

Grafting for Vegetable Production in Florida



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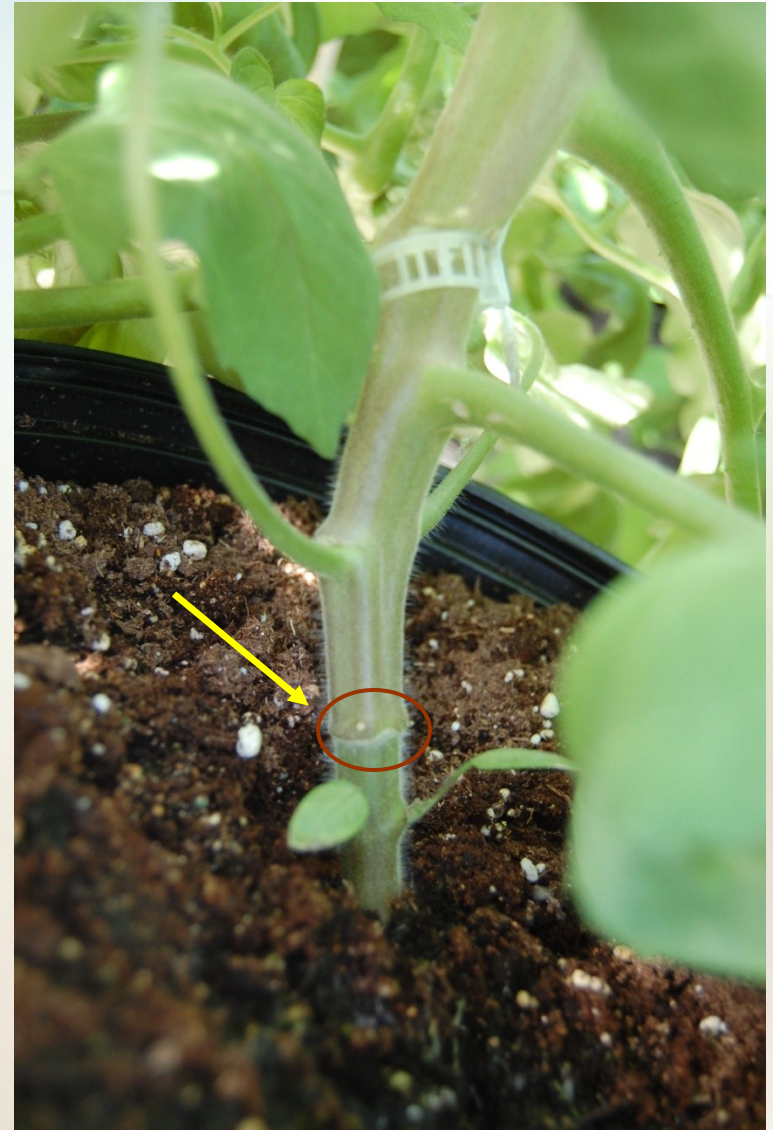
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What is Vegetable Grafting



Scion

Rootstock



History of Using “Graft Hybrid” in Vegetable Production

- **1920s**

Watermelon grafted onto *Cucurbita moschata* rootstock to fight *Fusarium* wilt

- **1950s-1960s**

Grafted eggplant transplants used for commercial production



(Lee, 1994; Lee and Oda, 2003)

USA

Crop	Item	Japan	Korea	China	Taiwan	
Watermelon	Area (ha) ^a	13,000	20,756	2,162, 456	13,431	50,810
	Graft (%) ^b	92	95	20	35	NA ^c
	Grafting method ^d	HIG,S	HIG, TAG	HIG, TAG, SG	HIG,TAG,SG	–
	Rootstocks ^e	Ls, Cl	Ls, Cmm	Ls, Cl	Cmm, Ls	–
Cucumber	Area (ha) ^a	12,800	5,630	1,702, 777	2,666	59,480
	Graft (%) ^b	75	75	30	11	NA ^c
	Grafting method ^d	TAG,SG	SG, TAG	HIG, TAG	TAG	–
	Rootstocks ^e	Cmm, Cf	Cmm, Cf	Cm, Sa, Cf	A	–
Melons	Area (ha) ^a	10,500	6,607	570,874	6,441	35,790
	Graft (%) ^b	30	90	5	0.1	NA ^c
	Grafting method ^d	TAG,SG	SG, TAG	HIG	–	–
	Rootstocks ^e	Cmm, Cm	Cmm	Cm, Cmm, Cl	–	–
Bitter melon	Area (ha) ^a	NA ^c	NA ^c	200,000	1,802	NA ^c
	Graft (%) ^b	–	–	2	30	–
	Grafting method ^d	–	–	HIG, TAG	TAG,CG	–
	Rootstocks ^e	–	–	Lc	La, Cm	–
Pickling melon	Area (ha) ^a	232	NA ^c	NA ^c	NA ^c	NA ^c
	Graft (%) ^b	–	–	–	–	–
	Grafting method ^d	TAG	–	–	–	–
	Rootstocks ^e	–	–	–	–	–
Tomato	Area (ha) ^a	12,700	6,144	1454, 533	4235	330 ^f
	Graft (%) ^b	40	25	1	25	70 ^f
	Grafting method ^d	SG, TAG	SG	SG	HIG, SG	SG
	Rootstocks ^e	Sl, St	Sl, Ss	Sl	Ss, Sl	Ss
Eggplant	Area (ha) ^a	10,800	325	1051, 537	1503	2200
	Graft (%) ^b	55	20	1	1.3	NA ^c
	Grafting method ^d	SG, TAG	SG	SG	–	–
	Rootstocks ^e	Ss	Ss	St	–	–
Pepper	Area (ha) ^a	3620	61,023	16,625	2405	32,140
	Graft (%) ^b	5	10	1	2.5	NA ^c
	Grafting method ^d	SG, TAG	SG	SG	–	–
	Rootstocks ^e	Ca	Ca,Cs	Cf	–	–
Data supplied by		M. Oda	J.M. Lee	Z. Bie and Y. Huang	S.J. Tsao	C. Kubota and M. Bausher



(Lee et al., 2010)

Crop	Item	Spain	Italy	France	Netherlands
Watermelon	Area (ha)	16,100	11,091	186	NA ^b
	No. grafts (million)	48.2	10.0	NA	NA
	Rootstocks ^c	RS-841 Shintoza Strongtosa	Macis RS-841 Shintoza	NA	NA
Melons	Area (ha)	38,600	28,199	14,747	3086
	No. grafts (million)	2.5	8.2	NA	NA
	Rootstocks ^c	RH-841 Shintoza Strongtosa	Shintoza Camelforce Dinero	RS-841 TZ-148 Dinero	NA
Cucumber	Area (ha)	7000	2065	631	NA
	No. grafts (million)	0.5	0.8	NA	NA
	Rootstocks ^c	Azman Hercules Titan	NA	NA	NA
Tomato	Area (ha)	55,300	115,477	4122	1800
	No. grafts (million)	72.8	15.1	50%	75%
	Rootstocks ^c	Maxifort Beaufort	Beaufort Maxifort He-Man	Maxifort Beaufort	NA
Eggplant	Area (ha)	3500	10,862	417	115
	No. grafts (million)	1.8	11.8	65%	75%
	Rootstocks ^c	Torvum Vigor Beaufort	Espina Salutum STT3	Beaufort Brigeor Maxifort	NA
Pepper	Area (ha)	24,100	11,721	NA	41
	No. grafts (million)	4.0	1.2	NA	NA
	Rootstocks ^c	Atlante	Tresor Rocal Atlante	Tresor Galaxy Snooker	NA

(Lee et al., 2010)

Methods of Grafting: Solanaceae

- **Splice grafting (tube grafting)**



Methods of Grafting: Cucurbits

One cotyledon

Hole insertion



- **Manual grafting**
100-500 grafts/hr
- **Grafting machine**
300-600 grafts/hr
- **Grafting robot**
600-1,200 grafts/hr
- **Price of grafted plants**
\$0.40-1.20 (U.S.)

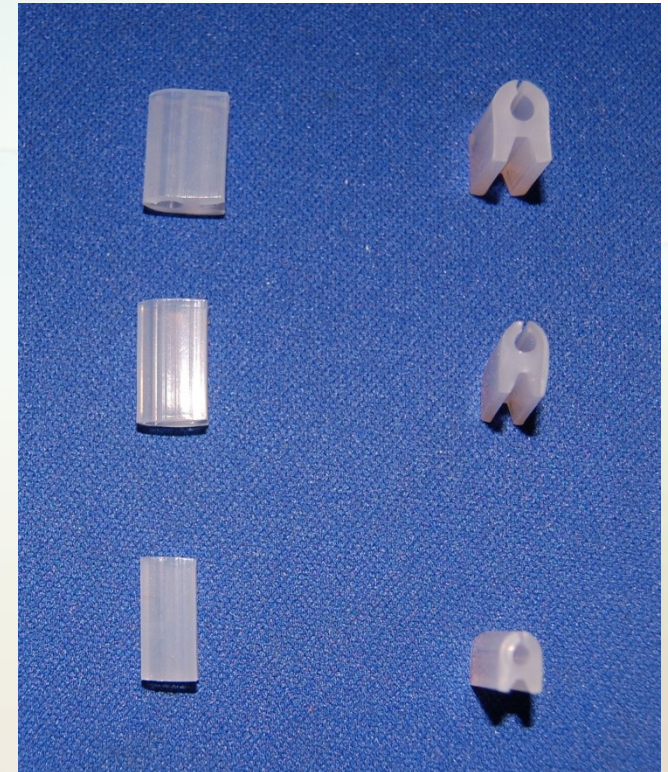


(Courtesy of Ted Carey)

Rootstock Suppliers

- **American Takii Seed:** tomato, eggplant, melon, cucumber
- **De Ruiter Seeds:** tomato
- **DP Seeds:** tomato, eggplant, pepper, watermelon, melon
- **Johnny's Selected Seeds:** tomato
- **Paramount Seeds:** tomato
- **Syngenta Seeds:** watermelon, melon

Grafting Clips



- **Johnny's Selected Seeds**
- **Hydro-Gardens**

Grafted Vegetable Plant Suppliers

Territorial Seed Company

<http://www.territorialseed.com/category/498/?r=LWGOOGA&gclid=CLqjiPfA864CFcee7QodAQmWHw>

Burpee

<http://www.burpee.com/grafted-tomato-plants/garden-ready-grafted-tomato-plants-article10590.html>

Ontario Plants Propagation Ltd.

http://www.ontarioplants.com/index.php?option=com_content&task=view&id=26&Itemid=58

Benefits of Vegetable Grafting

- **Resistance/tolerance to soil-borne diseases**

Fusarium wilt: cucumber, melon, watermelon, tomato

Fusarium crown and root rot: tomato, cucumber, watermelon

Monosporascus wilt: melon, watermelon

Verticillium wilt: tomato, eggplant, watermelon

Phytophthora blight: pepper

Bacterial wilt: tomato, eggplant

Root-knot nematodes: tomato, eggplant, pepper

(Barrett et al., 2012; Davies et al., 2008; Lee, 1994; Lee, 2003; Lee and Oda, 2003; Louws et al., 2010; Oda, 2007; Rivero et al., 2003)

Grafted eggplant production in solar greenhouse in China



What can we benefit from growing grafted vegetables?

- **Tolerance to environmental stresses**
e.g., low temperature, salinity, drought, flooding
- **Enhanced nutrient and water uptake**
- **Improved plant growth**
- **Yield increase**
- **Rootstock effect on fruit quality**

(Davies et al., 2008; Lee, 1994; Lee, 2003; Lee and Oda, 2003; Lykas et al., 2008; Oda, 2007; Rivero et al., 2003)

What can we benefit from growing grafted vegetables?

- **Complementary to breeding programs**
 - “graft hybrid”
 - rapid deployment of new genetic sources
 - take full advantage of germplasm



Scion

Desirable aboveground traits

Rootstock

Desirable belowground qualities

Dealing with Limitations and Challenges

- **Cost**

- seeds
- space
- supplies
- labor

Select scions and rootstocks

Plant the seeds

Schedule the best time to graft

Make the grafts

Monitor the healing process

Acclimate the healed grafts

Plant grafted transplants







Vegetable Grafting Program

Tomato and melon

Disease management

Yield

Organic production

Nutrient and water use efficiency

Fruit quality

Economic analysis

Use of resistant rootstocks for root-knot nematode control in tomato and melon production

- **Organic heirloom tomato production**
- **Specialty melon production**

Grafted organic heirloom tomato study

- **Controls: non-grafted, self-grafted**
- **Scions:**
 - ‘Flamme’ (orange, golf ball sized)
 - ‘Brandywine’ (red, beefsteak)
- **Rootstocks:**
 - ‘Multifort’ (interspecific tomato hybrid)
(*S. lycopersicum* x *S. habrochaites*)
 - ‘Survivor’ (tomato hybrid) (*S. lycopersicum*)

Non-grafted 'Brandywine'



'Brandywine'/ 'Survivor'



Meloidogyne javanica

Root-knot nematode study: Gallings ratings

Treatment	Organic field	Transitional field
-----Brandywine (BW)-----		
NGBW	7.18 a	9.30 a
BW/BW	5.86 a	7.30 b
BW/Multifort	1.72 b	3.88 c
BW/Survivor	0.28 b	0.54 d
-----Flamme (FL)-----		
NGFL	6.02 a	8.06 a
FL/FL	5.28 a	6.12 a
FL/Multifort	0.52 b	3.48 b
FL/Survivor	0.16 b	0.00 c

(0 = no galling, 10 = plant and roots are dead)

Grafting specialty melons for root-knot nematode management



Greenhouse inoculation study

- Non-grafted and self-grafted *Cucumis melo* var. *inodorus* 'Honey Yellow' (highly susceptible to RKN)
- 'Honey Yellow' grafted onto *Cucurbita maxima* × *C. moschata* 'Strong Tosa' (commercial rootstock)
- 'Honey Yellow' grafted onto *Cucumis metulifer* (African horned cucumber)
- Non-grafted and self-grafted rootstocks



- ***Meloidogyne incognita* race 1**
- **5,000 eggs/pot**

Root galling

**Non-grafted
'Honey Yellow'**



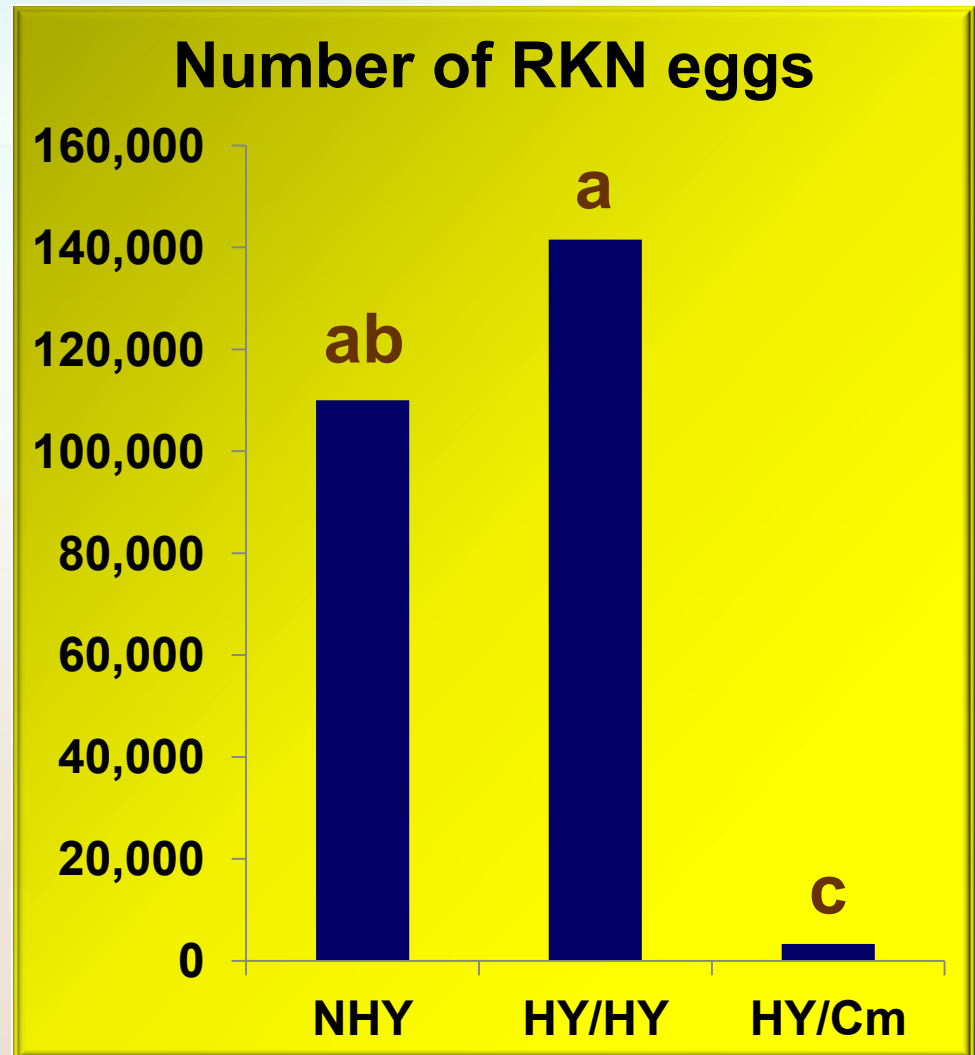
**'Honey Yellow'/
'Strong Tosa'**



**'Honey Yellow'/
*C. Metulifer***



Grafting with *C. Metulifer* reduced root-knot nematode reproduction



Organic field study

Non-grafted 'Honey Yellow'
Self-grafted 'Honey Yellow'
'Honey Yellow'/*C. Metulifer*



Non-grafted 'Arava'
Self-grafted 'Arava'
'Arava'/*C. Metulifer*



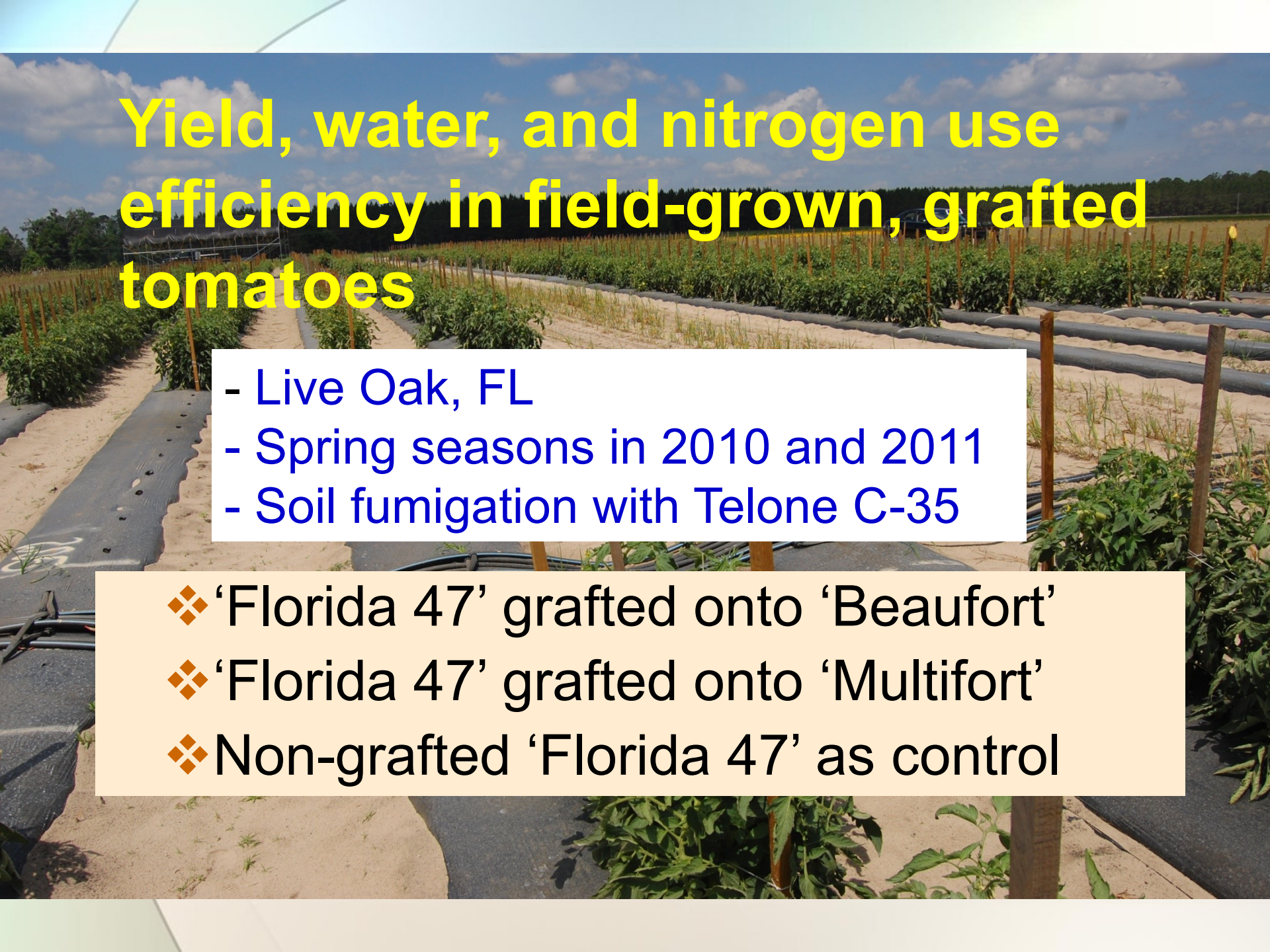
Treatment	Gall index	Number of J2 /100 cm ³ soil
Honey Yellow (HY)		
Non-grafted HY	7.14 a	378.2 a
Self-grafted HY	6.70 a	515.6 a
HY/ <i>C. Metulifer</i>	0.08 b	1.2 b
P-value	< 0.0001	0.015
Arava (Ar)		
Non-grafted Ar	5.20 a	200.2 a
Self-grafted Ar	4.45 a	140.2 a
Ar/ <i>C. Metulifer</i>	0.15 b	4.8 b

?

Improvement of root-knot nematode resistance = Fruit yield enhancement

Grafting with root-knot nematode resistant rootstocks as a crop rotation tool

Yield, water, and nitrogen use efficiency in field-grown, grafted tomatoes



- Live Oak, FL
- Spring seasons in 2010 and 2011
- Soil fumigation with Telone C-35

- ❖ 'Florida 47' grafted onto 'Beaufort'
- ❖ 'Florida 47' grafted onto 'Multifort'
- ❖ Non-grafted 'Florida 47' as control

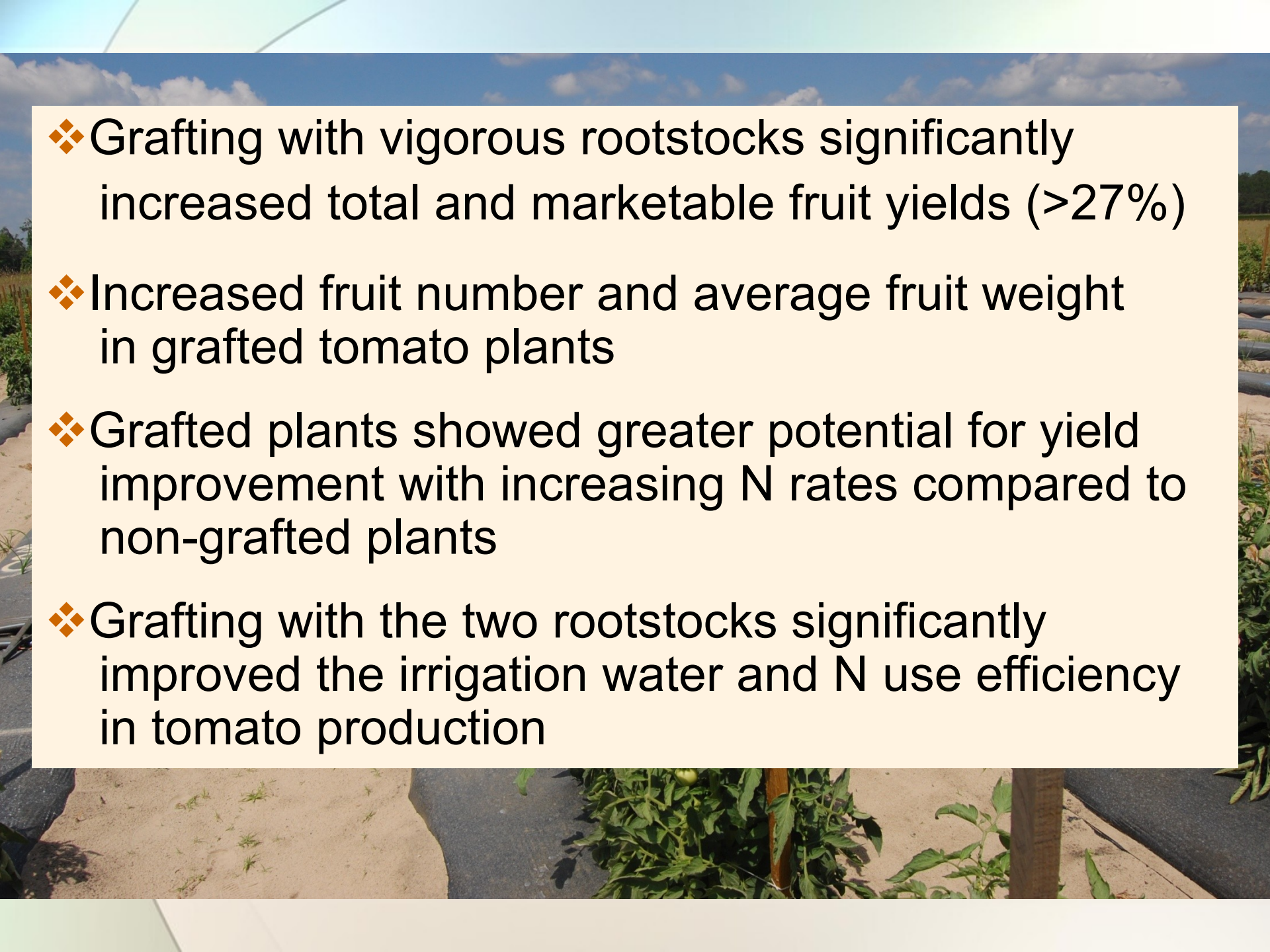
N rate (%)	Injected weekly N rate (kg/ha)					Total N rate (kg/ha)
	Week after transplanting					
	1-2	3-4	5-11	12	13	
25	-	-	-	-	-	56
50	3.0	4.0	5.0	4.0	3.0	112
75	6.1	8.0	10.0	8.0	6.1	168
100	9.1	12.0	15.0	12.0	9.1	224
125	12.1	16.0	19.9	16.0	12.1	280
150	15.1	20.0	24.9	20.0	15.1	336



Two Irrigation Regimes

- ❖ 9354 L/ha/day/string
(100%)
- ❖ 4677 L/ha/day/string
(50%)

- ❖ Grafting with vigorous rootstocks significantly increased total and marketable fruit yields (>27%)
- ❖ Increased fruit number and average fruit weight in grafted tomato plants
- ❖ Grafted plants showed greater potential for yield improvement with increasing N rates compared to non-grafted plants
- ❖ Grafting with the two rootstocks significantly improved the irrigation water and N use efficiency in tomato production

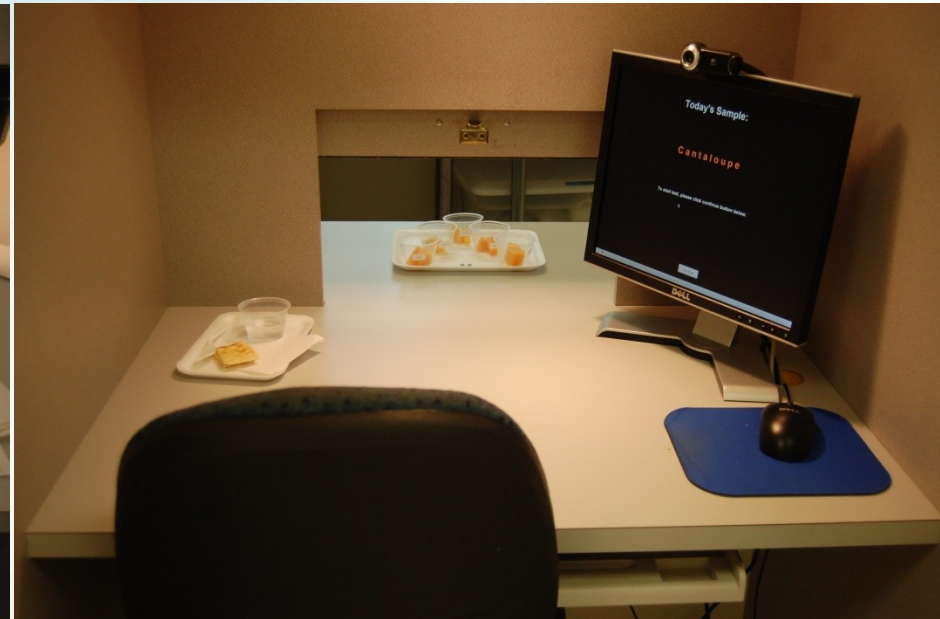


Fruit composition of organic heirloom tomato as affected by grafting

Treatment	Vitamin C (mg/100 g fresh wt)	SSC (%)	pH	TTA (% citric acid)
Non-grafted BW	32.33	4.93	4.45	0.32
Self-grafted BW	31.47	4.93	4.47	0.33
BW/MU	30.79	4.97	4.44	0.31
BW/SU	30.06	4.80	4.47	0.29
P-value	0.33	0.45	0.74	0.13

BW: 'Brandywine', MU: 'Multifort', SU: 'Survivor'

Sensory attributes of grafted tomato fruit



- Fruit assessed at full ripeness
- Overall appearance and acceptability, firmness, flavor, and sweetness
- Consumer sensory analysis, 1-9 hedonic scale (1 = dislike extremely, 9 = like extremely)

2010 Grafted tomato study ('Brandywine')

Treatment	BW	BW/BW	BW/MU	BW/SU
Overall appearance	6.4 a	6.3 ab	6.1 ab	5.8 b
Overall acceptability	6.8 a	6.2 b	6.2 b	6.1 b
Firmness	6.5	6.5	6.2	6.1
Tomato flavor	6.6 a	6.2 ab	6.0 b	6.0 b
Sweetness	6.2	5.9	5.8	5.8

75 consumer panelists

BW: 'Brandywine', MU: 'Multifort', SU: 'Survivor'

2011 Grafted tomato study ('Brandywine')

Treatment	BW	BW/BW	BW/MU	BW/SU
Overall appearance	6.3	6.1	6.4	6.5
Overall acceptability	6.2	6.4	6.0	6.3
Firmness	6.3	6.4	6.1	6.2
Tomtao flavor	6.1	6.3	5.9	6.4
Sweetness	5.6	6.1	5.7	6.1

69 consumer panelists

BW: 'Brandywine', MU: 'Multifort', SU: 'Survivor'

Grafted tomato production: Economic analysis

Organic 'Brandywine' tomato production:

- ✓ Non-grafted
- ✓ Grafted with 'Multifort' rootstock

Grafted transplant	Non-grafted transplant
\$0.78/plant	\$0.17/plant

- The cost of rootstock seeds accounted for 36% (\$0.28/plant) of the total cost of the grafted transplants and 46% of the cost difference between grafted and non-grafted plants

Non-grafted (high nematode pressure)

Yield (lb/ plant)	Estimated partial net return (\$/plant)							
	Tomato price (\$/lb)							
	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.20
0.15	0.10	0.13	0.16	0.19	0.22	0.25	0.28	0.31
0.35	0.46	0.53	0.60	0.67	0.74	0.81	0.88	0.95
0.55	0.82	0.93	1.04	1.15	1.26	1.37	1.48	1.59
0.75	1.18	1.33	1.48	1.63	1.78	1.93	2.08	2.23
0.95	1.54	1.73	1.92	2.11	2.30	2.49	2.68	2.87

Grafted high nematode pressure

Yield (lb/ plant)	Estimated partial net return (\$/plant)							
	Tomato price(\$/lb)							
	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.20
0.84	0.73	0.90	1.07	1.24	1.40	1.57	1.74	1.91
1.04	1.09	1.30	1.51	1.72	1.92	2.13	2.34	2.55
1.24	1.45	1.70	1.95	2.20	2.44	2.69	2.94	3.19
1.44	1.81	2.10	2.39	2.68	2.96	3.25	3.54	3.83
1.64	2.17	2.50	2.83	3.16	3.48	3.81	4.14	4.47
1.84	2.53	2.90	3.27	3.64	4.00	4.37	4.74	5.11
2.04	2.89	3.30	3.71	4.12	4.52	4.93	5.34	5.75

'Florida 47' tomato production in fumigated field:

- ✓ Non-grafted
- ✓ Grafted with 'Multifort' rootstock

Grafted transplant	Non-grafted transplant
\$0.67/plant	\$0.15/plant

Total transplant costs per acre (5,808 plants/A)

Grafted	Non-grafted
\$3,891.36	\$871.20

'Florida 47' tomato production in fumigated field:

- ✓ Partial budget analysis
- ✓ \$11.95 per 25-lb carton (tomato price)

Negative effects of grafting

	Transplants (\$/A)	Harvest (\$/A)	Added costs (\$/A)
Non-grafted	871.20	5,173.14	0
Grafted	3,891.36	7,249.17	5,096.19

Positive effects of grafting

	Gross returns (\$/A)
Non-grafted	18,235.93
Grafted	25,554.18

'Florida 47' tomato production in fumigated field:

- ✓ Partial budget analysis
- ✓ \$11.95 per 25-lb carton (tomato price)

	Added costs (\$/A)	Added returns (\$/A)
Non-grafted	0	0
Grafted	5,096.19	7,318.25

Additional net returns associated with grafting:

$$\text{\$7,318.25} - \text{\$5,096.19} = \text{\$2,222.06}$$

Integrated use of grafting in vegetable production

- Rootstock development and selection for disease control and yield improvement
- Rootstock-scion interactions
- Needs of different production systems
- Cost benefit analysis
- Fertilization and irrigation programs of grafted vegetable production
- Site-specific conditions

Acknowledgements

