Leachate was collected and reapplied to the plants. Stolons and runners were harvested in early autumn (12 and 13 Mar. 2002) and for each mother plant, stolon number, runner number, runner crown diameter, and root condition (fresh or dry) were recorded. Additionally, for each mother plant, leaves and roots were oven dried (70 °C) to determine the effect of growth substrate and container size on the leaf and root biomass. Harvested runners (12 and 13 Mar. 2002) were potted into 80-mL-cell trays, filled with hot compost, and placed under mist in the glasshouse for 6 weeks to aid in root development. Plug transplants were then grown on shelves for isolation from potentially "unclean" plant material until field planting on 12 June 2002. Approximately 30 'Aromas' plug transplants were randomly selected (10 June 2002) and chilled (approximately 4 °C) for 3 months to be evaluated for runner production of second generation organic strawberry parent plants in the 2002 to 2003 runner production system validation trial.

System validation. In 2002, hot compost mixed with 30% river sand (v/v) was used as the growth substrate (Table 1). Vermicast was not added as nutrients in the hot compost were sufficiently balanced. The cultivars Aromas, Sunset, and Gaviota were evaluated using three growing systems. These were suspended system (SS),

Table 1. Nutrient analyses, based on fertilizer compost methods, for growth substrates used in runner production trials.

Growth substrate	TKN[z]	TP[y]	TS[x]	Ca[w]	K[w]	Mg[w]	Na[w]	H_2O[v]	NO_3-N[u]	OC[t]	pH[s]
	(%)										
Cold compost[r], year 1	0.64	0.24	0.31	1.3	0.27	0.26	<0.1	61.1	0.04	19.6	7.7
Hot compost[q], year 1	0.62	0.23	0.16	1.3	0.27	0.40	<0.1	37.4	0.04	15.8	7.5
Hot compost[p], year 2	0.55	0.24	0.15	0.9	0.31	0.23	<0.1	48.6	0.03	9.3	6.4

[z] TKN = total nitrogen; Kjeldahl digestion [Association of Official Analytical Chemists (AOAC), 1981].
[y] TP = total phosphorus; organic material digestion method [New Zealand Food Safety Authority (NZFSA), 1969 (section 4-121)] and molybdovanandate colorimetry (Blakemore et al., 1987)
[x] TS = total sulphur; organic material digestion method [NZFSA, 1969 (section 4-121)] and inductively coupled plasma optical emission spectroscopy (Blakemore et al., 1987).
[w] K = potassium, Mg = magnesium, Na = sodium, Ca= calcium; ammonium acetate extractable cations; organic material digestion method [NZFSA, 1969 (section 4-121)] and atomic absorption (Athanasopoulas, 1989).
[v] H_2O = moisture; dried at 105 °C (221.0 °F) to constant weight (AOAC, 1981).
[u] NO_3-N = nitrate nitrogen; extracted in water (AOAC, 1981).
[t] OC = organic carbon; estimated from loss on ignition (Nelson and Somers, 1996).
[s] Substrate mixed with water at a rate of 1:2 (v/v; Blakemore et al., 1987).
[r] Cold compost was produced using temperate composting of mixed vegetable crop residue, horse manure and comfrey.
[q] Hot compost was produced by windrow composting of mixed vegetable crop residue, horse manure, sawdust and poultry wastes.
[p] Hot compost was amended (1: 1, v/v) with vermicast.

Table 2. Treatment combinations for container size, growth substrate, and number of plants used for each strawberry cultivar. Each plant represents a replicate.

Growth substrate	Cultivar	Container: Half-round channel[z]	Container: Square channel[y]	Container: PB5 bags[x]	Total
Cold compost[v]	Aromas	0[w]	6	2	**8**
Cold compost	Azena	0	6	3	**9**
Hot compost[u]	Aromas	5	0	3	**8**
Hot compost	Azena	5	6	2	**13**
Total		**10**	**18**	**10**	**38**

[z]Mother plants were evenly spaced in the 110-mm-diameter (4.3 inches), 2-m-long (6.6 ft) polyvinyl chloride (PVC) guttering pipe; approximately 1 L (0.26 gal) growth substrate per plant.
[y]Mother plants were evenly spaced in the 100 × 100-mm (3.9 inches), 2-m-long PVC guttering pipe; approximately 1.4 L (0.37 gal) growth substrate per plant.
[x]One mother plant/PB5 planter bag [120 × 120 × 230 mm (4.7 × 4.7 × 9.1 inches)]; approximately 2.25 L (0.594 gal) growth substrate per plant.
[w]Number of plants used.
[v]Cold compost was produced using temperate composting.
[u]Hot compost was produced by windrow composting.

enhanced suspended system (ESS), and a nursery bed (NB):

• SS, where mother plants grew on benches and runners were left to fall down off the benches, forming a curtain.

• ESS, which was similar to SS; however, the first two runners were potted into growth substrate using PB3/4 planter bags (64 × 64 × 150 mm) and placed onto the bench next to the mother plant. In both SS and ESS systems, runners were harvested and propagated in 80-mL cell trays under mist to produce plug transplants.

• NB, where mother plants were left to runner into a nursery bed containing the growth substrate. Bare-rooted transplants were produced. At planting, these were extracted directly from the bed.

A total of three double freezer shelves (4 m × 150 mm × 1 m) were situated as in the previous year. For the SS and ESS systems, a total of nine plug transplants for each system and each cultivar were potted into the growth substrate in PB5 bags (1 plant/bag, 23 Sept. 2002). The nine plug transplants from each cultivar were arranged in three-plant plots. Plots were replicated three times in randomized complete blocks, with a shelf representing a block. Irrigation emitters were placed in each bag (SS and ESS) and plants were watered as required. Five guard plants were positioned at either end of each shelf. In the ESS production system, the first two runners were potted into growth substrate on the 29 Nov. 2002 and these were also watered with irrigation emitters. Wire hooks were attached to the shelves (SS and ESS) in midsummer (23 Dec. 2002). Stolons from each mother plant then were looped around the hooks so that runners would not touch the ground. For the NB system, beds (1 m × 3 m × 200 mm) were lined (hydroponic plastic) and filled with growth substrate. There were three NB, with three mother plants of the same cultivar potted into PB5 bags and placed centrally (slightly embedded into the growth substrate) 750 mm apart. Mother plants were watered with individual drip emitters and runners were watered by hand on a daily basis as required.

Flowers were removed as they formed on all plants in the tunnel house. Fish fertilizer (8.1N–0.8P–1.4K; Simply Organic, Foliafeed Fertiliser Ltd., Dunedin, New Zealand) was applied at a rate of approximately 0.08 mL N (12, 21, and 26 Nov. 2002) to all mother plants. On 25 Dec. 2002, 22 Jan. 2003, and 26 Feb. 2003 fish fertilizer was again applied to mother plants and potted runner plants, at a rate of 0.05 mL N per plant. Pests and diseases were monitored and controlled throughout the trial period. Powdery mildew (*Sphaerotheca macularis* f.sp. *fragariae*) began appearing in Nov. 2002, most commonly on 'Sunset' and infected leaves were removed periodically. Later in the season 'Gaviota' had high levels of mildew in the bins and some on suspended system (SS and ESS) runner plants. A solution of 5% Effective Microorganisms (EM; New Zealand Nature Farming Society, Christchurch, New Zealand) was applied to the 'Gaviota' nursery bed three times at a rate of 0.33 $L \cdot m^{-2}$ (11 Apr. 2003) and 0.25 $L \cdot m^{-2}$ (15 and 23 Apr. 2003). Browning of some leaves was seen after the first application; however, mildew did appear to decline in the 'Gaviota' bed after the EM application.

Gray mold (*Botrytis cinerea*) was not observed in SS or ESS system, neither on mother plants nor their runners. However, in the nursery beds, gray mold infections started in late Feb. 2003 as canopy density increased. Although senescent foliage and gray mold-affected material was removed weekly, infections increased steadily with over 50% of runners infected by Mar. 2003. Full tunnel house venting continued even though temperatures were cooler in Mar. and Apr. 2003 to increase air flow and reduce gray mold infection.

Several small patches of aphids were seen in mid-Jan. 2003. A garlic (*Allium sativum*) and pyrethrum solution (Bettacrop Organics, Auckland, New Zealand) was applied to the affected areas at a rate of 25 $mL \cdot L^{-1}$ with a concentration of 12 $g \cdot L^{-1}$ a.i. (15 Jan. and 2 May 2003). Permission was obtained from BioGro to use this restricted product. Two-spotted spider mites (*Tetranychus urticae*) began establishing in the tunnel house (late Oct. 2002) and predators [*Phytoseiulus persimilis* (Mite-E; BioForce, Pukekohe, New Zealand)] were released into the tunnel house for control (15 Nov. 2002). A small population of whiteflies (*Trialeorodes vaporariorum*) were seen in mid-Nov. 2002; however, they were in low numbers and by late Dec. 2002 the whitefly population disappeared without the need of intervention.

Runners and stolons were counted for each mother plant from the SS and ESS systems on 28 Jan. and 12 Mar. 2003. Runners in the NB system from the three mother plants were intergrown and it was not possible to count stolons, nor runners for each individual mother plant. Therefore, for the NB system no stolon counts exist, but runners were counted for the entire bed and this was then averaged per mother plant. After the initial runner and stolon counts (28 Jan. 2003), two mother plants per replicate were randomly selected and harvested on the two suspended systems. Runners were propagated into 80-mL-cell trays containing the standard growth substrate and put under the mister to initiate root development.

Plants required about 2 weeks to

root during which the misting unit was automatically controlled by a wet sensor. Sensor sensitivity was gradually reduced until irrigation was no longer needed (18 Feb. 2003). The plants under the mister were fertilized with leachate from hot compost diluted with water (50:50) during the first and third weeks under mist.

The second runner count (12 Mar. 2003) included runners from both the remaining (not previously harvested) mother plants and newly produced runners from the mother plants harvested in Jan. 2003. All runners were harvested and put under the mister as described above. Plants were at a different physiological stage in March and most of the runners' peg roots had deteriorated. This, along with cooler temperatures, prolonged the rooting time (3 to 4 weeks).

Field Performance. In both years site preparation began 6 months prior to planting. Compost was added to a crop of oats (*Avena sativa*) grown and worked into the soil as green manure. Soil fertility tests were obtained (Celentis Analytical, Hamilton, New Zealand) prior to planting and were very similar for both years, with a pH of 6.7 and 6.8 (soil:water = 1:2; v/v; Blakemore et al., 1987); cation levels (determined with atomic absorbance spectroscopy on ammonium acetate extract; Davies, 1952) for calcium at 4.4 and 4.4 cmol·kg^{-1}, magnesium at 2.8 and 2.7 cmol·kg^{-1}, potassium at 3.6 and 3.8 cmol·kg^{-1}, and sodium at 0.5 and 0.6 cmol·kg^{-1}; and organic carbon content (dry combustion; Nelson and Sommers, 1996) of 13.2% and 13.5% for Field Trial 1 and Field Trial 2, respectively.

In both field trials, the ground was mounded and strawberries were planted at a spacing of eight plants/m in a staggered double row through polyethene. Plots were buffered to minimize edge effects. The trials were irrigated as required throughout the season using t-tape (Hydroflow Distributors Ltd., Takapuna, Auckland, New Zealand). Organic wheat straw (*Triticum aestivum*) was laid between the rows to reduce weed problems and provide a clean area for fruit ripening. An exclusion cage was erected over the plants for protection from pests and invertebrates. Stolons were removed as required throughout the production season and flowers were removed until October to ensure good plant establishment.

Field Trial 1. The trial consisted of eight replications for each plant origin treatment (bare-rooted conventional or organic plug transplants) resulting in 16 ten-plant plots allocated over four rows, in a randomized block design. 'Aromas' organic runners were obtained as plug transplants as described above in the "system requirements" section, whereas the conventional runners were obtained from a commercial runner grower as bare-rooted transplants. All runners were planted on 12 June 2002.

Harvest began on 3 Dec. 2002 and continued weekly until 11 Feb. 2003. Total yield and fruit size (grams) per plot was recorded; however, no fruit quality assessments were done in this year.

Field Trial 2. In the second year, organically produced ESS and NB transplants were planted on 25 Mar. and 30 May 2003. Conventionally produced transplants were planted on the 30 May 2003 only, since bare-rooted conventional transplants are not available until May. 'Aromas' and 'Sunset' transplants from the ESS (plugs) and NB (bare-rooted) were randomly chosen from the runner production trial.

Harvesting began on 25 Nov. 2003 and berries were picked weekly for 21 weeks through 16Apr. 2004. Total yield and average fruit size (grams) per plot was recorded. Fruit quality was assessed with respect to insect/pest damage, sunburn, fruit rot (predominantly caused by gray mold), and fruit distortion [predominantly caused by wheat bug (*Nysius huttoni*)].

The field trial consisted of two replications of each treatment combination of plant origin (bare-rooted conventional or ESS plug or bare-rooted NB transplants), cultivar ('Aromas' or 'Sunset') and planting date (March or May, with bare-rooted conventional runners planted in May only). The trial was laid out in a randomized block design with eight plants per replicate.

Statistical analyses. Runner production. For the first runner production trial (system requirements), one-way analysis of variance (ANOVA) was used to determine main effects of growth substrate, container size, and cultivar on the number of runners produced, root and foliar biomass. The general linear model (GLM) was used to further explore potential treatment interactions. All analyses were conducted using Minitab 14 (Minitab Inc., State College, Pa.).

In the second year (system validation), for the SS and ESS systems, the nine plug transplants from each cultivar were arranged in three-plant plots. Plots were replicated three times in randomized complete blocks, with a shelf representing a block. ANOVA (GLM) and Fisher's least significant difference (LSD) test were used to analyze for treatment effects, interactions, and treatment differences using Minitab 14. Regression analyses were conducted between runner and stolon counts as well as between Jan. and Mar. 2003 runner assessments.

Field evaluation. In year 1, ANOVA was used to determine the effect of row and runner origin on yield (expressed in total and weekly fruit weight, fruit number, and fruit size). Multiple comparisons were conducted using Fisher's LSD test ($\propto = 0.05$). The software S-Plus (Insightful Corp., Seattle, Wash.) was used.

In year 2, univariate analysis of variance was used to determine the effect of row, cultivar, runner origin, and planting date on yield (expressed in total and weekly fruit weight, fruit number, and fruit size) and fruit quality (expressed in total and weekly numbers of fruit damaged (insect/pest), sunburned, diseased (gray mold), and distorted (wheat bug). May plantings only were used to compare runner origin between the conventional and the two organic production systems. Multiple comparisons were conducted using Fisher's LSD test ($\propto = 0.05$). The software Systat 11 (Systat Software, Inc., Richmond, Calif.) was used.

Results and discussion

Runner production. System requirements. No disease or pest problems arose during the year 1 trial. There were no significant interactions ($P > 0.1$) between container size, growth substrate, and cultivar for runner, foliar, and root biomass assessments and therefore these are not discussed further. The number of runners produced per mother plant was highly influenced by container size, but not by growth substrate (Table 3). There was no difference between the two cultivars for runner number, root,

Table 3. Main effects of growth substrate, container size, and cultivar on runner production per mother plant, and corresponding root and foliar biomass (dry weights). Both the means (±SD) and level of significance of the main treatment effects are presented.[z]

	Runners (no./mother plant)	Root biomass (g)[y]	Foliar biomass (g)
Growth substrate (GS)[x]	$P = 0.059$	$P < 0.001$	$P = 0.54$
Hot compost	12.4 ± 8.7	36.1 ±10.8	47.3 ±4.0
Cold compost	7.0 ± 8.5	23.1 ±7.3	46.5 ±3.7
Container size (CS)	$P < 0.001$	$P < 0.001$	$P = 0.411$
Channel, half-round[w]	9.7 ± 7.1	30.1 ± 7.6	48.3 ± 4.5
Channel, square[v]	5.9 ± 8.6	24.8 ± 8.6	46.2 ± 4.6
PB5 bags[u]	18.2 ± 5.1	41.0 ± 12.1	48.3 ± 4.5
Cultivar [CV (PB5 only)]	$P = 0.713$	$P = 0.773$	$P = 0.111$
Aromas	19.0 ± 4.9	33.7 ± 7.9	46.1 ± 3.4
Azena	17.4 ± 5.7	27.5 ± 6.6	48.2 ± 3.8

[z]$P > 0.1$ for interactions GC × CS, GC × CV, CS × CV, and GC × CS × CV.
[y]1 g = 0.0353 oz.
[x]Cold compost was produced using temperate composting; hot compost was produced by windrow composting.
[w]110-mm-diameter (4.3 inches), 2-m-long (6.6 ft) polyvinyl chloride (PVC) guttering pipe; approximately 1 L (0.26 gal) growth substrate per plant.
[v]100 × 100 mm (3.9 inches), 2-m-long PVC guttering pipe; approximately 1.4 L (0.37 gal) growth substrate per plant.
[u]120 × 120 × 230 mm (4.7 × 4.7 × 9.1 inches); approximately 2.25 L (0.594 gal) growth substrate per plant.

or foliar biomass; therefore, cultivar data was combined for further analysis (Table 3). Although leaf biomass increased with root biomass:

$$y_{\text{leaf weight}} = 0.158x_{\text{root weight}} + 42.1$$

($R^2 = 0.216$; $P < 0.01$) and visual canopy differences were evident between treatments, no container size and growth substrate effects could be observed using the dry weight of leaves (Table 3). The observed, but weak ($R^2 = 0.216$), relationship between root and leaf biomass is generally in agreement with findings by Fort and Shaw (1998).

Container size suppressed the average number of runners produced per mother plant and total root biomass because both channel systems were totally clogged with strawberry roots, indicating that the channels did not provide sufficient space. Thus, the growth substrate effect on number of runners produced and on root biomass could not be assessed, suggesting that container size is important. For channel systems, organic fertigation management may have the potential to compensate for limited substrate, as has been developed for tomato production (Nakano et al., 2004), by potentially adopting and modifying a hydroponic strawberry plug plant production system as described by Bish et al. (2001).

Based on the observations of the preliminary trial, the sanitation approaches appeared adequate. For validation of organic runner production systems, the use of PB5 bags was recommended. Since addition of vermicast did not alter the nutrient profile of the hot compost, hot compost alone was used in year 2, to reduce substrate costs. Hot compost afforded additional benefits over cold compost, such as reduced risk of disease and reduced pest or weed contamination from the heat treatment in windrow composting.

SYSTEM VALIDATION. Overall, pest and disease issues were small to negligible in the suspended systems unlike in the nursery beds. In the nursery beds, gray mold and powdery mildew infections were difficult to manage and control, particularly toward the end of the runner production season.

Cultivar Gaviota continuously produced runners from the parent plant, whereas the other two cultivars tended to produce a fixed number of initial stolons. As initial stolon counts increased, January runner counts also increased for 'Aromas':

$$y_{\text{runner}} = 2.26x_{\text{stolon}} + 3.64$$

($R^2 = 0.689$; $P < 0.01$); 'Sunset':

$$y_{\text{runner}} = 4.37x_{\text{stolon}} + 5.38$$

($R^2 = 0.671$; $P < 0.01$); and, to a lesser extent, 'Gaviota':

$$y_{\text{runner}} = 1x_{\text{stolon}} + 8.85$$

($R^2 = 0.235$; $P < 0.05$). Since initial stolon counts and runner production were similar, only runner data are presented in detail. However, the regressions suggest that stolon counts may be predictive for runner production in selected cultivars.

The number of runners produced per mother plant was affected by the production system ($P < 0.001$) with a similar pattern observed for the three cultivars tested (Table 4). All cultivars produced approximately two to three times more runners per mother in the NB than in the two suspended systems (Table 4). However, when evaluated on a square meter basis, the two suspended systems produced more runners than the nursery bed system, indicating that the NB system produced the lowest number of runners (Table 4). Other advantages for suspended systems are optimization of space and better disease control for both root and foliar diseases (Durner et al., 2002; Hancock and Simpson, 1995; Hicklenton and Reekie, 2002).

ESS appeared to give some advantage in plant numbers over the SS method. For example, the average number of runners produced per square meter in Jan. 2003 was 68 and 102 for SS and ESS systems, respectively; and in Mar. 2003 runner numbers were 124 and 187 for SS and ESS, respectively. A modified ESS system could be designed to allow more primary runners to be potted or to root in a trough-system to further increase the number of runners produced per mother.

Production of plug transplants is not common in New Zealand, but plug transplants are used extensively in Europe and Northern America (Bish et al., 2002; Poling and Maas, 2000). Bish et al. (2001) found that mother plants produced an average of 30–40 runners using a suspended hydroponic greenhouse production system with mother plants that had not been derived from micropropagation. This is in agreement with runner numbers found (Mar. 2003 counts) in our trial.

As expected, all cultivars produced higher runner counts ($P < 0.05$) in Mar. 2003 than in Jan. 2003. However, the runners collected in Mar. 2003 took approximately 1 to 2 weeks longer to root under the mist. This was probably due to the cooler temperatures and the drying out of runner rooting initials.

Timing for runner collection will be a compromise between maximizing runner quantity and quality, the misting period required for rooting and plug plant production, and, finally, time of

Table 4. Effect of growing system and cultivar on mean number of runners produced per mother plant and per square meter. Runners were counted on 28 Jan. and 12 Mar. 2003 and the corresponding number of runners/m² was then calculated.

		Actual runner mean (no./mother plant ± SD)			Calculated runner mean (no./m²)[z]		
		28 Jan. count	12 Mar. count		28 Jan. count	12 Mar. count	
Growing system[y]	Cultivar	Three-plant plot[x]	Two-plant plot[w]	One-plant plot[v]	Three-plant plot[x]	Two-plant plot[w]	One-plant plot[v]
NB	Aromas	31 n.d.[u]	n.a.[t]	96 n.d.	31	n.a.	96
SS	Aromas	20 ± 4.6	20 ± 4.4	41 ± 2.8	79	80	164
ESS	Aromas	26 ± 13.1	27 ± 13	54 ± 2.1	105	107	214
NB	Sunset	44 n.d.	n.a.	97 n.d.	44	n.a.	97
SS	Sunset	17 ± 8.4	19 ± 8.1	18 ± 7.9	69	76	73
ESS	Sunset	17 ± 8.2	18 ± 8.2	27 ± 9.3	68	72	109
NB	Gaviota	46 n.d.	n.a.	109 n.d.	46	n.a.	109
SS	Gaviota	15 ± 8.2	20 ± 8.1	37 ± 26.6	65	78	147
ESS	Gaviota	29 ± 4.8	35 ± 3.5	59 ± 13	117	139	235
NB	All	39 ± 12.1	n.a.	101 ± 6.3	39	n.a.	101
SS	All	17 ± 7.1	20 ± 7.2	31 ± 18.7	68	78	124
ESS	All	25 ± 10.3	27 ± 8.3	47 ± 8.5	102	109	187

[z]1 plant/m² = 0.0929 plant/ft².
[y]NB = nursery bed; SS = suspended system; ESS = enhanced suspended system.
[x]Jan. 2003 assessment based on three-plant plot replicates.
[w]Mar. 2003 assessment based on two-plant plot replicates: Runners were harvested in Jan. 2003. Data include additional production of runners since the January harvest.
[v]Mar. 2003 assessment based on one-plant plot replicate.
[u]n.d. = not determined; in nursery beds, runners from the mother plants were intergrown and could not be associated with their corresponding mother plants.
[t]n.a. = not applicable.

field planting. In New Zealand, young plug transplants are physiologically advanced to allow for earlier plantings compared to conventionally produced bare-rooted runners. Planting earlier is likely to give an advantage in higher overall yield in the fruiting season.

The tunnel house system to exclude insects and weeds worked well for runner production. Benches and drainage water collection were satisfactory for reuse. Shelf height should be at least 1 m to allow good mother plant access but also to provide sufficient height for the draping stolons.

Field evaluation. Field Trial 1. Over the 11 harvests (3 Dec. 2002 to 11 Feb. 2003), organic 'Aromas' plug plants produced an average of 18.5 fruit/plant with an average weight of 17.1 g/berry or 315 g/plant. In comparison, bare-rooted conventional 'Aromas' transplants produced an average of 13.4 fruit/plant with an average weight of 17 g/berry or 227 g/plant. Plants originating from the organic tray plant production system gave more fruit ($P < 0.01$) while maintaining fruit size, and hence yielded more ($P < 0.01$) than bare-rooted transplants from conventional culture. This difference in yield between plant origins could be due to the tray plant vs. bare-rooted nature of the original plant material, transplant source, and/or transplant quality (Durner et al., 2002; Duval et al., 2003; Kokalis-Burelle, 2003; Stapelton et al., 2001).

There were very few pest and disease issues during the first year of the field trial. Late in the season, wheat bug was noticed and resulted in some distorted fruit (<5%) between Feb. to Mar. 2002.

Field Trial 2. Planting time effects. Over the harvest period, each plant produced an average yield of 733 and 552 g/plant for the March and May plantings, respectively. The yield differences ($P < 0.001$) of 181 g/plant observed between the planting dates occurred during the first 8 weeks of picking and is clearly illustrated in Fig. 2.

Cultivar effects. The average plant yield for 'Sunset' (658 g/plant) and 'Aromas' (626 g/plant) was not significantly different ($P > 0.1$); however, 'Sunset' had a greater proportion of small berries (average 50 fruit/plant and 13.1 g/fruit) compared to 'Aromas' (45 fruit/plant and 14.0 g/fruit; $P < 0.05$). Fig. 3 presents an overview of plant yield for the two cultivars by planting date and runner-origin with corresponding strawberry fruit weights. Performance of the two cultivars in terms of yield and fruit size was above the typical range for 'Sunset' and 'Aromas' conventional strawberry production in New Zealand (NZBP, unpublished).

Plant origin effects. Using May data only (Fig. 3A), there was a significant effect of plant origin ($P < 0.05$) and a plant origin × cultivar interaction ($P < 0.05$). 'Aromas' plants originating from the two organic production systems (bare-rooted NB and ESS plug transplants) had a greater plant yield (591 g/plant) than the bare-rooted conventionally sourced transplants (426 g/plant; $P < 0.05$), but there was no difference in fruit weight between the three plant origins ($P > 0.1$; Fig. 3B). There was also no difference in yield between the two organic production systems for 'Aromas' ($P > 0.1$). In contrast, there were no effects and interactions for yield and fruit number for 'Sunset' ($P > 0.05$). The effect of transplant quality (as defined by type, harvesting, size, age, chilling, and source) on field performance has been studied (Butler et al., 2002; Crawford et al., 2000; Duval et al., 2002, 2003; Kokalis-Burelle, 2003; Stapelton et al., 2001) but with conflicting results (Crawford et al., 2000). Our study supports that there was a transplant effect on field performance.

During the 21-week harvest, damage caused by slugs was minimal and similar for both cultivars ($P > 0.1$) with an average of 2.6 fruit/plant (or

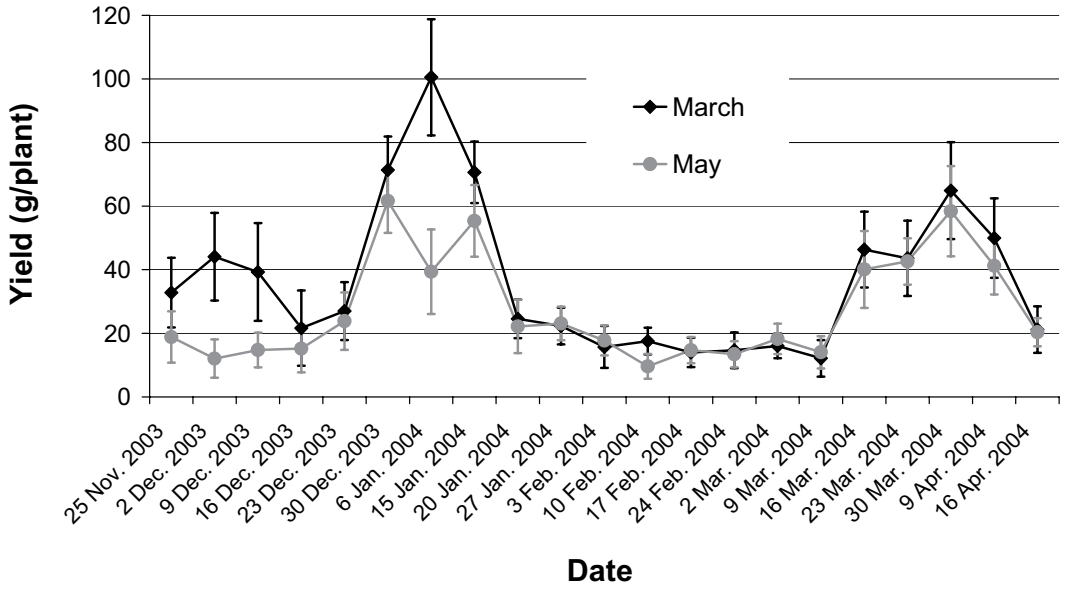

Fig. 2. Average weekly fruit yield per plant for Mar. and May plantings. Data were pooled for both cultivars (Aromas, Sunset) and runner-origins (organic, conventional). Error bars represent the SD of the mean; 1 g = 0.0353 oz.

6%) affected. There were no treatment effects ($P > 0.05$) with regard to slug damage. Wheat bug damage was first observed in January with a second peak in early March. These peaks coincided with the flight peaks during the 2003 to 2004 growing season (M.A.W. Stufkens, personal communication). During these peak times, up to 40% of fruit was damaged. During the harvest period, 'Aromas' showed fewer distorted fruit (2.69 fruit/plant) compared with 'Sunset' (5.74 fruit/plant; $P < 0.01$). This equates to a total of approximately 7% and 12% fruit distortion for 'Aromas' and 'Sunset', respectively.

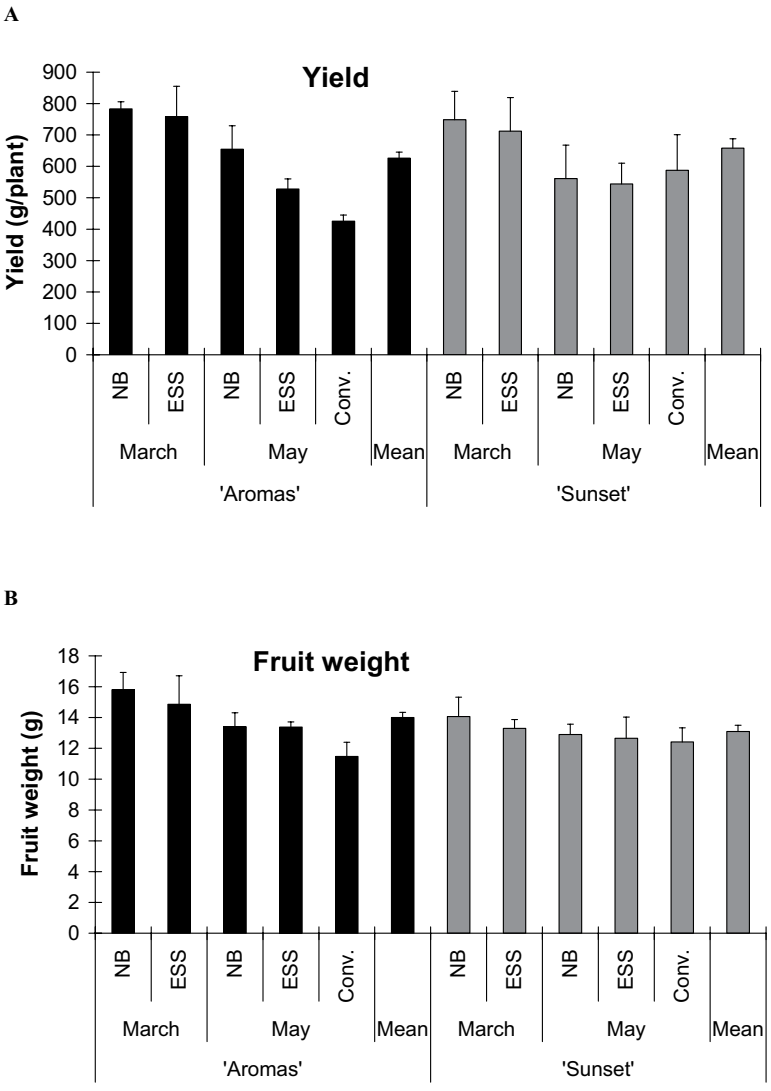

Fig. 3. Total strawberry yield (A) and average strawberry fruit weight (B) picked during the 21 weeks of harvest for cultivars Sunset and Aromas separated by March and May planting dates and by the different runner origins: organic production nursery bed [NB (bare-rooted)] and enhanced suspended system [ESS (plug transplants)] vs. conventional production [Conv. (bare-rooted)]. For NB, mothers were left to runner into a nursery bed containing the growth substrate; for ESS, mother plants grew on benches and runners, except the first two which were potted into growth substrate, were left to fall down off the benches forming a curtain. Error bars represent the SD of the mean; 1 g = 0.0353 oz.

There was virtually no disease during the first 10 weeks of harvest, although some sunburn was present. There was a small but significant difference ($P < 0.05$) between cultivars for the amount of fruit damaged by sunburn and disease. On a weekly basis, an average number of 0.23 and 0.32 fruit/plant were affected by sunburn or disease for 'Aromas' (0.6%) and 'Sunset' (0.7%), respectively.

Conclusion

Research presented here on organic indoor tray plant production and field evaluation in general agrees with the recent advances in strawberry plug transplant technology as reviewed by Durner et al. (2002). Based on disease and pest problems, sanitation, and number of runners produced per square meter, the ESS is recommended for organic production systems. Quality indoor runner production under organic conditions can be achieved with a high level of sanitation (e.g., white hydroponic plastic (or similar product) for groundcovers and general cleanliness) and insect-barriers (e.g., UV-resistant screen or similar product). PB5 bags or similar-sized growing containers for strawberry mother plants followed by PB3/4 bags for runners were found suitable for maintaining healthy mother plants. Alternatively, a larger trough could be used for holding both mother and first runner plants. Suspension of mother plants at a height of at least 1 m on single shelving was suitable for adopting a suspended system. A well-prepared hot compost (± vermicast) was adequate as the basic growth substrate. No additional nutrition was required, particularly with the collection and recycling of drainage-water; however, irrigation management could be adjusted to reduce the risk of nutrient leaching. It is important to regularly monitor pests and diseases of mother and runner plants to maintain high quality standards.

Field evaluation of organically produced runners (bare-rooted and plug transplants) vs. bare-rooted conventionally produced runners showed that there were generally no differences in yield or fruit quality among runner sources. It is noteworthy that for 'Aromas' organically produced bare-rooted transplants and/or plug transplants resulted in higher yields than the bare-rooted conventionally produced runners. This trend was observed in both years. The biggest impact on yield, however, was the planting date. The earlier planting time in Mar. 2003 increased average plant yield by approximately 181 g/plant from 552 to 733 g/plant for May 2003 and Mar. 2003 plantings, respectively. This compares with an average yield of 350 to 450 g/plant for the conventional strawberry growers in the Canterbury region (NZBP, unpublished).

Our results show that by appropriate site selection and with good glasshouse sanitation, good quality strawberry runners can be produced organically. Organic runners not only performed as well as bare-rooted conventionally produced runners, but also indoor production has the potential for an earlier planting date, which in this region where frost damage is not a risk there is potential for a significant increase in yield. This, in turn, not only offset the increased cost per runner plant but also increased the profit per plant (Walter et al., 2006). In conclusion, organic strawberry runner production not only is achievable but also is economically viable.

Literature cited

Association of Official Analytical Chemists. 1981. Official methods of analysis of the AOAC. 13th ed. AOAC, Washington, D.C.

Athanasopoulas, N. 1989. Flame methods manual for atomic absorption. GBC Sci. Equipment Pty Ltd., Dandenong, Australia.

Blakemore, L.C., P.L. Searle, and B.K. Daly. 1987. Methods for chemical analysis of soils. New Zealand Soil Bur. Sci. Rpt. 80. New Zealand Soil Bur., Lower Hutt.

BioGro New Zealand, Inc. 2001. BioGro New Zealand organic standards. Version 1. 30 Apr. 2001. 31 Mar. 2005. <http://www.biogro.co.nz/content/files/1010430_intro.pdf>.

Bish, E.B., D.J. Cantliffe, and C.K. Chandler. 2001. A system for producing large quantities of greenhouse-grown strawberry plantlets for tray production. HortTechnology 11(4):636–638.

Bish, E.B., D.J. Cantliffe, and C.K. Chandler. 2002. Temperature conditioning and container size affect early season fruit yield of strawberry plug transplants in a winter, annual hill production system. HortScience 37(5):762–764.

Butler, L.M., G.E. Fernandez, and F.J. Louws. 2002. Strawberry plant growth parameters and yield among transplants of different types and from different geographic sources, grown in a plasticulture system. HortTechnology 12(1):100–103.

Crawford, T.D., D.G. Himelrick, J.L. Sibley, and J.A. Pitts. 2000. Effect of runner plantlet size on performance of strawberry plug transplants. Small Fruits Rev. 1(1):15–21.

Davies, E.B. 1952. The New Zealand Soil Advisory Service. Trans. Intl. Soc. Soil Sci. Comm. 2/4:340–348.

Durner, E.F., E.B. Poling, and J.L. Maas. 2002. Recent advances in strawberry tray transplant technology. HortTechnology 12(4):545–550.

Duval, J.R., C. Chandler, D.E. Legard, and P. Hicklenton. 2002. Performance of hand- and machine-dug transplants in the Florida production system. Acta Hort. 567:289–291.

Duval, J.R., C. Chandler, D.E. Legard, and P. Hicklenton. 2003. Reducing mechanical damage during transplant digging increases early season fruit yield of strawberry. HortTechnology 13(1):106–109.

Fort, S.B. and D.V. Shaw. 1998. Phenotypic correlations between root and shoot traits of strawberry in fumigated and nonfumigated soils. HortScience 33(2):222–224.

Hancock, J. and D. Simpson. 1995. Methods of extending the strawberry season in Europe. HortTechnology 5(4):286–290.

Hicklenton, P.R. and J.Y-C. Reekie. 2002. The nursery connection: Exploring the links between transplant growth, development, establishment and productivity, p. 136–146. In: S.C. Hokanson and A.R. Jamieson (eds.). Strawberry research to 2001. Proc. 5th North Amer. Strawberry Conf. 2002. ASHS Press, Alexandria, Va.

Kokalis-Burelle, N. 2003. Effect of transplant type, plant growth-promoting rhizobacteria, and soil treatment on growth and yield of strawberry in Florida. Plant Soil 256:273–280.

Larsen, D.K. and D.W. Shaw. 1995. Strawberry nursery soil fumigation and runner plant production. HortScience 30(2):236–237.

Larsen, D.K. and D.W. Shaw. 2000. Soil fumigation and runner plant production: a synthesis of four years of strawberry nursery field trials. HortScience 35(4):642–646.

Lieten, F. 2000. Recent advances in strawberry plug transplant technology. Acta Hort. 513:383–388.

Nakano, A., H. Kawashima, H. Sakuma, and Y. Uehara. 2004. Effects of organic fertigation on the growth, yield, sugar and

inorganic content and delta 15N values of tomato. Bul. Natl. Inst. Veg. Tea Sci. 3:129–136.

Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon and organic matter, p. 961–1010. In: J.M. Bigham, J.M. Bartels, D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnston, and M.E. Sumner. (eds.). Methods of soil analysis. Part 3. Chemical methods. SSSA–ASA, Madison, Wis.

New Zealand Berryfruit Propagators Ltd. 2003. Strawberry runner plant scheme. Lower Hutt, New Zealand.

National Organic Program. 2004. NOP regulations (standards) and guidelines. 31 Mar. 2005. <http://www.ams.usda.gov/nop/NOP/NOPhome.html>.

New Zealand Food Safety Authority. 2004. MAF Standard OP3, Appendix Two. NZFSA technical rules for organic production. Version 4, May 2004. New Zealand Food Safety Authority, Ministry of Agr. and For., Wellington. 31 Mar 2005. <http://www.nzfsa.govt.nz/organics/framework/ooap-rules.htm>.

New Zealand Food Safety Authority. 1969. New Zealand fertilisers regulations 1969. Organic material digestion method. Section 4–121. New Zealand Govt., Govt. Printer, Wellington.

Paranjpe, A.V. 2001. Strawberry production around the world. University of Florida. Gainesville. 31 Mar. 2005. <http://www.hos.ufl.edu/protectedag/Strawberry.htm>.

Paranjpe, A.V., D.J. Cantliffe, and R. Koenig. 2004. Developing a system to produce organic plug transplants for organic strawberry production. Proc. Fla. State Hort. Soc. 117: 276–282.

Paranjpe, A.V., D.J. Cantliffe, E.M. Lamb, P.J. Stoffella, and C. Powell. 2003. Winter strawberry production in greenhouses using soilless substrates: An alternative to methylbromide soil fumigation. Proc. Fla. Hort. Soc. 116:98–105.

Poling, E.B. and J.L. Maas. 2000. Strawberry plug transplant technology. Acta Hort. 513:393–401.

Stapelton, S.C., C.K. Chandler, D.E. Legard, J.F. Price, and J.C. Sumler, Jr. 2001. Transplant source affects fruiting performance and pests of 'Sweet Charlie' in strawberry in Florida. HortTechnology 11(1):61–65.

van Bueren, E.T.L. 2002. Organic plant breeding and propagation: Concepts and strategies. PhD Diss., Lab. of Plant Breeding, Wageningen Univ., The Netherlands. 31 Mar. 2005. <http://www.gcw.nl/dissertations/3329/dis3329.pdf>.

van Bueren, E.T.L., P.C. Struik, and E. Jacobson. 2003. Organic propagation of seed and planting material: An overview of problems and challenges for research. NJAS–Wageningen J. Life Sci. 51(3):263–277.

Walter, M., C. Snelling, K.S.H. Boyd-Wilson, G. Williams, and G.I. Langford. 2006. Development of a commercially viable system for organic strawberry-runner production. Acta Hort. (in press).