2019 Annual Spring Conference of KSHS

Current Situations of Korean Strawberry Industry and Strawberry Transplant Propagation Using Plant Factory Technology

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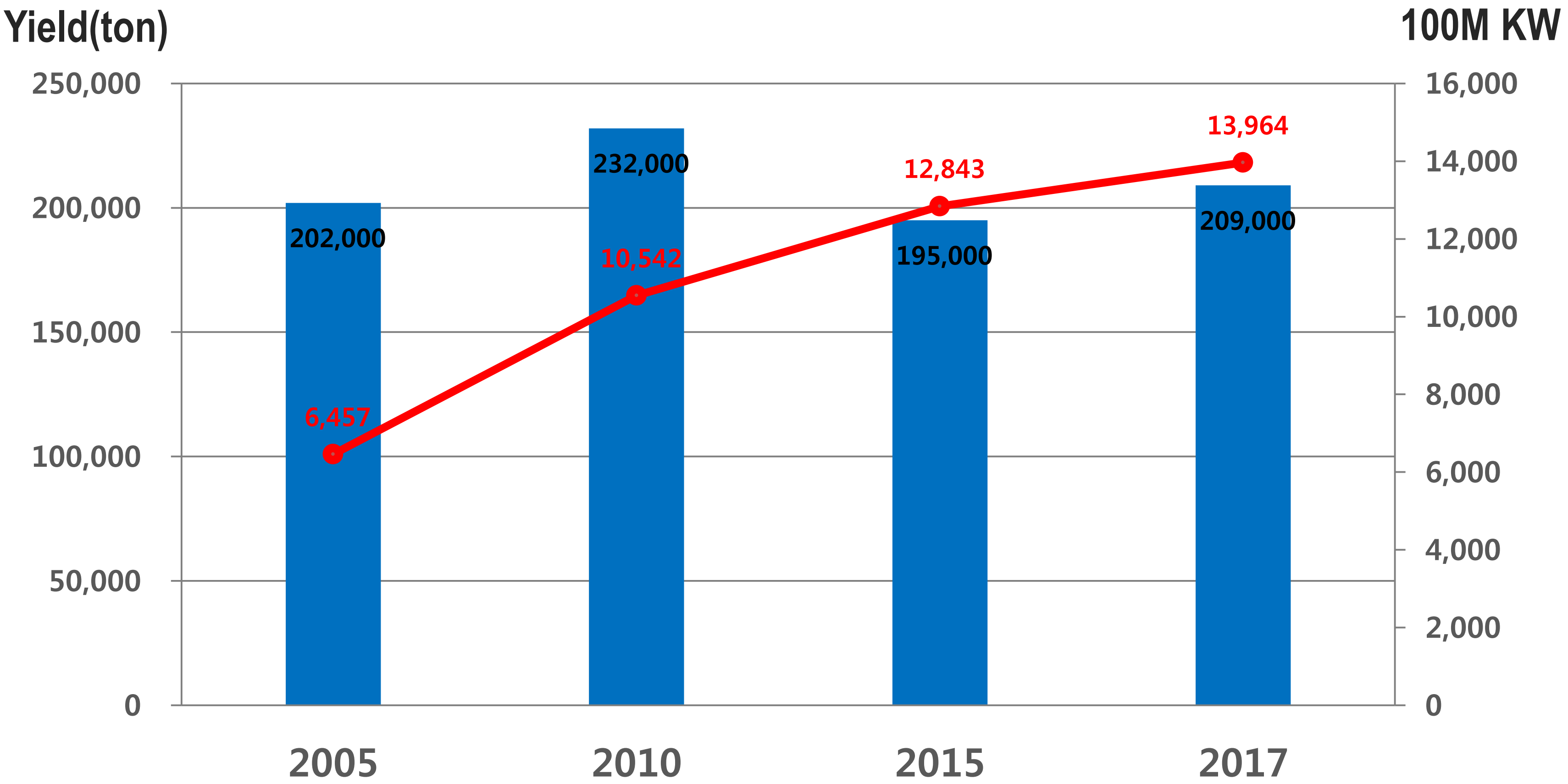
Strawberry industry in Korea (in 2017)

- 209,000 tons (Fruit yield)
- 1.2 billion USD (Production value)

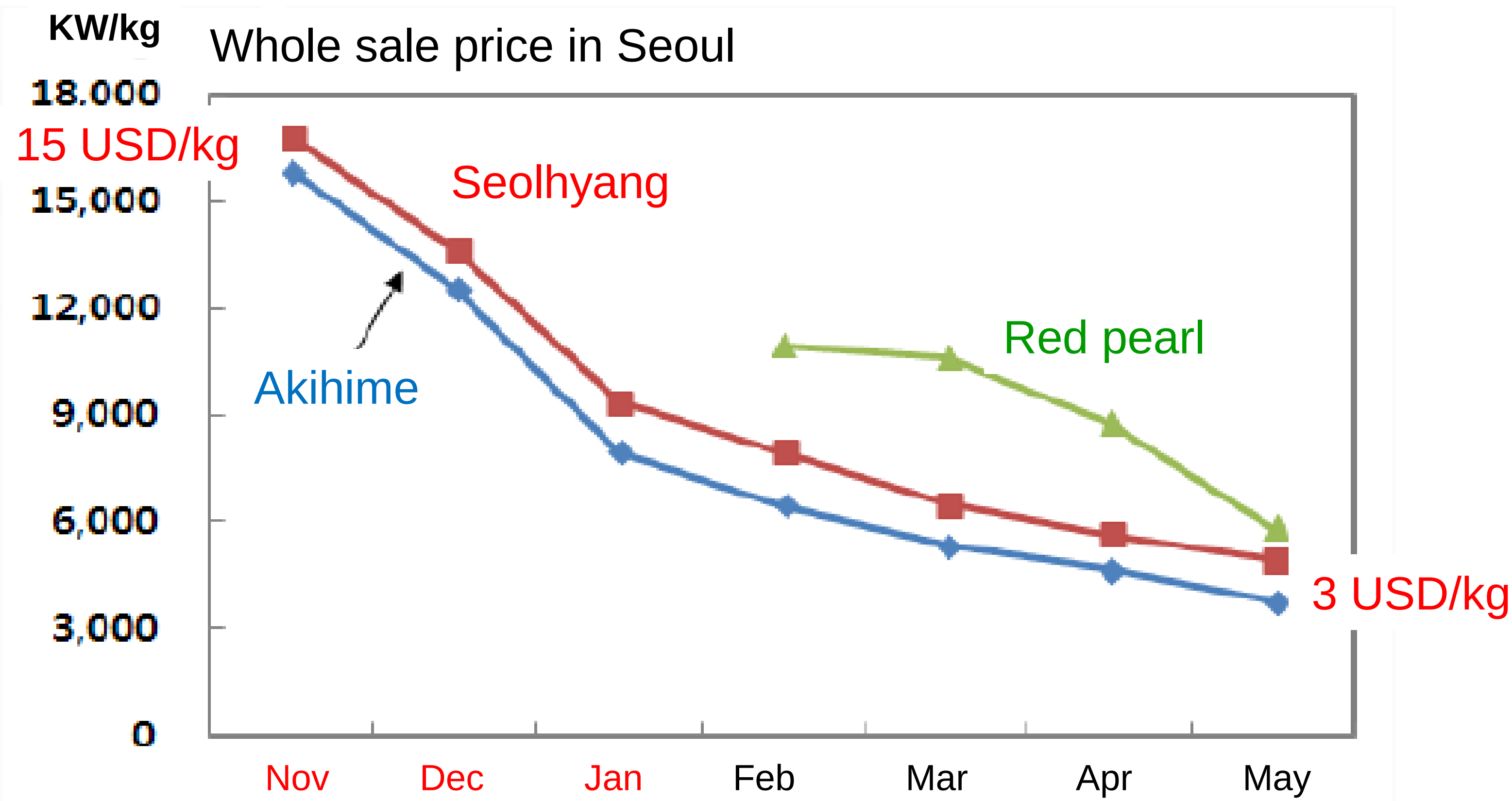


Red line : Production value

Blue bars : Yield

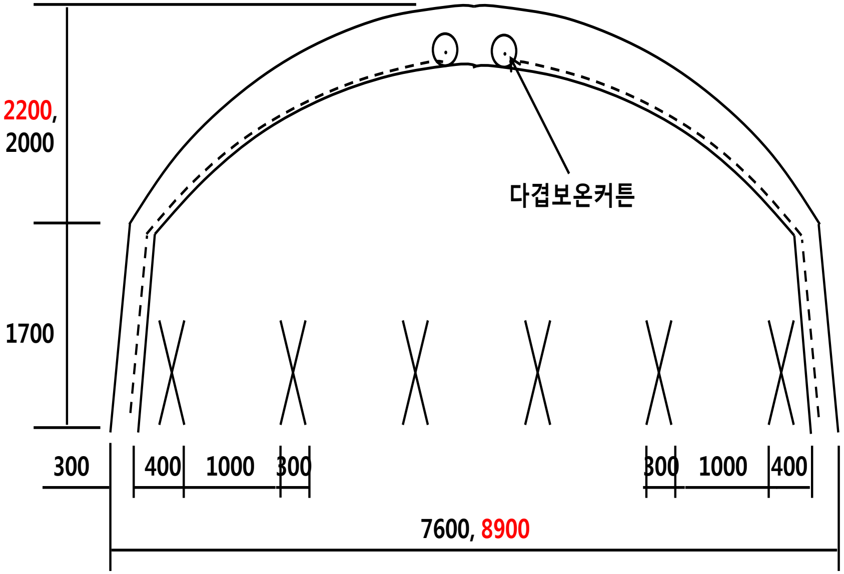
Whole sale price

- Season is critical (earlier and earlier!!) for fruit price.
- Competition with Korean melon & watermelon after March
- Almost 100% in greenhouses



Multi-layered plastic greenhouses for strawberry production

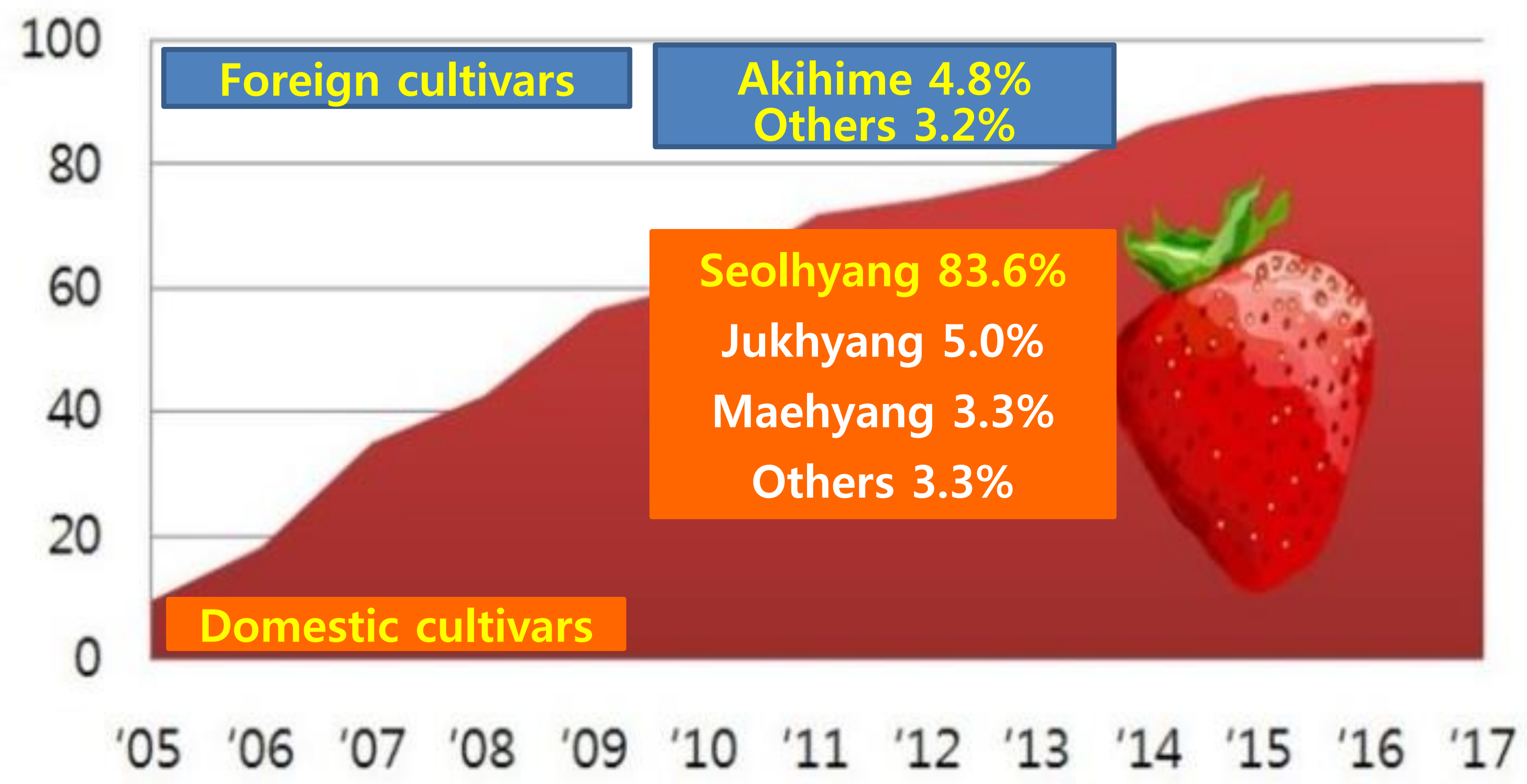
- + Water curtain system
- +/- Heating systems (boilers and/or heat pumps)



Predominant Korean-bred Cultivars

40 domestic cultivars were bred and registered since 2004.

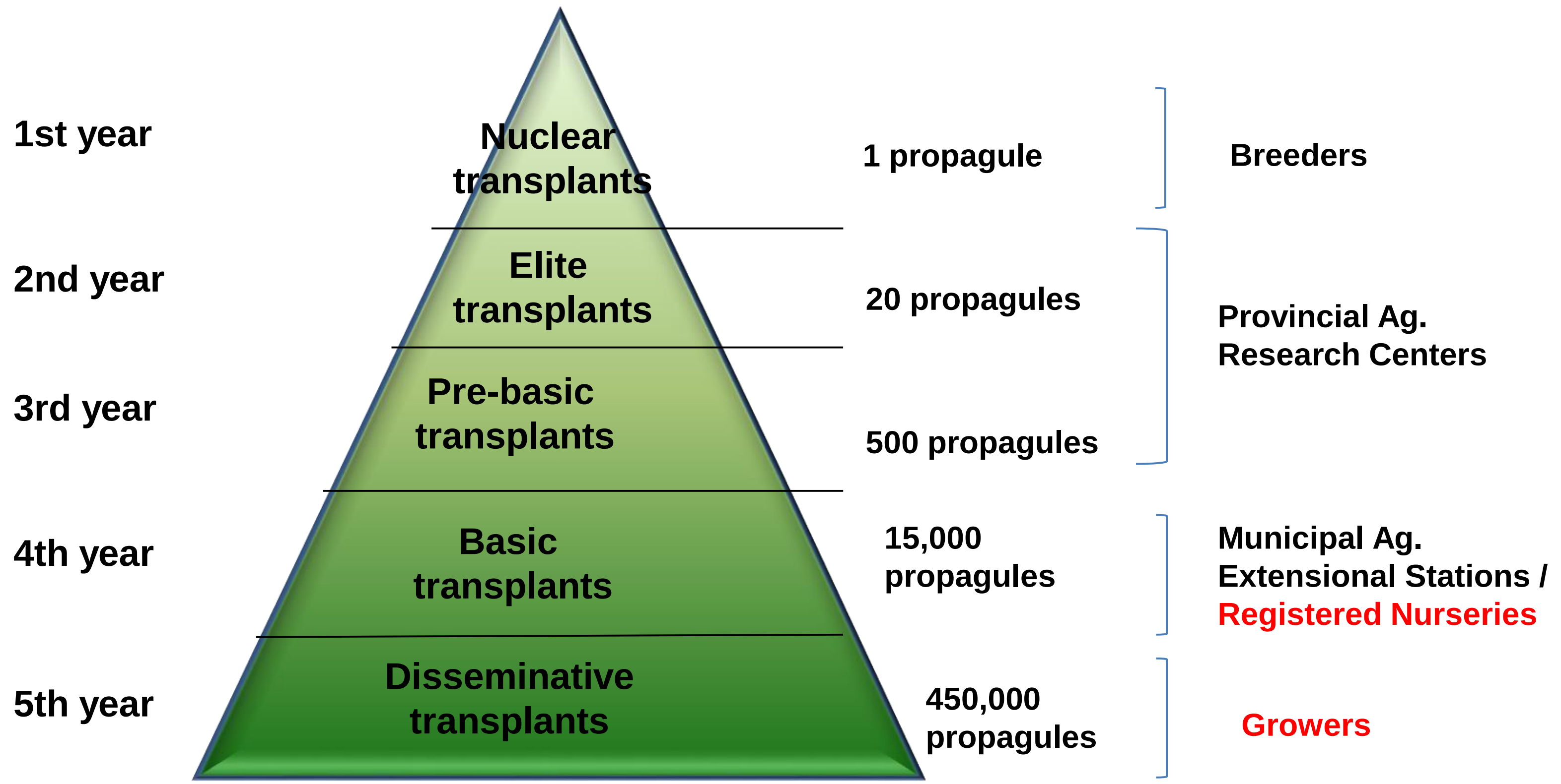
4% in 2004 → 92% in 2018



(RDA, 2017; KATI, 2018)

Establishment of Propagation and distribution system in Korea

- Operated since 2011, a public-private cooperative system



Propagation and distribution system for domestic cultivars in Korea

- It requires ca. 600 million transplants per year.
- It is necessary to establish a rapid propagation and distribution system, <u>especially when new promising cultivars are bred</u>.

Conventional propagation methods

Low propagation rate of transplants in the conventional methods (25-30 transplants from a mother plant per year) is a major problem for rapid distribution of newly-bred cultivars.

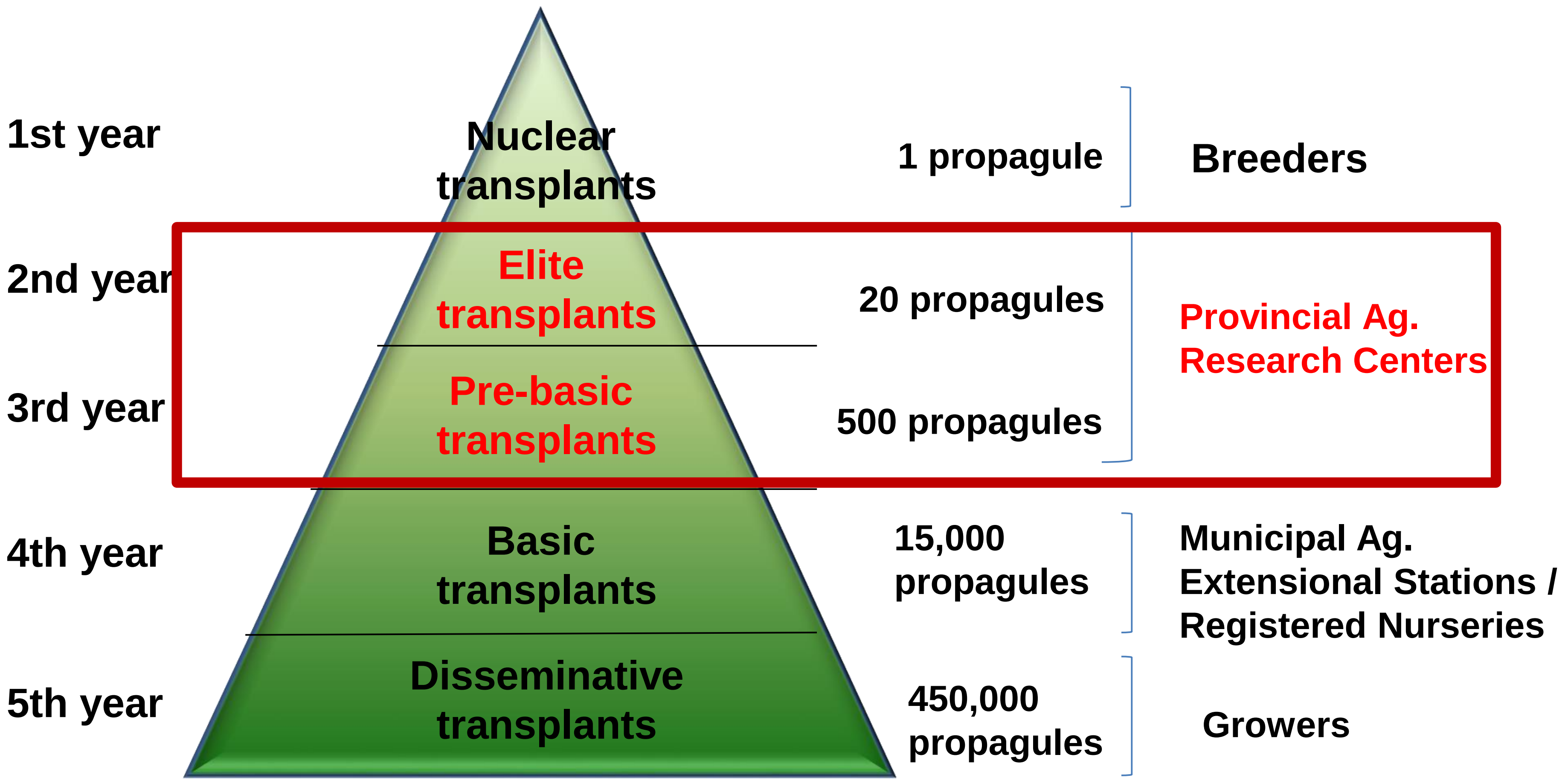
Structural and functional elements of PFAL (Plant Factory using Artificial Lighting)

- Thermally insulated warehouse-like structure
- Multiple racks (ca. 40 cm between racks vertically) equipped with lighting devices
- Air conditioning facilities
- CO_2 delivery system
- Fans for circulating room air
- Nutrient solution delivery system

PFAL for strawberry transplant production (S-PFAL system)

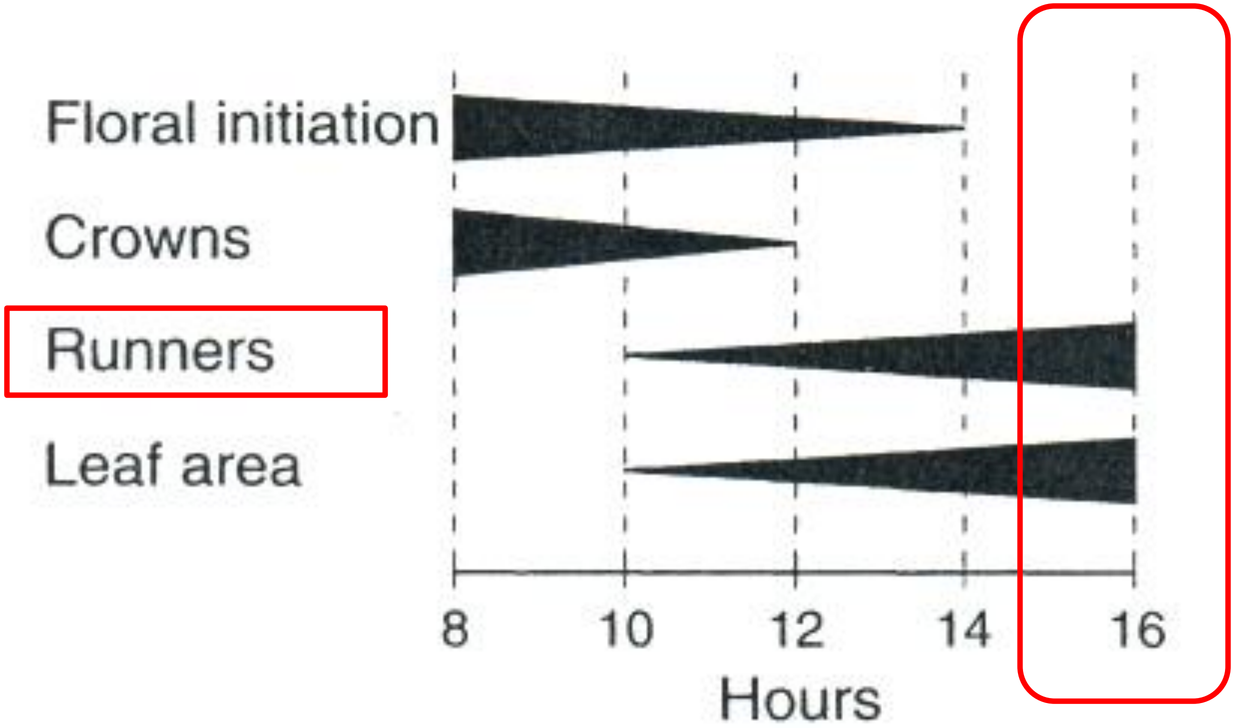
Seoul National Univ., Korea

S-PFAL for producing elite and pre-basic transplants



Photoperiod

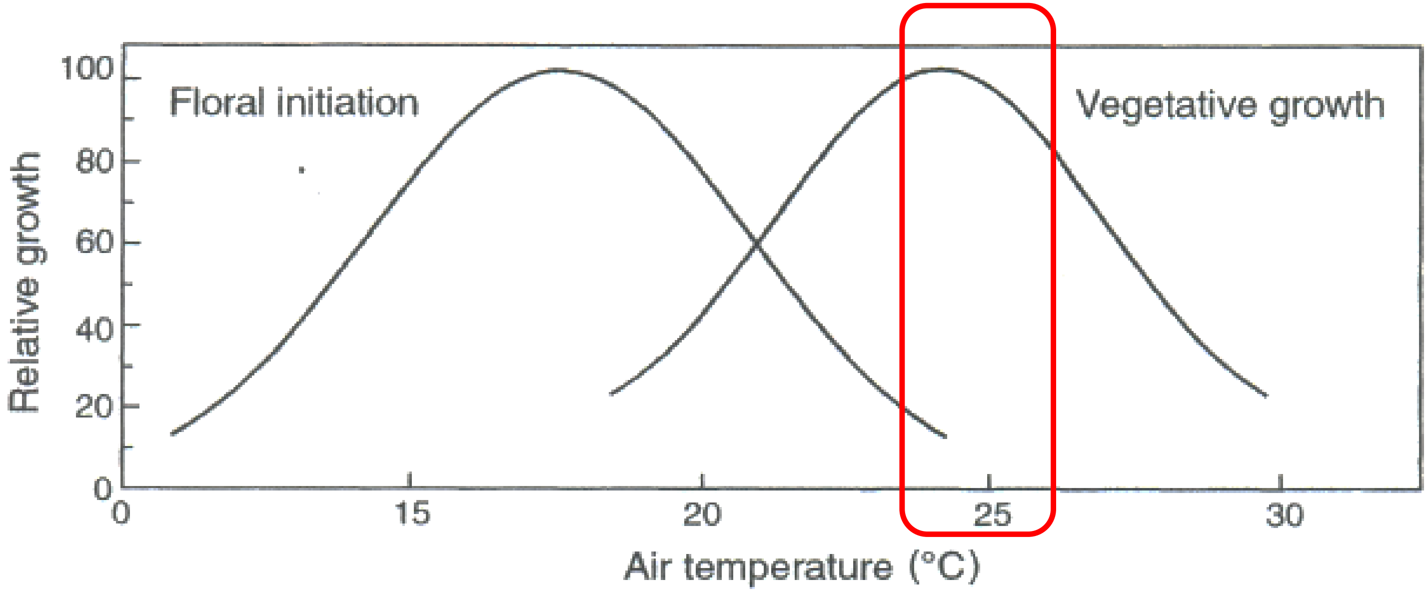
Long day condition
(photoperiod of 16 h d^{-1})



Hancock, 1999

Air temperature

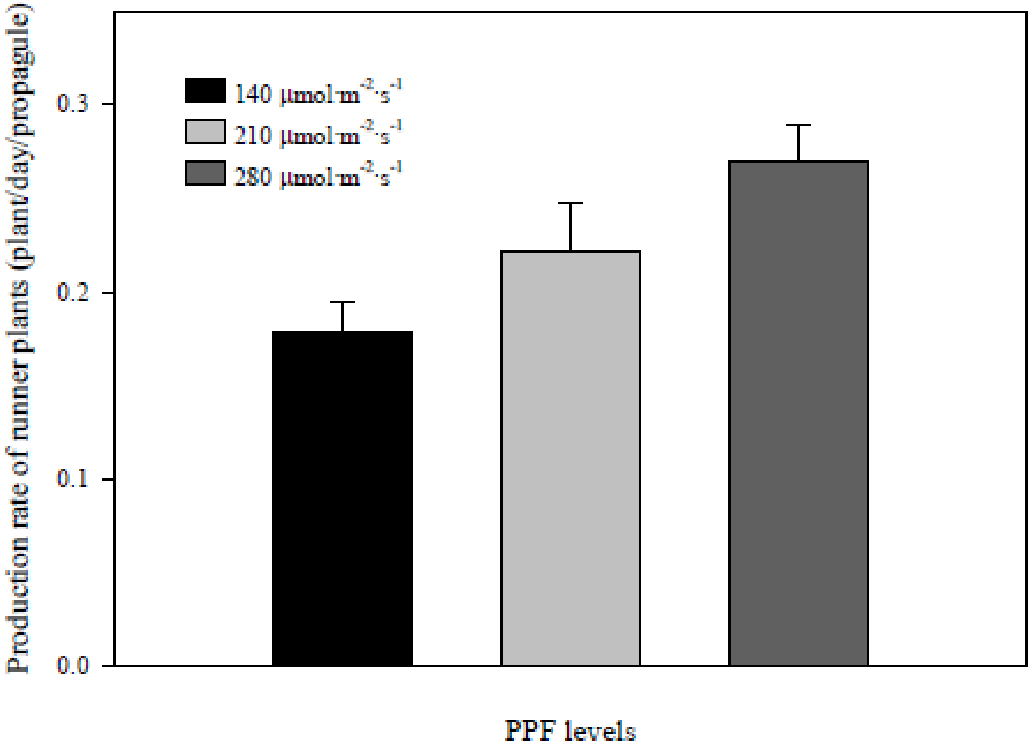
Warm air temperature
(air temperature of 26/23°C, photo- / dark periods)



Hancock, 1999

Light intensity

PPF of 240 $\mu mol \cdot m^{-2} \cdot s^{-1}$



Kim et al. 2010.

CO_2 concentration

CO_2 concentration of 900 μmol·mol^{-1}

CO_2 (ppm)	Runner number per plant	Total runner length per plant (cm)	Average runner length (cm)	Daily growth of runner length (cm $plant^{-1}$ d^{-1})	Daughter plant number per plant
300	4 ± 1d	164.5 ± 12.8d	45.4 ± 5.1a	3.29 ± 0.26d	2 ± 1b
450	6 ± 1c	258.1 ± 19.3c	43.5 ± 4.9a	5.16 ± 0.39c	4 ± 1c
600	8 ± 1b	351.7 ± 15.1b	42.3 ± 1.6a	7.03 ± 0.30b	6 ± 1b
750	10 ± 2a	419.1 ± 70.6a	43.2 ± 5.3a	8.38 ± 1.41a	8 ± 1a
900	11 ± 2a	465.4 ± 61.0a	44.9 ± 3.7a	9.31 ± 1.22a	9 ± 2a
R	0.942	0.942	-0.045	0.942	0.960

Chun et al, 1997

Fertigation

- Sub-irrigation for ca. 10 minutes, twice a day
- Modified Yamazaki's nutrient solution for strawberry (2 N, 1.5 P, 3 K, 2 Ca, 1 Mg, and 1 S me·L^{-1}; 0.7 mS·cm^{-1})

Chun et al, 2011

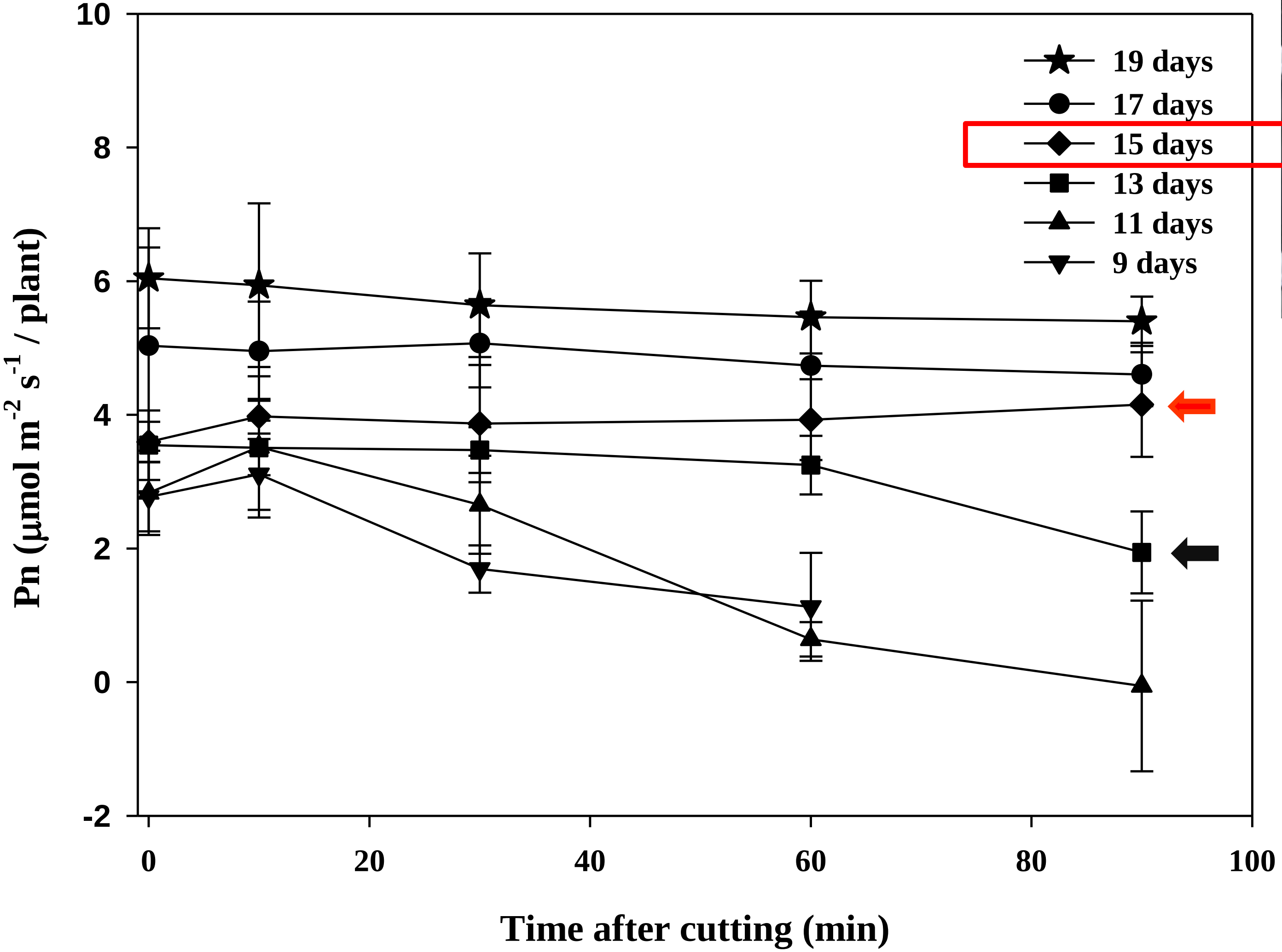
Can a young runner plant autotrophically grow?

Earliest time to separate runner plant from propagule?

- Runner is a passage of carbohydrates, water and nutrients from its mother plant to the runner plant.
- When can the young runner plant autotrophically grow after being separated from its propagule?

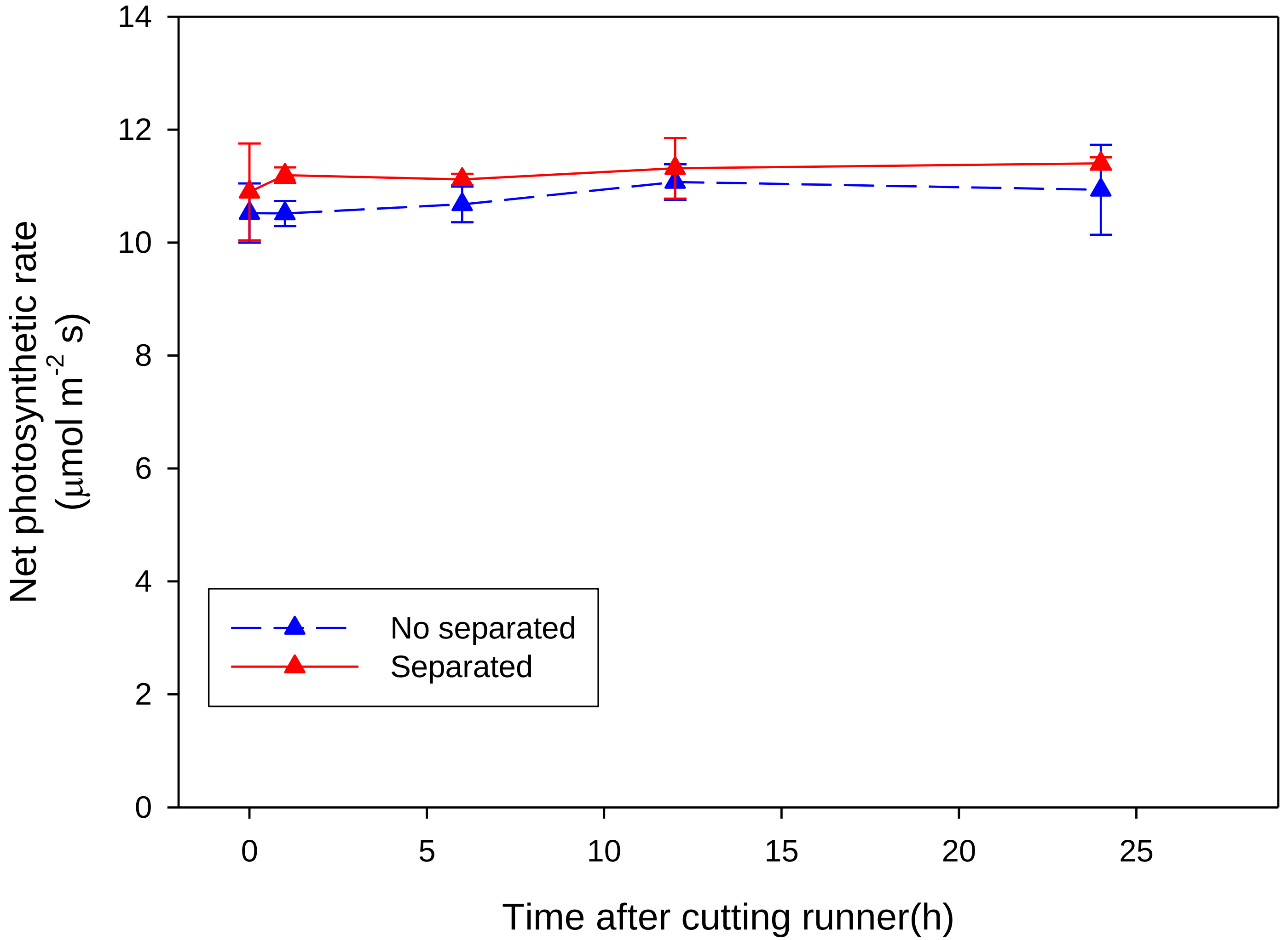
Autotrophic growth - Photosynthetic rate of runner plants (1)

Separated from mother plants 15 days after fixing runner tips



Autotrophic growth - Photosynthetic rate of runner plants (2)

Runner plants separated from their mother plants 15 days after fixing runner tips recorded the greater Pn than not separated ones.



Subsequent growth of runner plants

S15 S20 S25 S30

Growth of runner plants as affected by timing of separation from their propagules <u>15 - 30 days after fixing runner tips.</u>

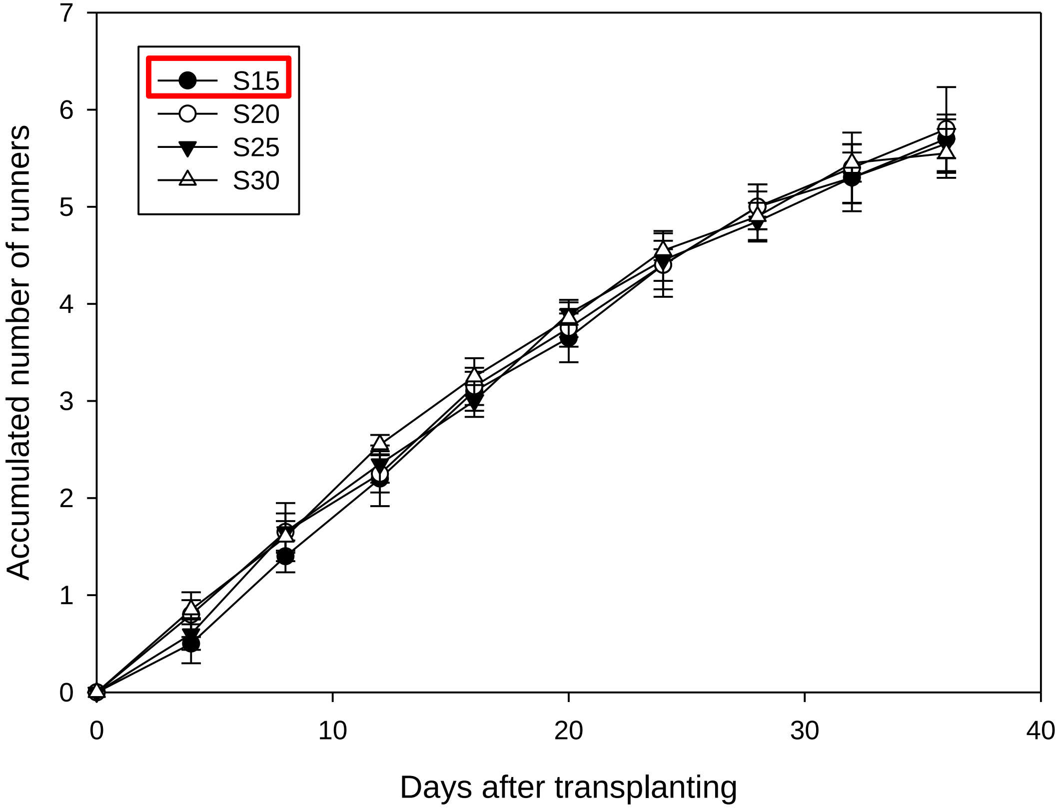
Growth and propagation parameters

Growth of runner plants grown until 30 days after fixing runner tips as affected by time separated from their stock plants

	No. of leaves	No. of runners	Crown diameter (mm)	Leaf area (cm2/plant)	Maximum length of petioles	Dry weight (g/plant)		
						leaves	Stems	Roots
S15*	4.0a	3.0a	6.7b	160.7a	106.2b	0.93a	0.43bc	0.18b
S20	3.5ab	3.0a	7.2ab	150.5a	121.0b	0.90a	0.4c	0.19ab
S25	3.3b	3.2a	7.7a	178.2a	146.3a	1.01a	0.49ab	0.23ab
S30	3.2b	3.2a	7.6a	160.9a	152.7a	0.85a	0.54a	0.25a

*Separated X days after fixing runner tips

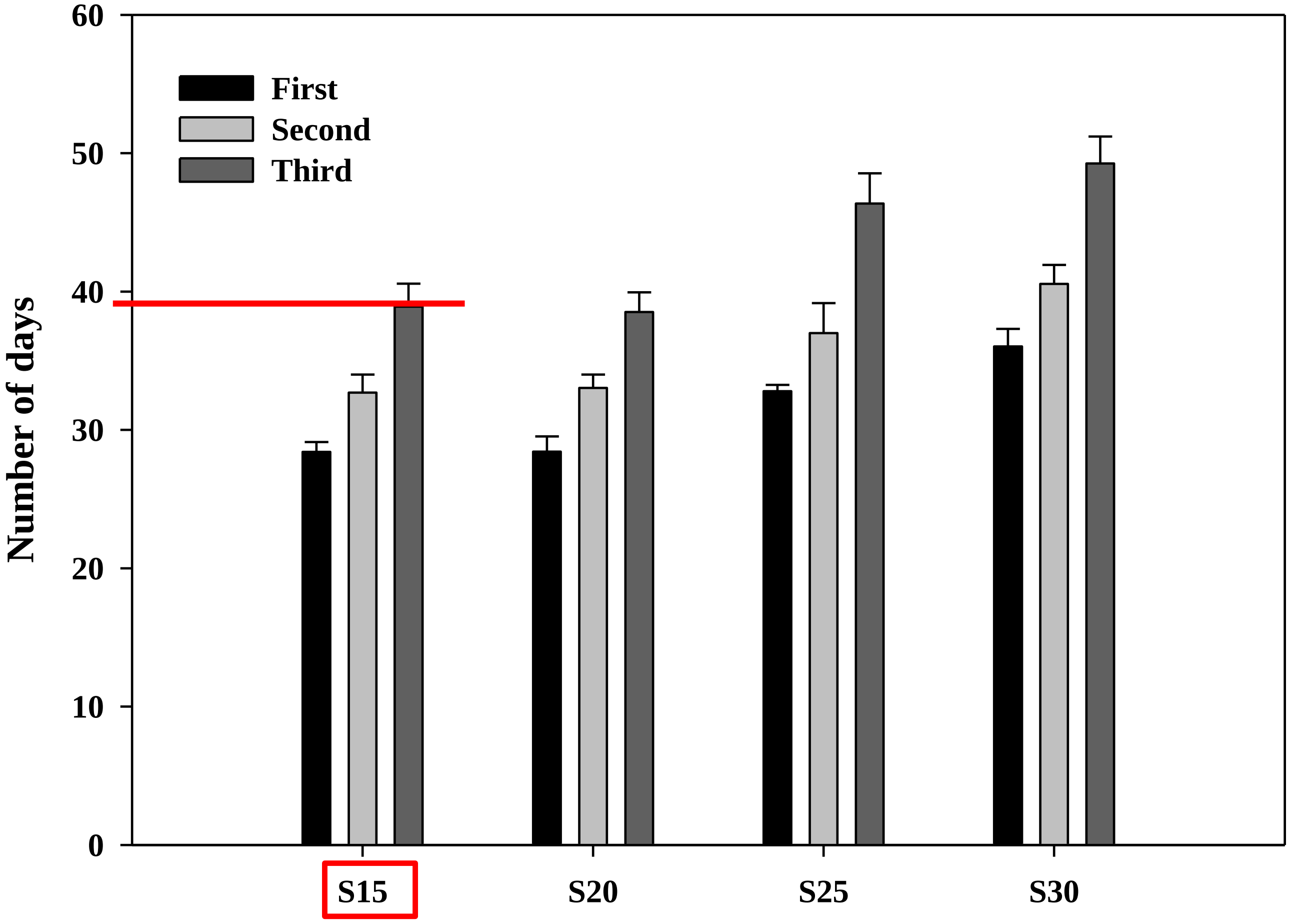
Accumulated number of runners per propagule



Time course of accumulated number of runners <u>for 36 days </u>as affected by size of propagules.

Propagation cycle

Runner plant separation 15 days after runner tip fixation

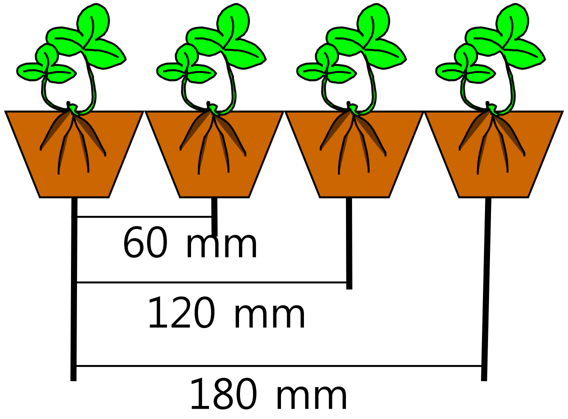


Timescales for producing runner plants as affected by size of propagules.

Plant density - propagules (1)

Efficient use of the limited cultivation area of a S-PFAL

- Distance between two adjacent propagules
  - 60, 120, and 180 mm



Plant density - propagules (2)

Planting density of propagules : 44 propagules/m^2

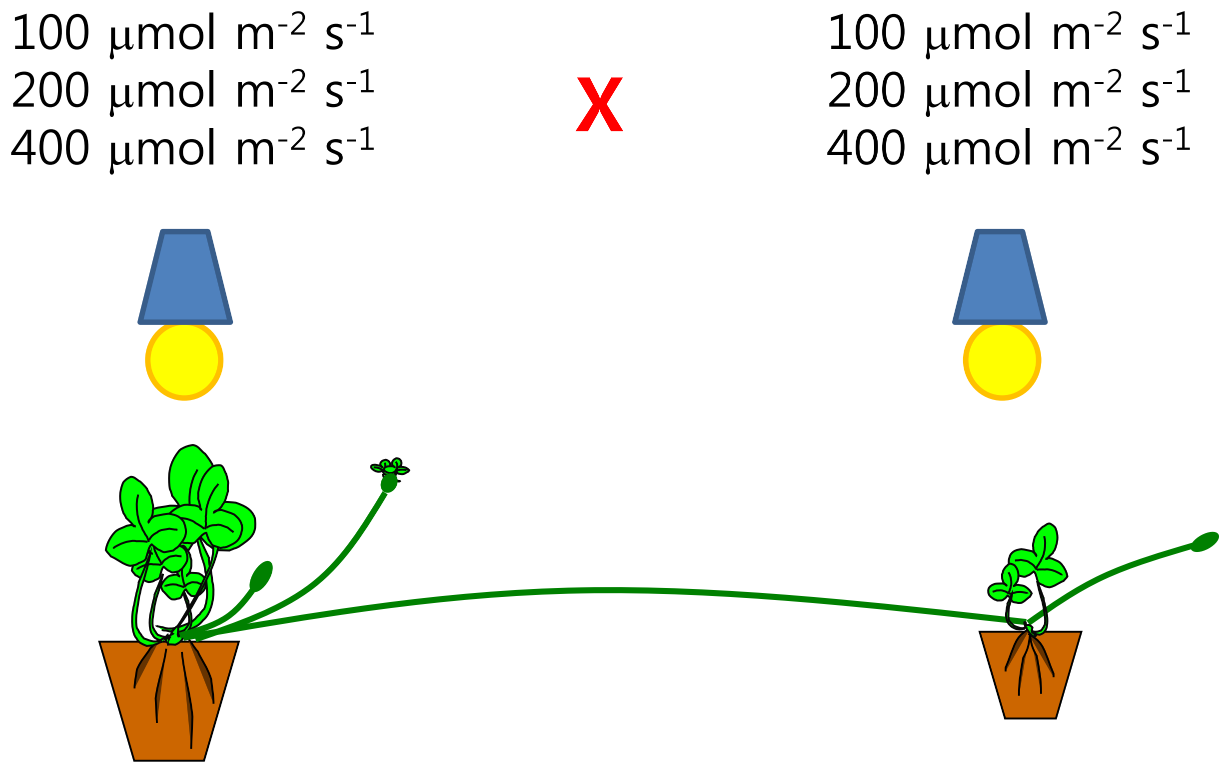
Growth of propagules as affected by planting distance between propagules for 40 days.

Planting distance (mm)	No. of leaves (/plant)	No. of runners (/plant)	Crown diameter (mm/plant)	Fresh weight (g/plant)			Dry weight (g/plant)		
				Leaves	Crown	Root	Leaves	Crown	Root
60	5.8a	4.2a	10.2b	12.0a	2.1a	3.1b	3.1a	0.4a	0.4a
120	6.3a	4.3a	10.9a	13.3a	2.6a	3.3ab	3.9a	0.5a	0.4a
180	6.2a	4.5a	10.6ab	13.5a	2.7a	3.9a	3.9a	0.5a	0.5a

Planting density - runner plants (1)

Mutual shading by propagules and runner plants?

- PPF levels above propagules and runner plants
  - 100, 200, and 400 μmol m^{-2} s^{-1}



Planting density - runner plants (2)

Planting density of runner plants : 132 runner plants/m^2

PPF ($\mu mol \cdot m^{-2} \cdot s^{-1}$)		No. of leaves (/plant)	Crown diameter (mm)	Fresh weight (g / plant)		Dry weight (g / plant)	
P^z	R^y			Shoot	Root	Shoot	Root
400	400	5.0a	6.9a	8.23a	2.75a	2.47a	0.37a
	200	4.8ab	6.6abc	7.08ab	2.14b	2.08b	0.25b
	100	4.3bc	7.0ab	6.95abc	2.09b	1.95b	0.23b
200	400	4.0c	6.4abc	5.79bcd	1.79bc	1.52c	0.25b
	200	4.3bc	6.2bc	5.96bcd	2.03bcd	1.32cd	0.19bc
	100	4.8ab	6.5abc	5.66cd	1.68bcd	1.25c	0.19bc
100	400	5.0a	5.9cd	4.92d	1.38cde	0.91de	0.14cd
	200	4.3bc	6.0cd	4.82d	1.49de	0.86e	0.13d
	100	4.0c	5.3d	3.49e	0.97e	0.63e	0.09d
Significance							
P		ns	**	**	**	**	**
R		ns	ns	ns	ns	ns	ns
P X R		**	ns	ns	ns	ns	ns

^{z}PPF levels of propagules
^{y}PPF levels of runner plants

Container size for propagules (1)

- Container size (or root volume) of propagules
- 145, 73, 34 and 21 mL

145mL 73mL 34mL 21mL

145mL 73mL 34mL 21mL

Container size for propagules (2)

Container size (root volume) : 21 mL

Growth of runner plants as affected by container size grown for 35 days.

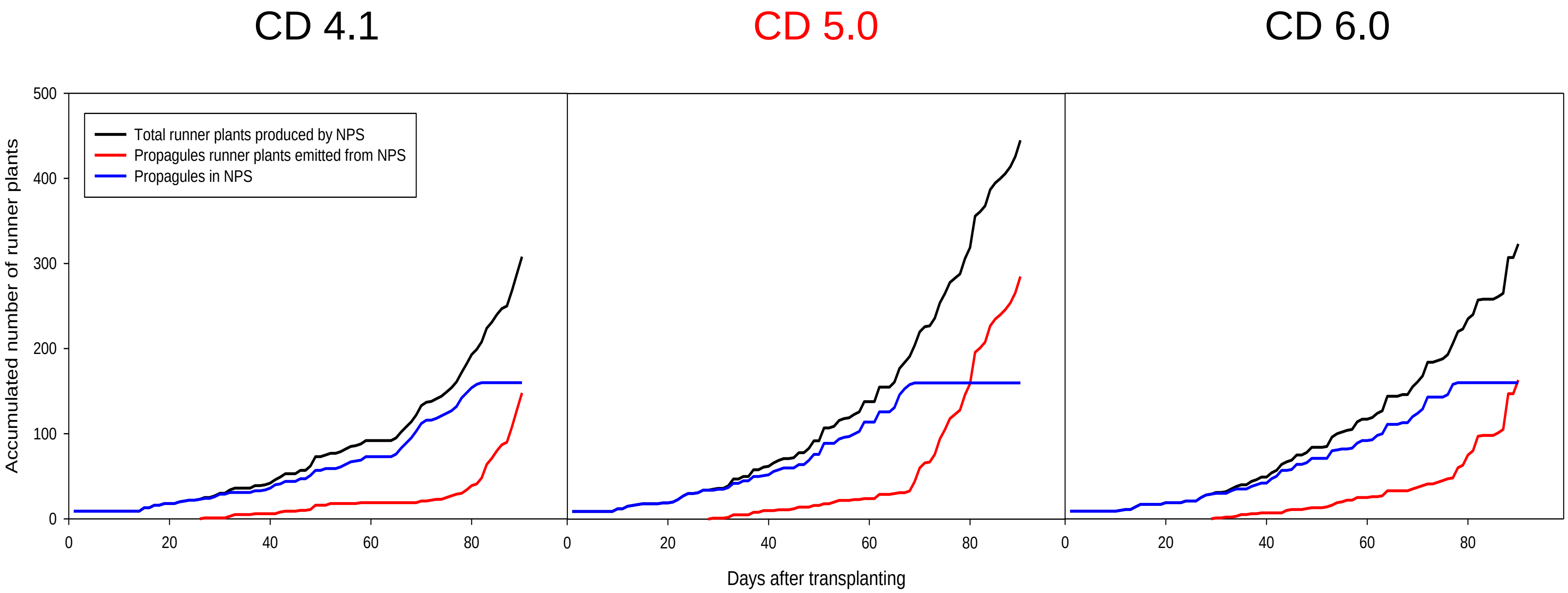
	No. of leaves (/plant)	No. of runners (/plant)	Crown diameter (mmt)	Leaf area (cm^2 /plant)	Fresh weight (g/plant)				Dry weight (g/plant)			
					Leaves	Runners	Crown + petioles	Root	Leaves	Runners	Crown + petioles	Root
145mL	6.4a[z]	3.0a	9.02a	319.3a	7.69a	9.44a	5.22b	4.02a	1.25b	1.30a	0.34a	0.62b
73mL	6.8a	2.8a	9.40a	348.2a	6.98a	7.84a	5.66ab	4.09a	1.39ab	1.20a	0.39a	0.69ab
34mL	6.6a	2.6a	9.16a	330.9a	6.97a	7.52a	5.94ab	4.19a	1.41ab	1.10a	0.34a	0.72ab
21mL	6.8a	2.4a	9.70a	379.6a	7.85a	4.32a	6.50a	4.46a	1.56a	0.71a	0.40a	0.80a

Size of propagules (crown diameter, 1)

	Crown diameter (mm)	Number of leaves (/plant)	Number of runners (/plant)
CD 4.1	4.1±0.1	1.7±0.5	1.0±0.0
CD 5.0	5.0±0.1	2.0±0.0	1.9±0.3
CD 6.0	6.0±0.1	3.0±0.0	2.3±0.3

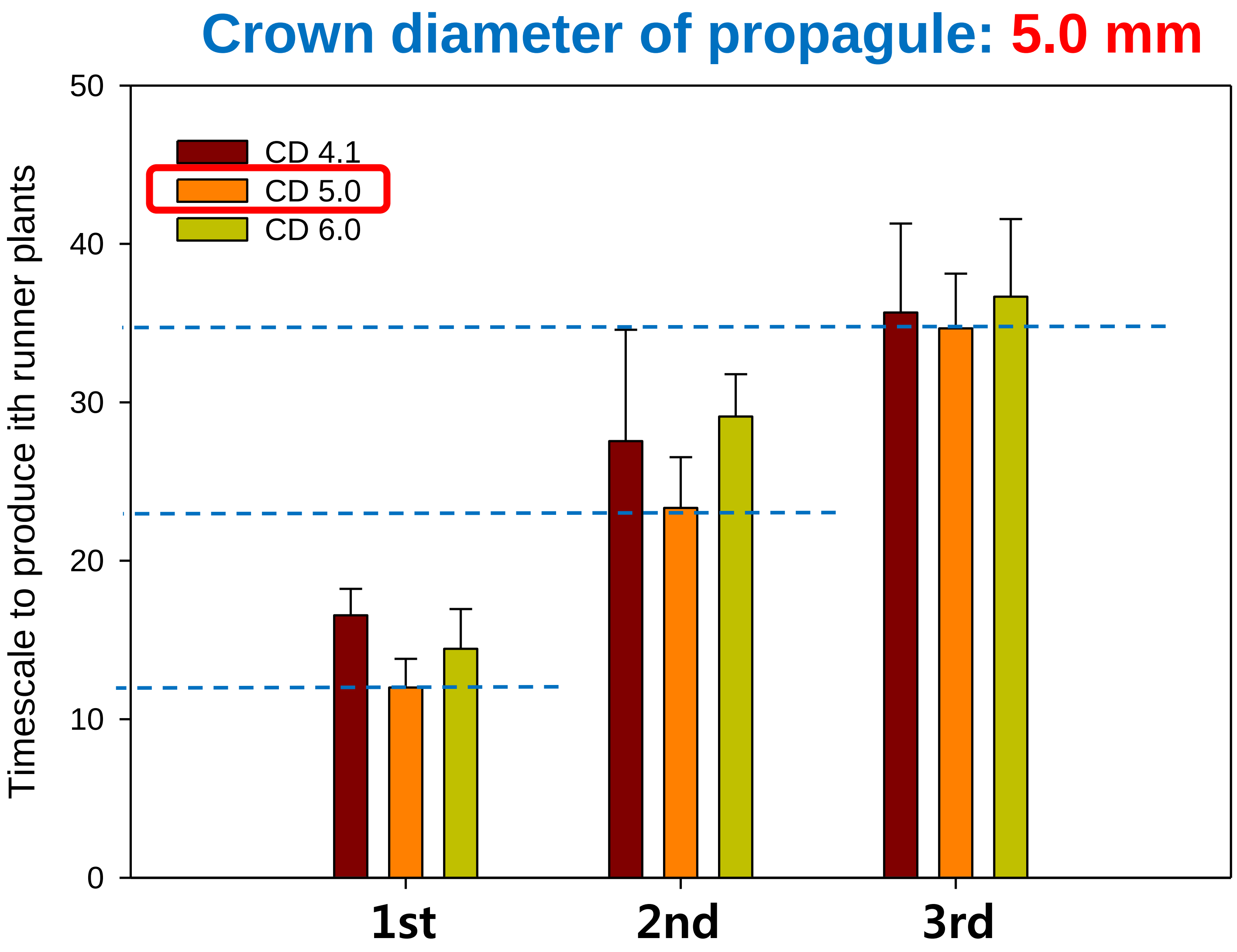
CD 4.1　　CD 5.0　　CD 6.0

Size of propagules (crown diameter, 2)



Time course of accumulated number of runner plants as affected by crown diameter of propagules for 90 days after transplanting propagules

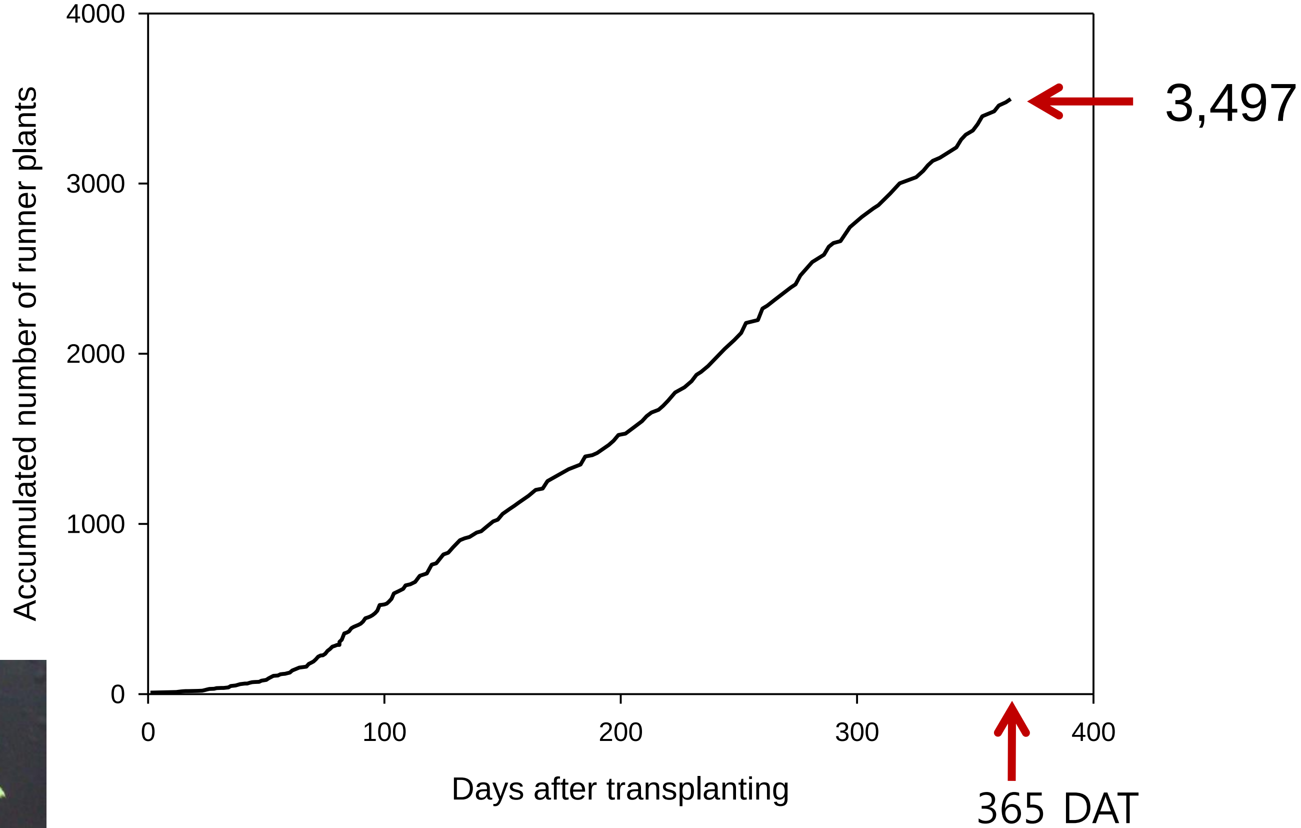
Size of propagules (crown diameter, 3)



Yearly production of runner plants

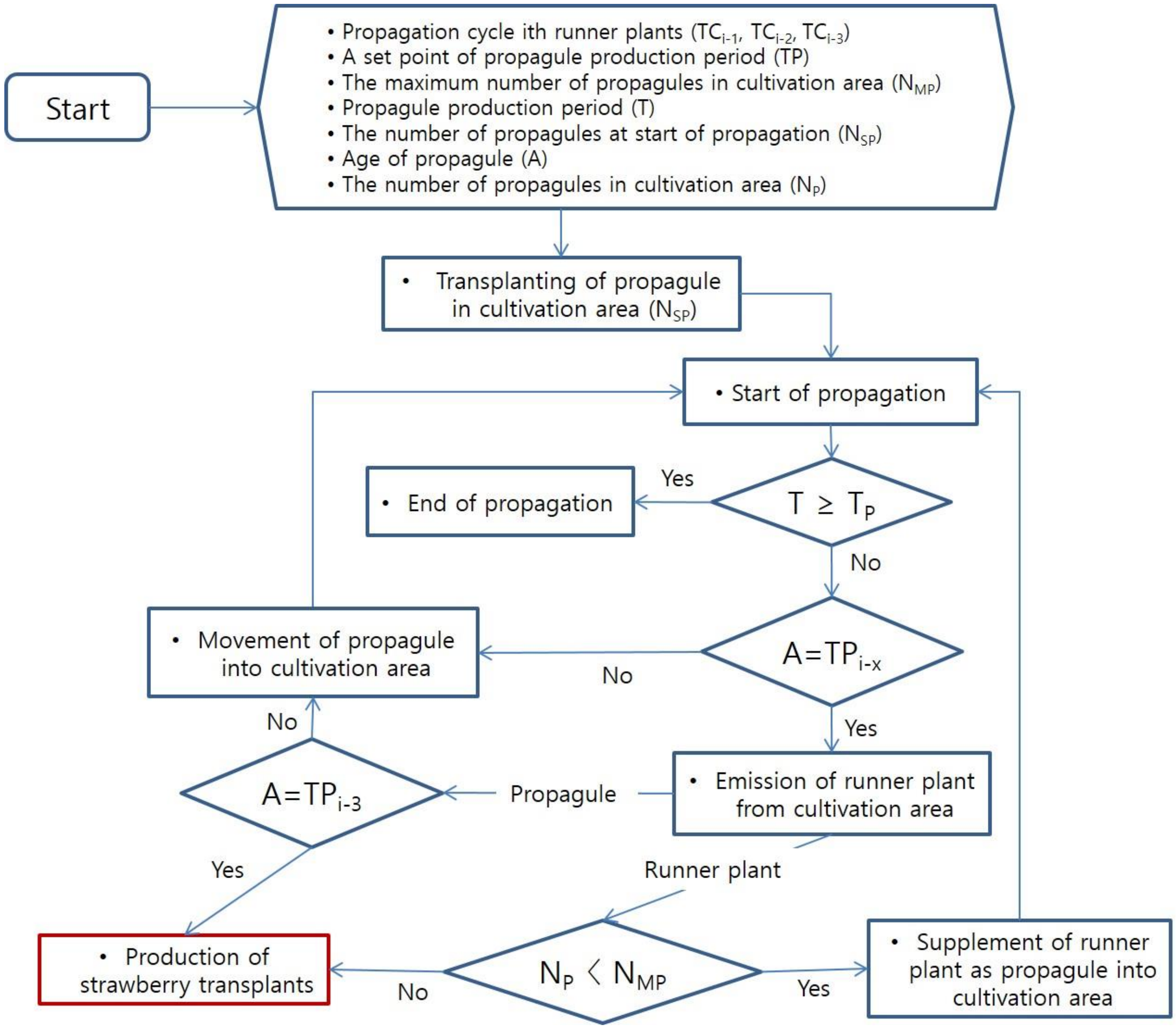
CD 5.0

cultivation area of 3.6 m^2

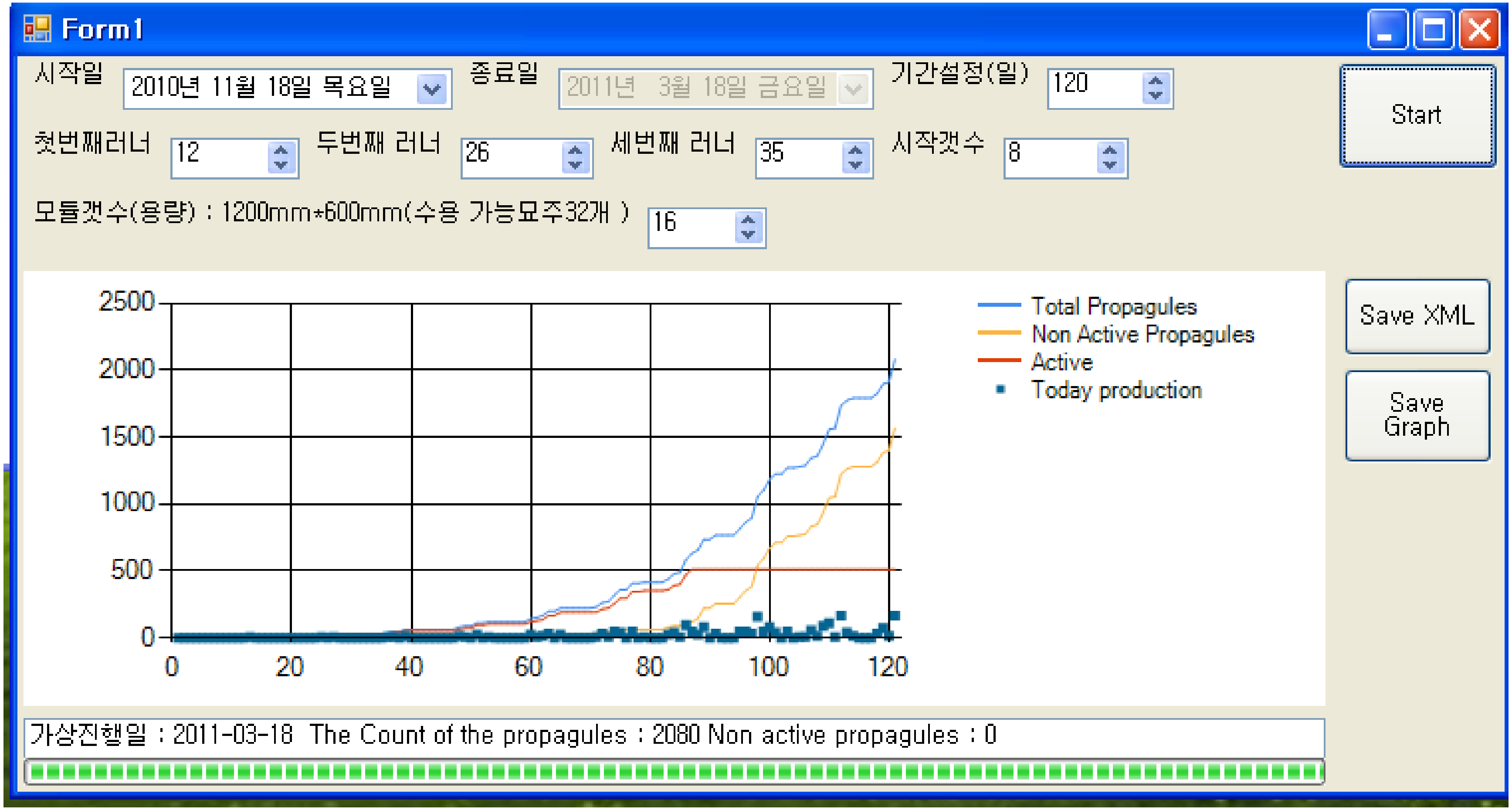


from 9 propagules

Software flowchart for simulating production

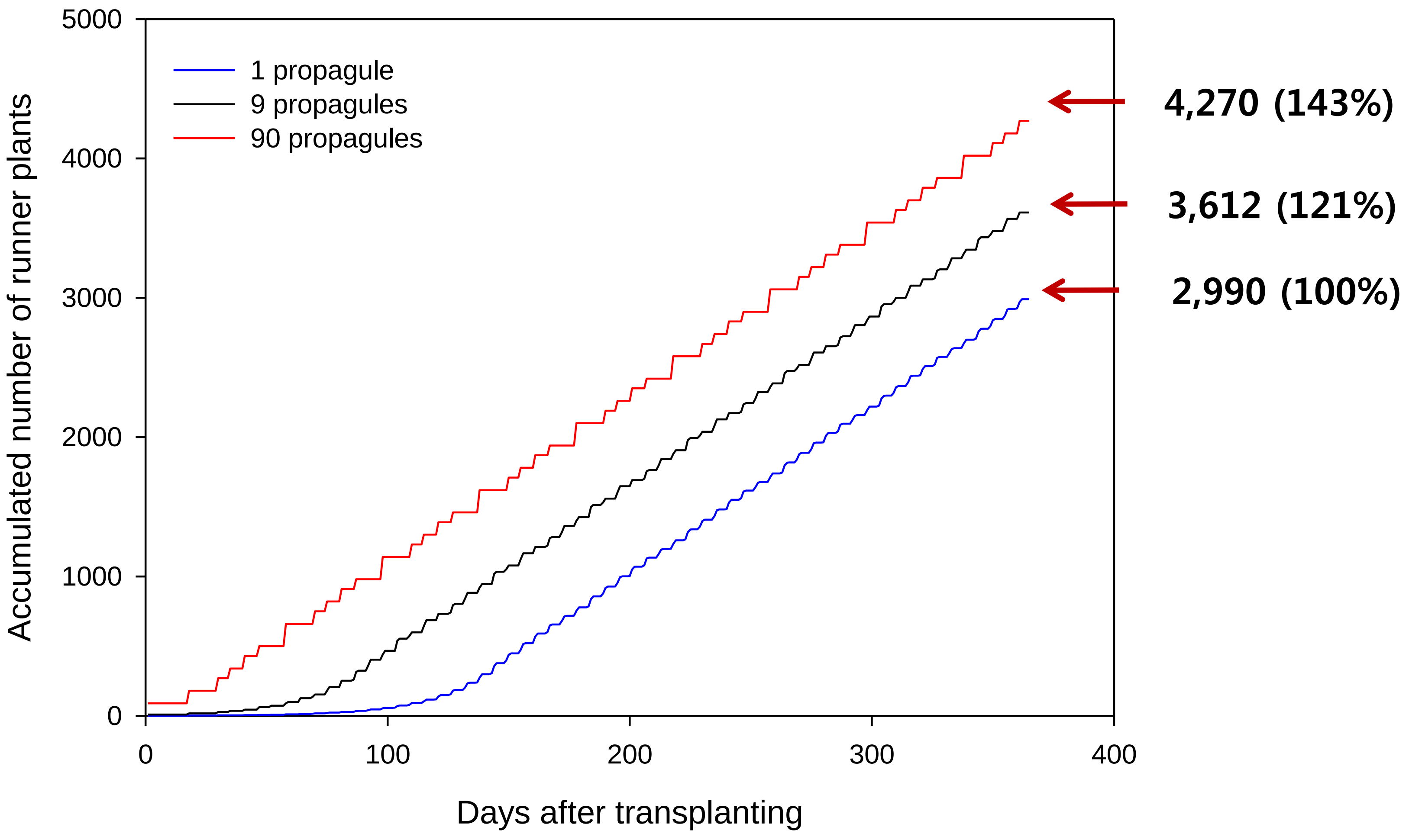


Simulation program



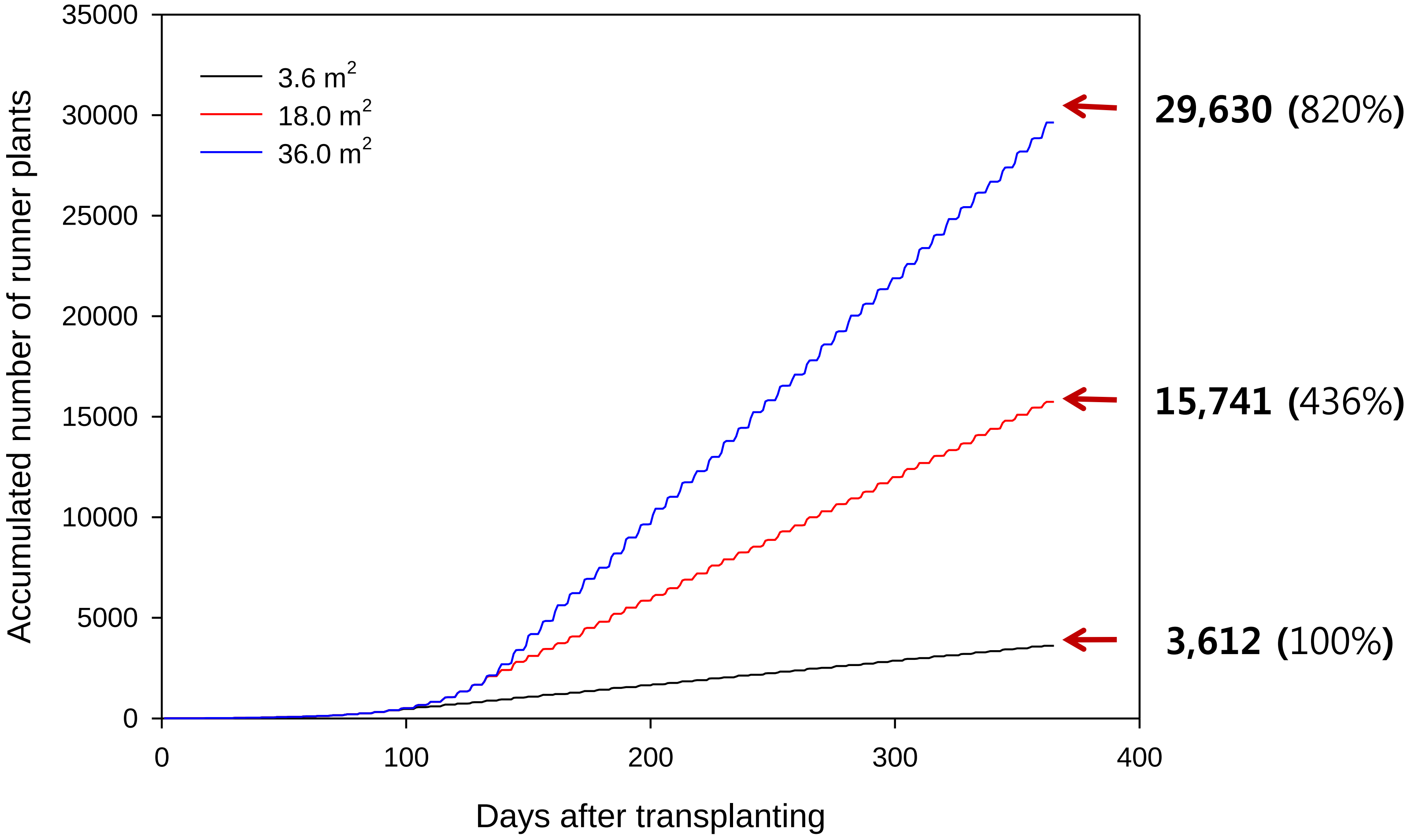
Simulation - initial number of propagules

cultivation area of 3.6 m^2



Simulation - cultivation area

from 9 propagules



Operation flow of ATPM in S-PFAL

ca. 40 days to produce THREE propagules
and ONE transplants from a propagules

Consignment or Storage

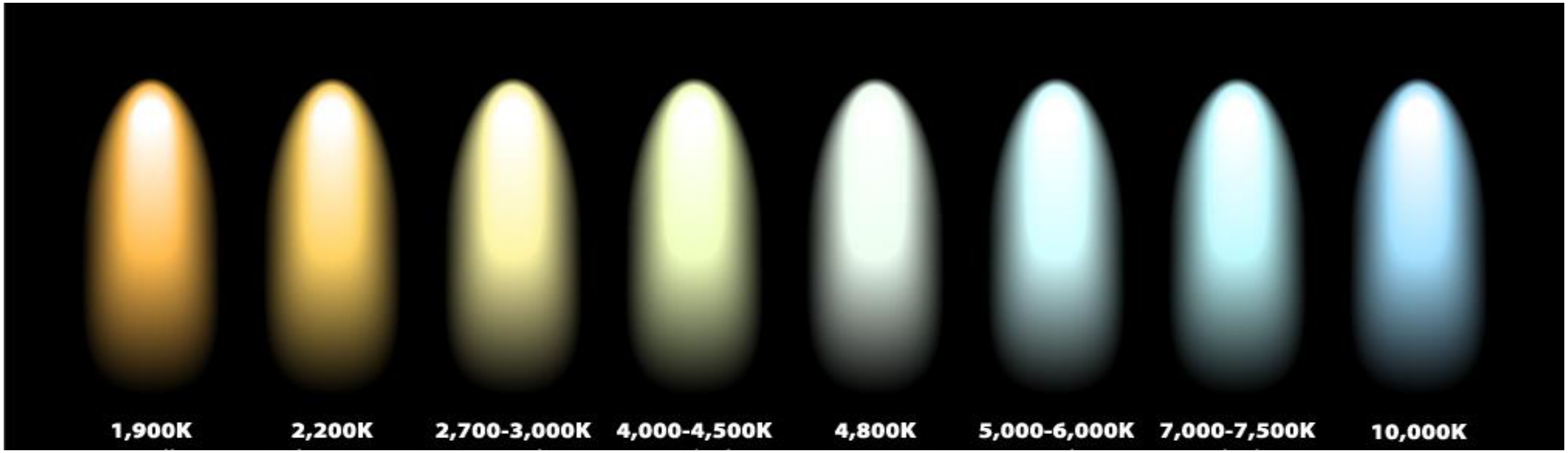
Electric consumption

Simulated number of runner plants produced from 10 propagules for one year, electric consumption, and electric charge to produce runner plants

PPF (μmol m^{-2} s^{-1})	Number of runner plants[z]	Electric consumption		Electricity cost (KRW) [w]
		In a CTPS (MWh) [y]	Per runner plant (kWh) [x]	
150	10,638	15.8	1.5	58.3
190	11,270	22.3	2.0	77.5
240	12,094	28.9	2.4	**93.7**
300	13,058	36.0	2.8	108.1

[z]Simulated number of runner plants produced from 10 propagules in the 9 m^2 CTPS (cultivation area: 11.52 m^2) for a year.
[y]Electric consumption for operating a CTPS for a year as affected by number of fluorescent lamps.
[x]Electric consumption to produce a runner plant. Electric consumption of lighting was presumed 75% of total electric consumption to operate a CTPS
[w]Electric charge of electric consumption to produce a runner plant, 39.2 won/kWh.

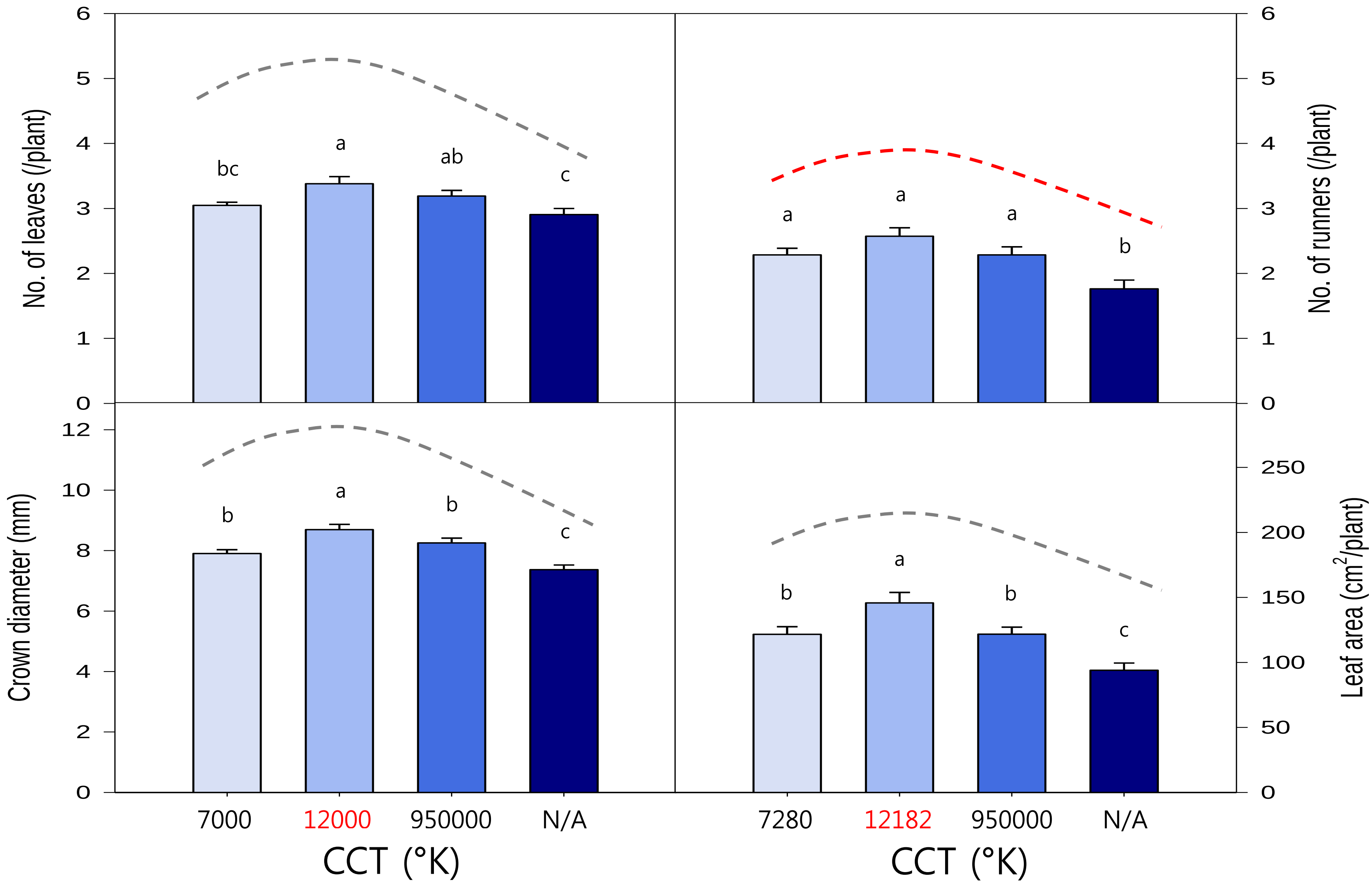
White LEDs as artificial light sources for a S-PFAL



- Phosphor types of white LEDs are produced by adding phosphors to the blue LED to convert a portion to green, yellow and red having different correlated color temperatures (CCT)

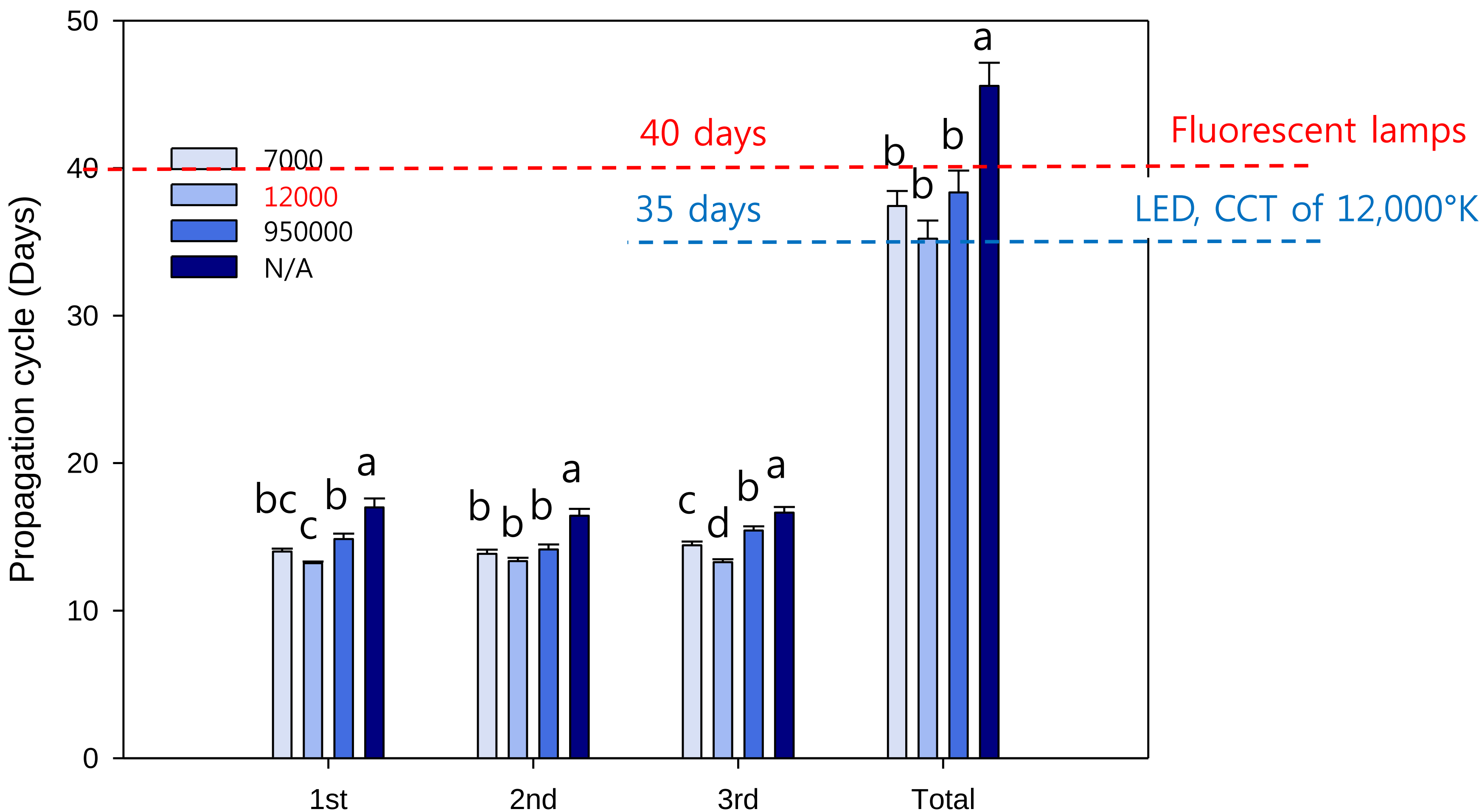
(Zhao et al., 2002)

Growth of runner plants grown under LEDs having different correlated color temperature (CCT)



Shortened propagation cycle by adapting LEDs

Greater system productivity with reduced electricity cost



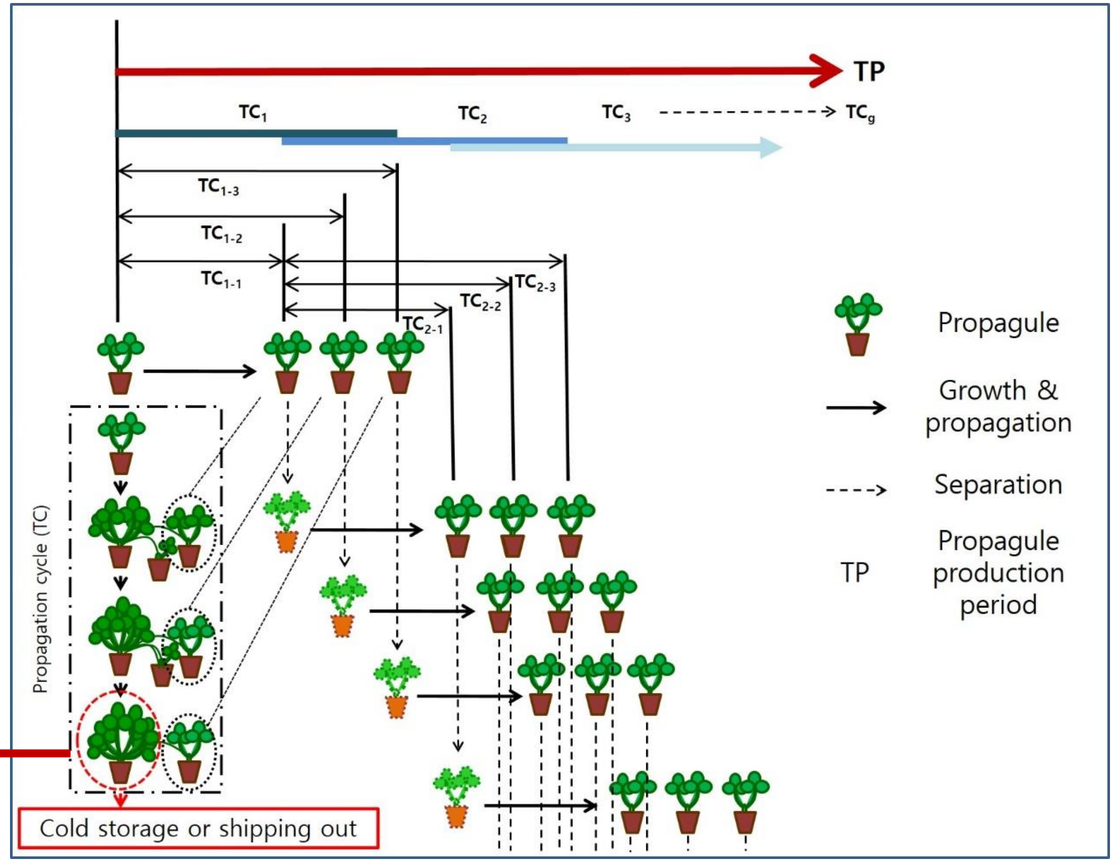
Storage of transplants produced in a S-PFAL

Transplanting

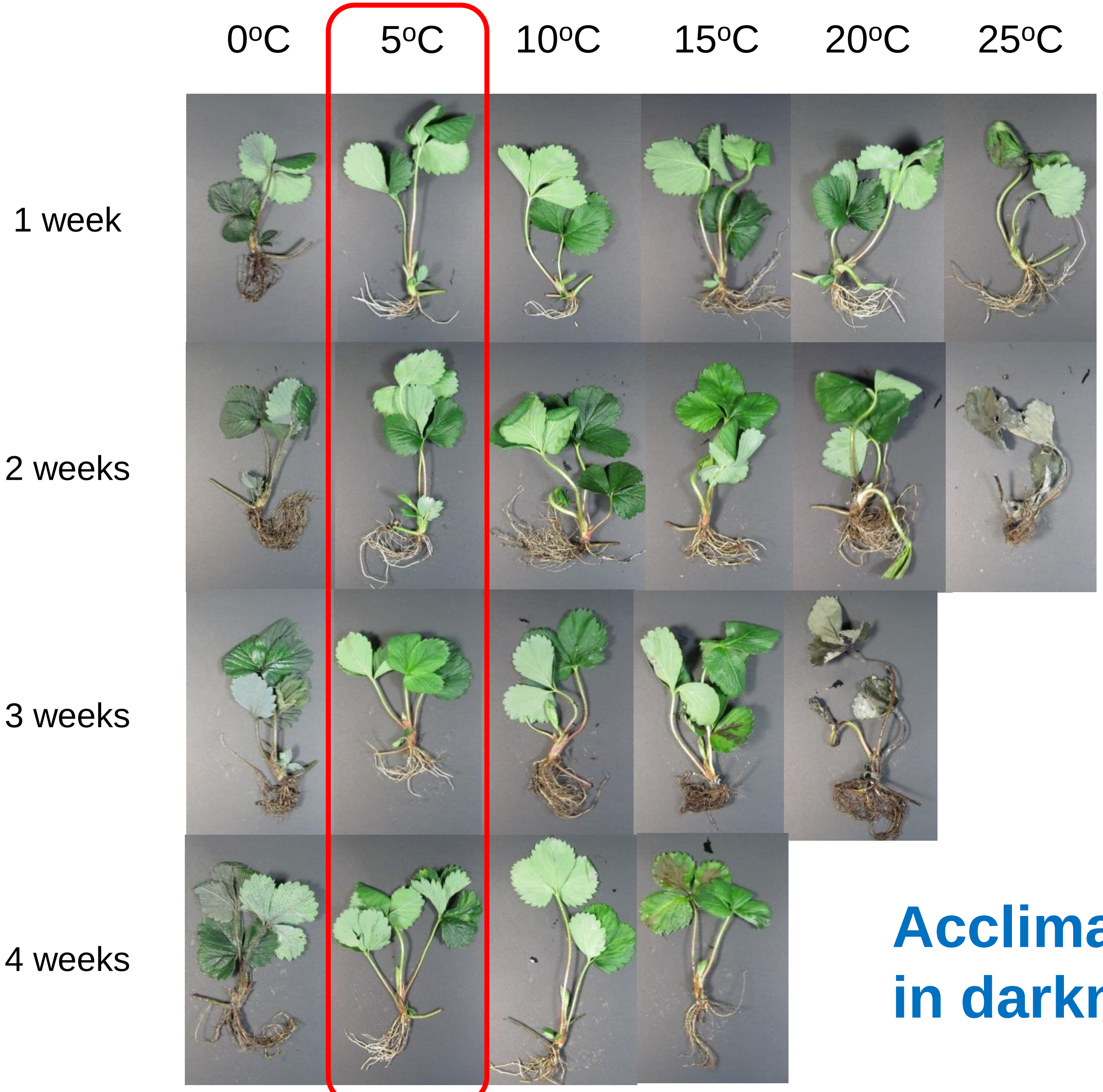
Light acclimation

Long-term Cold storage at -1.5°C

Temperature acclimation



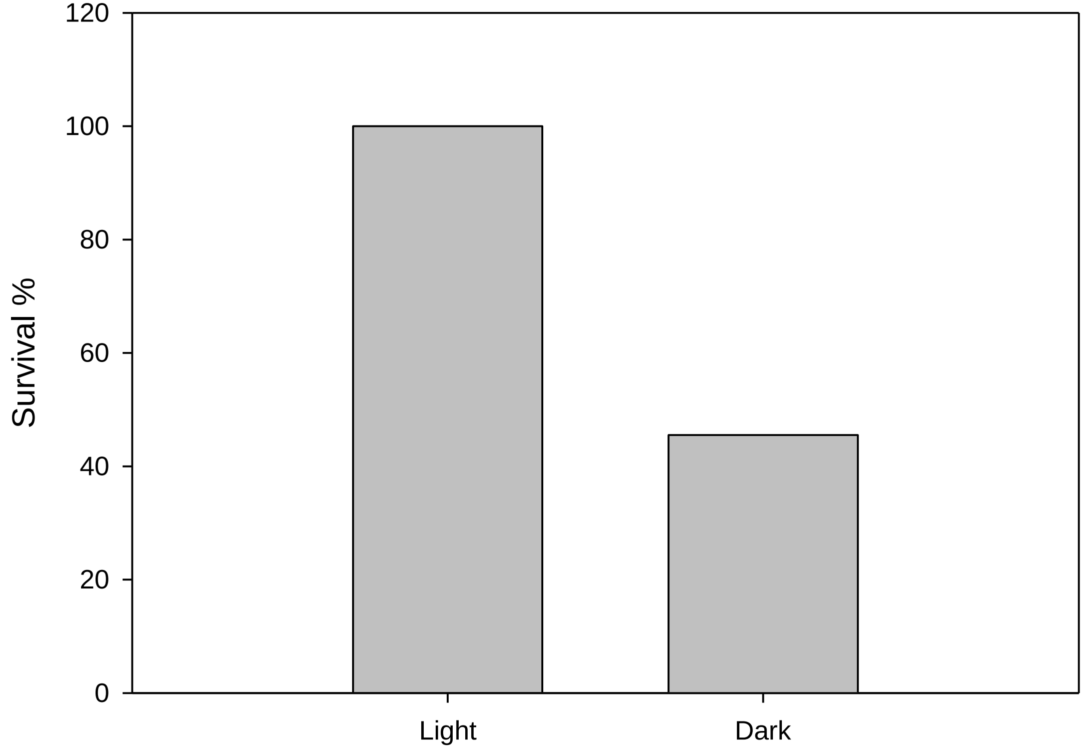
Acclimation at 5°C before long-term cold storage



Acclimation at 5ºC in darkness

Light acclimation after long-term cold storage

Light acclimation at 100 μmol·m^{-2}·s^{-1} for 2 days



Survival rate of runner plants 2 days after transplanting as affected by light condition (100 μmol·m^{-2}·s^{-1}) after transplanting.

Summaries

- Strawberry transplants could be rapidly produced using ATPM in a S-PFAL year round and proper storage conditions before being transplanted for fruit production or transplant production were determined.
- S-PFALs have been installed on a trial basis at research agencies where nuclear stocks of major domestic cultivars are maintained.
- The trials were satisfactory, and so scaling-up is currently being reviewed for producing elite and pre-basic transplants in ‘the Korean national program for strawberry propagation’.

Special Thanks to;

Prof. Sung Kyeom Kim
Ms. Miseon Jeong
Ms. Hyein Lee

Thank you berry much!

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