FINAL PROJECT REPORT **YEAR**: 3 of 3

Project Title: Improving fruit set, production efficiency, and profitability of pears

PI: Todd Einhorn
Organization: OSU-MCAREC
Telephone: 541-386-2030 ext. 216
Email: todd.einhorn@oregonstate.edu

Co-PI: Stefano Musacchi
Organization: WSU-TFREC
Telephone: 509-663-8181
Email: stefano.musacchi@wsu.edu

Cooperators: Growers: Mike Sandlin (WA), Don Kiyokawa (OR), Gorham Blaine (OR), Yan Wang

Total Project Request: Year 1: $75,151 **Year 2:** $72,278 **Year 3:** $74,012

Other funding sources: Match funding of $20,384 from DCA-UNIBO, Italy

Budget 1: Todd Einhorn
Organization Name: OSU-MCAREC **Contract Administrator:** L.J. Koong
Telephone: 541 737-4866 **Email address:** l.j.koong@oregonstate.edu

Item	2012	2013	2014
Salaries[1]	29,250	37,072	38,183
Benefits	20,183	20,788	21,411
Wages	7,040	7,040	7,040
Benefits	774	774	774
Equipment[2]	2,500	0	0
Supplies[3]	8,000	1,000	1,000
Travel[4]	4,300	2,500	2,500
Miscellaneous[5]	3,104	3,104	3,104
Total	75,151	72,278	74,012

Footnotes: **[1] Salaries are calculated as 0.75 FTE of Full Time Technician's salary and OPE, for management of all experimental designs and field plots, operation of root pruner, PGR applications, plant measurements, and data management; 4 months of a 0.49 FTE Graduate Student Research Assistantship at the monthly rate of $1,736. The increase in salaries for years two and three reflects a 3 % rate increase. Wages are for 2 part-time employees to work a combined total of 640 hours ($11/hr) to aid in plant measurements, harvest, and training of field plots. [2]Equipment costs cover supplies and fabrication of root pruner. [3]Includes purchase of trees for new 'Bartlett' planting (funding for trellis supplies and irrigation is not being requested), PGR's, tags, flagging, and tree training supplies for field trials. [4]I am requesting the transfer of travel funds initially requested for Stefano Musacchi and his technician ($6,100 for 2013 and 2014) to support an MS student at OSU given Stefano Musacchi's new position and relocation to Wenatchee, WA. He will no longer have a technician in Bologna, Italy to travel to the States to participate in the project in 2013-2014. The remaining travel budget will be allocated to travel to and from regional PNW research sites, and to support travel of Musacchi to Hood River from Wenatchee, including per-diem, and lodging. [5]Miscellaneous costs are MCAREC per acre plot fees (3,104/acre), for a one-acre Bartlett planting.**

Objectives

1. Develop plant growth regulator protocols for early and consistent fruit set. Test and adapt current protocols successfully utilized in Europe on PNW varieties. Characterize PGR effects on flowering, fruit set, and vegetative growth.

2. Apply current root pruning technologies available in the US to existing, and future, plantings. Test application timing, depth, and severity of root removal, and characterize the effect of these treatments on shoot growth, flower development, fruit set, fruit size and productivity.

3. Develop new plantings of competitive orchard systems. Develop demonstration orchards at MCAREC of single axe and bi-axe planar hedgerows. Work collaboratively with growers to establish planar commercial high-density blocks.

Significant Findings

Objective 1:

- Eight trials were conducted to evaluate ReTain on pear fruit set and production; 60% of the trials resulted in significantly greater fruit set or yield, 40% did not. When effective, increased production ranged from a three-fold increase to only modest, numerical gains. For 'd'Anjou', ReTain was only effective when applications were made ~10 to 14 days after bloom at a rate of 1 pouch per acre. Applications near full bloom only improved fruit set for Comice in one of 3 trials, a cultivar purported to have a short ovule longevity period.
- Ethylene production rate of untreated 'd'Anjou' and Comice flowers steadily increased from bloom, peaking around 14 days after bloom, and declining to ~0 by 30 d after bloom. ReTain markedly reduced, but did not completely inhibit, ethylene production of flowers and fruitlets. Differences in the absolute rate of production were observed between 2013 and 2014. Applications of ReTain need to be applied just prior to this peak.
- Ethephon applications (300 ppm) ~45 d after full bloom significantly improved return bloom, fruit set and yield of 'd'Anjou' trees the year after application.

Objective 2:

- Root pruning was applied to orchards between 2012 (6^{th} leaf d'Anjou') and 2014 (4^{th} and 5^{th} leaf 'd'Anjou'). In all trials, root pruning reduced vegetative growth (between 20% and 40%). Reduction in shoot length and trunk growth was positively related to tree age and the severity of pruning (two sides elicited a stronger response than one).
- Root pruning was too severe on 6^{th} leaf trees, resulting in reduced yield and fruit size the year of application. Root pruning was not re-applied, but carry-over effects on vegetative growth and fruit size lasted through 2014. In contrast, shoot length of trees pruned in their 4^{th} leaf recovered fully the year subsequent to application, but trunks remained significantly smaller.
- In all trials, double-sided root pruning consistently improved return bloom, fruit set, yield, and yield efficiency the year after application. In 2014, trees root-pruned in their 4th leaf (2013) had ~70% greater yield than controls (i.e., 41 bins per acre vs. 24 bins per acre) with no negative effect on fruit size or quality.
- Root pruning in consecutive years was also evaluated (4^{th} and 5^{th} leaf). 5^{th} leaf trees pruned two years in a row had an equivalent reduction of shoot growth in both years (20%) in addition to producing similar yields as trees root pruned once in the 4^{th} leaf (i.e., ~70% greater yield than untreated trees).

Objective 3:

- A training systems trial (single-axe vs. bi-axe) with d'Anjou' and 'Bartlett' on OH x F 87 was established in 2012. In-row tree spacing varied: 'Bartlett' was established at 2, 4, or 6 ft. and 'd'Anjou' at 4 or 8 ft. Trees required restarting in their 2^{nd} leaf due to poor health. Bartlett tree size at the end of 2014 was slightly smaller at the closest spacing.
- In 2013, a rootstock trial was planted to evaluate the performance of 'd'Anjou' on OH x F 87, OH x F 69 or Pyro 2-33 at three different training systems (V, bi-axe, single-axe) and three

different in-row spacings (3, 4.5 and 6 ft.). After the 2nd leaf, trees on Pyro 2-33 were significantly smaller than OH x F 87 or OH x F 69. Individual axes of bi-axe trained trees were 40% smaller than single axe trees, irrespective of rootstock. Tree size was slightly smaller for trees planted at 3 ft., albeit nonsignificanlty.

Results and Discussion

Objective 1 (PGRs):

ReTain: Eight experiments were performed to evaluate the effect of the ethylene inhibitor AVG (a.i. of ReTain, Valent Biosciences Corp.) on pear (Anjou and Comice) fruit set and production. Each trial was designed as a randomized complete block; replicates varied. Whole trees were treated in all trials. Trees were sprayed to runoff with a pressurized handgun. In all experiments a surfactant (Sylgard 309) was added to ReTain at 0.1% (v:v). For Experiments 1-8 below please refer to Table 1 for supporting summary data.

Exp 1. 2012, 10th leaf Anjou/OH × F 97, MCAREC, OR (4 single-tree replicates)
Treatments: 1. Control; 2. ReTain 40 ppm applied at 80% of full bloom; 3. ReTain 80 ppm applied at 80% of full bloom; 4. ReTain 40 ppm applied two weeks after full bloom; 5. ReTain 80 ppm applied two weeks after full bloom.
Results: Fruit set and yield improved proportionately with rate. **Yield tripled** for highest ReTain rate (80 ppm) at 2 weeks after bloom; fruit size reduced (by cropload); 80% bloom applications reduced yield; seed counts of ReTain treatments similar to controls.

Exp 2. 2012, 17-year-old Comice/OH × F 97, MCAREC, OR (4 single-tree replicates)
Treatments: 1. Control; 2. ReTain 40 ppm applied at 80% of full bloom; 3. ReTain 80 ppm applied at 80% of full bloom; 4. ReTain 40 ppm applied two weeks after full bloom; 5. ReTain 80 ppm applied two weeks after full bloom.
Results: Fruit set and yield improved proportionately with rate. **Yield doubled** for highest ReTain rate (80 ppm) at 2 weeks after bloom; fruit size reduced (by cropload); 80% bloom applications increased yield; seed counts of ReTain treatments similar to controls.

Exp 3. 2013, 18-year-old Comice/OH × F 97, Hood River, OR (4 single-tree replicates)
Treatments: 1. Control; 2. ReTain 30 ppm applied at 50% of full bloom; 3. ReTain 60 ppm applied at 50% of full bloom; 4. ReTain 120 ppm applied at 50% of full bloom; 5. ReTain 30 ppm applied two weeks after full bloom; 6. ReTain 60 ppm applied two weeks after full bloom; 7. ReTain 120 ppm applied two weeks after full bloom.
Results: **ReTain 120 ppm applied at 2 weeks after full bloom led to 40% higher** fruit set and fruit number at harvest compared to controls. All other treatments had either similar or less (all 50% bloom timings) yield than controls; fruit size was reduced for ReTain 120 ppm applied 2 weeks after bloom.

Exp 4. 2013, 5th leaf Anjou/OH × F 97, Mt. Adams, WA (6 single-tree replicates)
Treatments: 1. Control; 2. ReTain 30 ppm applied at 80% of full bloom; 3. ReTain 60 ppm applied at 80% of full bloom; 4. ReTain 120 ppm applied at 80% of full bloom; 5. ReTain 30 ppm applied one week after full bloom; 6. ReTain 60 ppm applied one week after full bloom; 7. ReTain 120 ppm applied one week after full bloom; 8. ReTain 30 ppm applied two weeks after full bloom; 9. ReTain 60 ppm applied two weeks after full bloom; 10. ReTain 120 ppm applied two weeks after full bloom.
Results: **ReTain treatments did not significantly increase yield** relative to controls; a numerical increase in fruit number and yield was observed at the 2 weeks after full bloom timing for 60 and 120 ppm ReTain applications.

Exp 5. 2013, three separate plots were treated in Odell, OR with the same treatment regime: ~30-year-old Anjou /unknown rootstock; 4th leaf Anjou/OH × F 87; and, 7th leaf Anjou /OH × F 87.

Treatments: 1. Control; 2. 1 pouch ReTain/acre (applied 10 d after full bloom); 3. 0.5 pouch ReTain/acre (applied 10 d after full bloom).
Results: ReTain **significantly increased fruit set** for 2 of 3 trials in a rate responsive manner. The other trial had numerically increased fruit set. Trees were not harvested from these trials.

Exp 6. 2013, 4th leaf Anjou/OH × F 87, Dee Flat, OR
Treatments: 1. Control; 2. 1 pouch ReTain (applied 10 d after full bloom); 3. 1 pouch ReTain (applied 10 d after full bloom) + root pruning 1 side of tree row; 4. 1 pouch ReTain (applied 10 d after full bloom) + root pruning 2 sides of tree row.
Results: **Yield (fruits per tree ~doubled** for all ReTain trts; fruit size was reduced.

Exp 7. 2014, 12-year-old 'd'Anjou'/OH × F 97, Hood River, OR (4 single-tree replicates)
Treatments: 1. Control; 2. ReTain 30 ppm applied at two weeks after full bloom; 3. ReTain 60 ppm applied two weeks after full bloom; 4. ReTain 120 ppm applied two weeks after full bloom.
Results: **ReTain treatments did not significantly increase yield** relative to controls; yield was numerically higher for 120 ppm rate.

Exp 8. 2014, 19-year-old Comice/OH × F 97, Hood River, OR (4 single-tree replicates)
Treatments: 1. Control; 2. ReTain 30 ppm applied at two weeks after full bloom; 3. ReTain 60 ppm applied two weeks after full bloom; 4. ReTain 120 ppm applied two weeks after full bloom.
Results: **ReTain treatments did not significantly increase yield** relative to controls.

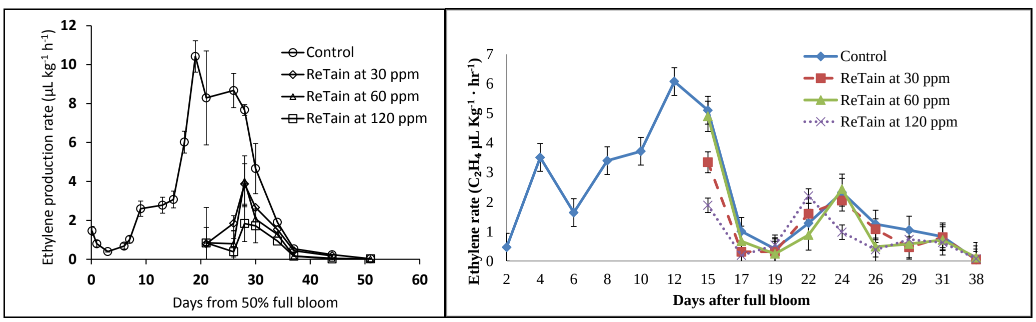

Figure 1. Ethylene production rate of flowers and fruitlets from 2013 (left) and 2014 (right).

The mode of action of ReTain on fruit set is via disruption of ethylene synthesis in fruit tissues. Ethylene is a natural plant hormone responsible, in part, for senescence processes. Hence, the objective of using ReTain to improve fruit set is to limit ethylene production in fruitlets that might otherwise induce abscission. Despite the label recommendation of bloom-time applications, ReTain **was not** effective when evaluated during the bloom period, with the exception of one experiment; however, applications at ~2 weeks after bloom had significantly greater efficacy in that trial. In fact, in all trials where a positive effect on fruit set was observed, the timing was ~14 days after bloom at a rate of 1 pouch per acre (~133 ppm).

Ethylene production rate of untreated 'd'Anjou' and Comice flowers steadily increased from bloom, peaking around 14 days after bloom and then declining to ~0 by 30 d after bloom. ReTain markedly reduced, but did not completely inhibit, ethylene production of flowers and fruitlets (greater effect in 2013). Differences in the absolute rate of production were observed in 2013 and 2014 (Fig 1). In 2014, we were anticipating higher levels of ethylene production, and as a consequence, missed the ideal application timing; prior to the peak (Fig 1). In fact, there may be a threshold level of ethylene necessary for fruitlet abscission (>5 μl/kg/hr). In this case, 2014 treatments would not have been expected to improved fruit set. The fairly rapid metabolism of ReTain, in combination with low threshold ethylene rates, provide further support for the lack of effect from bloom-time applications.

Exp 1. 2012- 'd'Anjou'	Yield per tree		Projected Yield	Fruit size	Seeds
	(lb)	(fruit no.)	(0.55 ton bins per ha)	(no. per 20 kg box)	(no. per fruit)
Untreated Control	88 b	172 c	59	90 a	4.9 a
40 ppm ReTain® (80% FB)	57 c	118 cd	40	90 a	3.5 ab
80 ppm ReTain® (80% FB)	52 c	111 cd	35	90 a	3.2 b
40 ppm ReTain® (2 WAFB)	160 a	409 b	109	110 b	4.0 ab
80 ppm ReTain® (2 WAFB)	198 a	558 a	136	120 c	4.0 ab

Exp 2. 2012- 'Comice'	Yield per tree		Projected Yield	Fruit size	Seed count
	(lb)	(fruit no.)	(0.55 ton bins per ha)	(no. per 20 kg box)	(no. per fruit)
Untreated Control	77 c	138 c	52	80 a	5.4 a
40 ppm ReTain® (80% FB)	95 b	189 bc	64	90 bc	4.5 ab
80 ppm ReTain® (80% FB)	106 b	235 ab	72	100 c	3.9 b
40 ppm ReTain® (2 WAFB)	100 b	215 b	69	100 c	5.6 a
80 ppm ReTain® (2 WAFB)	127 a	269 a	86	100 c	5.8 a

Exp 3. 2013- 'Comice'	Yield per tree		Projected Yield	Fruit size	
	(lb)	(fruit no.)	(0.55 ton bins per ha)	(no. per 20 kg box)	g
Untreated Control	181 b	405 b	50	100	206 a
30 ppm ReTain® (50% FB)	150 c	348 c	41	100	197 a
60 ppm ReTain® (50% FB)	148 c	362 c	41	110	185 ab
120 ppm ReTain® (50% FB)	149c	365 c	41	110	184 ab
30 ppm ReTain® (2 WAFB)	161 bc	391 bc	44	100	191 ab
60 ppm ReTain® (2 WAFB)	195 ab	445 b	54	100	199 a
120 ppm ReTain® (2 WAFB)	219 a	569 a	60	110	176 b

Exp 4. 2013- 'd'Anjou'	Yield per tree		Projected Yield	Fruit size	
	(lb)	(fruit no.)	(0.55 ton bins per ha)	(no. per 20 kg box)	g
Untreated Control	150 a	95 a	45	70	289
30 ppm ReTain® (50% FB)	134 ab	75 b	36	80	264
60 ppm ReTain® (50% FB)	122 b	74 b	35	70	276
120 ppm ReTain® (50% FB)	168 a	98 ab	46	70	268
30 ppm ReTain® (1 WAFB)	119 b	79 b	37	70	299
60 ppm ReTain® (1 WAFB)	133 ab	76 b	36	80	262
120 ppm ReTain® (1 WAFB)	151 a	91 a	43	70	272
30 ppm ReTain® (2 WAFB)	111 b	69 b	33	70	281
60 ppm ReTain® (2 WAFB)	161 a	97 a	46	80	264
120 ppm ReTain® (2 WAFB)	175 a	101 a	48	70	268

Exp 5. 2013- 'd'Anjou' Trials	Fruit set (%)		
	7th leaf	30-year-old	4th leaf
Untreated Control	11 b	22	5 b
60 ppm ReTain® (10 dafb)	18 ab	21	10 ab
120 ppm ReTain® (10 dafb)	22 a	31	14 a

Exp 6. 2013- 'd'Anjou' RP	Yield per tree		Projected Yield	Fruit size	
	(lb)	(fruit no.)	(0.55 ton bins per ha)	(no. per 20 kg box)	g
Untreated Control	16 b	11 b	13	80	265 a
1-side Root Pruning NO ReTain	13 b	12 b	11	90	228 b
2-side Root Pruning NO ReTain	18 b	11 b	15	90	234 b
ReTain 120 ppm 10 dafb	27 a	24 a	23	100	202 bc
1-side Root Pruning + ReTain	25 a	22 a	21	100	222 b
2-side Root Pruning + ReTain	22 ab	26 a	18	100	198 bc

Exp 7. 2014- 'd'Anjou'	Yield per tree		Projected Yield	Fruit size	
	(lb)	(fruit no.)	(0.55 ton bins per ha)	(no. per 20 kg box)	g
Untreated Control	213	420 ab	59	100	201
30 ppm ReTain® (2 WAFB)	194	378 b	53	100	191
60 ppm ReTain® (2 WAFB)	227	454 ab	63	90	228
120 ppm ReTain® (2 WAFB)	214	471 a	59	90	212

Exp 8. 2014- 'Comice'	Yield per tree		Projected Yield	Fruit size	
	(lb)	(fruit no.)	(0.55 ton bins per ha)	(no. per 20 kg box)	g
Untreated Control	112	275	31	100	209
30 ppm ReTain® (2 WAFB)	95	217	26	90	217
60 ppm ReTain® (2 WAFB)	118	277	32	100	203
120 ppm ReTain® (2 WAFB)	96	252	26	100	199

The fact that fruits from ReTain treatments showed no difference in seed number relative to control fruit (Table 1) suggests that a lack of fertilization was not the critical factor limiting fruit set potential.

Ethephon and NAA: Three trials were established to evaluate ethephon or NAA applications on flowering and production of 'd'Anjou' in the season subsequent to application. In 2012, 300 ppm ethephon was applied at either 20 dafb or 50 dafb; the latter timing was meant to coincide with the flower imitation period of 'd'Anjou'. Ethephon significantly increased yield with the greatest response occurring at the later application timing (Fig 2). In 2014, the experiment was repeated using 150, 300 or 450 ppm Ethephon. Return bloom, fruit set and yield need to be evaluated in 2015. In addition, NAA was also trialed to improve return bloom and productivity. Applications were made at 45 dafb using low concentrations (5 ppm) and repeated weekly for 3 weeks (5 ppm at each timing). Return bloom, fruit set and yield need to be evaluated in 2015.

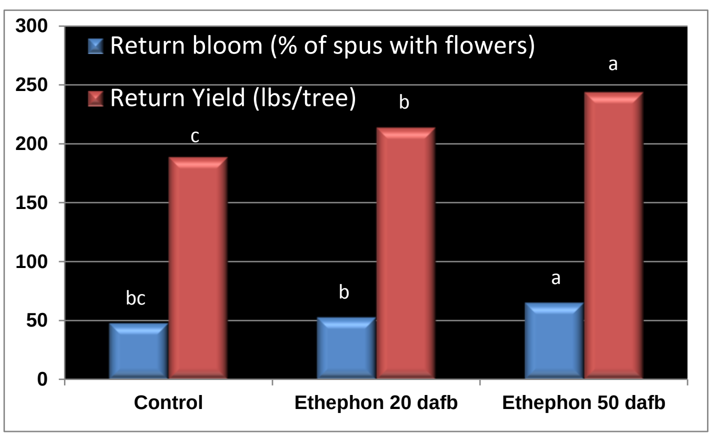

Figure 2. Effect of ethephon applications on 'd'Anjou' return bloom and yield the year after application. Ethephon was applied at 300 ppm to runoff. Data are means of 6 replicate trees.

Objective 2 (Root Pruning):
Root pruning was performed in commercial orchards prior to bloom when ~10% of the flowers were open. The implement (fabricated by Mr. Herbie Annala, Hood River producer) was tractor mounted and pulled in low gear ~1.5 ft. from tree trunks down either one or two sides of the tree row. Root pruning treatments were compared to untreated control trees in randomized complete block designs, replicated four times throughout the orchard. Whole rows were treated in experiment 1; in experiment 2, replicates comprised 8 contiguous trees. The depth of the steel shank was 1.5 ft. and the angle was

5 degrees off from the vertical (angle facing into the tree row). All other cultural practices were performed according to commercial standards.

Experiment 1: 2012 6th leaf 'd'Anjou' Trial- Double-sided root pruning reduced shoot growth of 6th leaf 'd'Anjou' trees by 40% in year one (Fig 3). Single-sided root pruning also significantly reduced shoot growth, compared to controls. Trunk size (TCA) was slightly reduced in 2012; however, yield, fruit size and vegetative growth were all significantly reduced compared to untreated control trees (in a rate responsive manner; Table 2). Typically, root pruning does not negatively affect production the year of application. We can speculate that too much root volume was removed; hence, we did not impose root pruning in this orchard in subsequent years. In 2013 (year 2), return bloom and fruit set were significantly increased by double sided root pruning (Table 2).

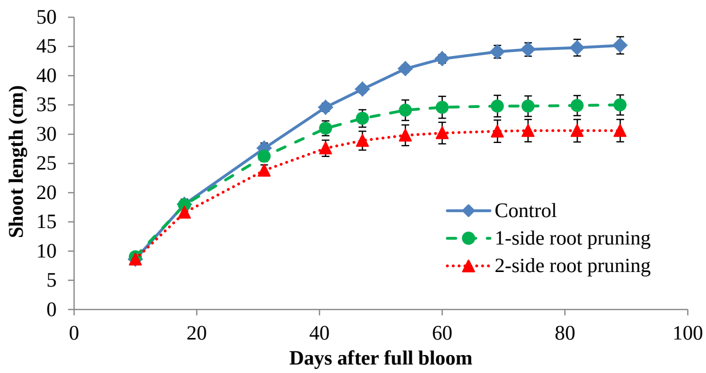

Figure 3. Shoot growth of 6th leaf 'd'Anjou' trees root pruned in 2012 to two levels (1 side of tree row or both sides of tree row).

Table 2. Effects of root pruning (one or both sides of the tree row) on 6th, 7th, and 8th leaf Anjou production and vegetative growth compared to an untreated control. Due to the severe root pruning effects on growth and production in 2012, trees were not root pruned in subsequent years.

Expt./Treatment	PAR Light Interception (%)	TCA (cm^2)	Avg. Annual Shoot Length (cm)	Fruit Set (%)	Avg. Fruit Size (g)	Avg. Total Yield (lbs/tree)	Avg. Fruit Count (Fruit #/tree)	Avg. Bloom/ Limb (Cluster #)	Yield Efficiency (%)
2012									
Untreated control	-	96.4 a*	47.2 a	10 a	230 c	75 c	148 a	80	0.353
One-sided root prune	-	94.1 ab	36.3 b	10 a	205 b	55 b	122 b	71	0.266
Two-sided root prune	-	89.8 b	30.7 c	7 b	191 a	46 a	106 c	70	0.234
Pr(>F)		0.017**	<.001	<.001	<.001	<.001	<.001	0.3938	0.1606
2013									
Untreated control	41.1 a	124.4 a	50.4 a	8 a	265	62	104.5	62.3 a	0.225
One-sided root prune	39.6 b	118.7 a	45.7 b	10 ab	255	62	110.5	79.9 b	0.236
Two-sided root prune	37.2 b	110.5 b	41.1 c	14 b	245	73	132.6	77.8 b	0.299
Pr(>F)	<.05	<.001	<.001	0.0294	0.1654	0.0853	0.1216	<.05	0.244
2014									
Untreated control	42.2 a	140.6 a	49.9	24 b	251 b	64	114	49.9 b	0.206
One-sided root prune	41.9 a	132.6 b	48.3	21 ab	231 a	62	120	59.7 ab	0.211
Two-sided root prune	39.6 b	123.2 c	47.7	16 a	226 a	66	132	61.9 a	0.244
Pr(>F)	<.001	<.001	0.2342	0.0483	<.001	0.0678	0.0518	<.05	0.688

*letters signify significant difference with LSD test, all values are means of 4 replicates, n=25

**analysis of variance pr(>f).05

Positive effects of root pruning on year 2 bloom and fruit set have been previously documented. Generally, the effect is associated with altered partitioning of carbohydrates, since shoot growth is typically reduced. Subsequently, light interception is often improved, which, in turn, strengthens fruit bud development. The higher bloom and fruit set in 2013 led to increased yield, though not significant at 0.05 (Table 2). Combined yield over the two years, however, did not compensate for the reductions in year-one production. Strong carryover effects were also observed on vegetative growth (trunks and shoots were significantly reduced by root pruning). In the third year, reproductive parameters responded similarly to 2013; double-sided root pruned trees had higher bloom and fruit set (% and number of fruit at harvest) compared to other treatments (Table 2). Interestingly, fruit size remained significantly smaller than control fruit, precluding a yield advantage. Tree size remained smaller, but annual shoot growth recovered. Ultimately, root pruning limited carbon pools (both storage and annual) necessary to support the increased fruiting response.

Experiment 2: 2013 4th leaf 'd'Anjou' Trial- The second experiment comprised a trellised block of 4th leaf Anjou/OH×F 87 (4 x 12 ft; 908 trees/acre) trained to a V. Trees had completely filled their space. Equivalent root pruning treatments were performed in year 1 as described above for Exp 1.

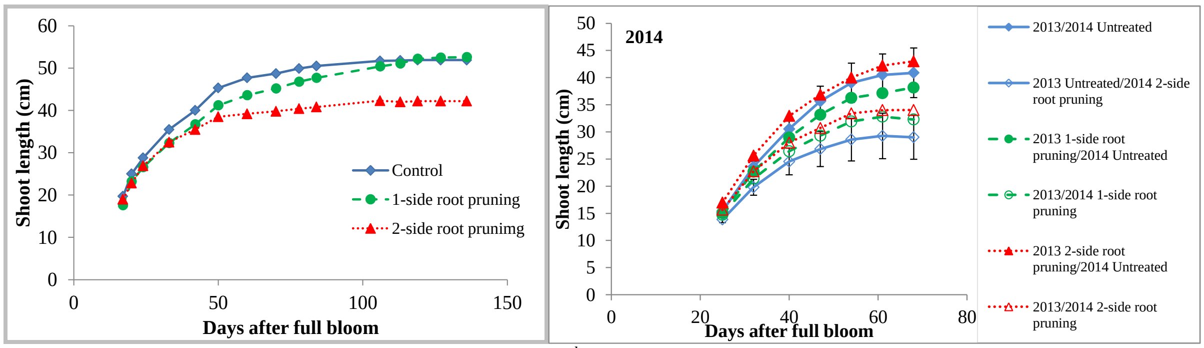

Figure 4. Shoot growth as affected by root pruning 4th leaf 'd'Anjou' trees in 2013 (left panel) and/or in 2014 (right panel).

Shoot growth was reduced relative to the severity of root pruning (Fig 4 left); however, the overall reduction in growth was ~half that observed in experiment 1- somewhat intuitive, since trees were nearly half the age and size. Interestingly, one-sided shoots appeared to recover during the season, plausibly due to the limited stress and regeneration of roots.

Table 3. Effects of root pruning (one or two sides of the tree row) on 4th leaf and 5th leaf 'd'Anjou' tree growth and production. In 2014 (year 2), treatments were either reapplied to the same trees (i.e., at the same level as in 2013) or not administered (i.e., trees left untreated). In addition, untreated trees were root pruned (2-sided only) for the first time in their 5th leaf.

Expt./Treatment by year		TCA (cm^2)	Avg. Annual Shoot Length (cm)	Avg. Bloom/ Limb (# clusters)	Fruit Set (%)	Total Yield (lbs/tree)	Avg. Fruit Count (no. fruits/tree)	Projected Prod. (bins/acre)	Avg. Fruit Size (g) (g)	Yield Efficiency (%)
2013 treatment		2013								
Untreated control		40.8*	53.2 a	30	11	16.1	28	13	265.3	0.179
One-sided root pruning		27.5	51.3 ab	26	13	13.5	27	11	228.3	0.221
Two-sided root pruning		30.8	42.2 b	33	13	18.3	34	15	233.7	0.269
Pr(>F)		0.0773	<.05	0.5621	0.7376	0.5608	0.4941		0.1648	0.0773
2013 treatment	2014 treatment	2014								
Untreated control	Untreated control	57.8 a	40.1	34.3 b	70.0	29.3 b	53	24	220 d*	0.23 b
Untreated control	Two-sided root pruning	48.2 b	32.1	34.3 b	73.6	31.6 b	62	26	221 d	0.297 b
One-sided root pruning	Untreated	37.7 c	40.6	40.1 b	69.8	28.9 b	67	24	233 cd	0.34 b
One-sided root pruning	One-sided root pruning	48.6 b	33.1	40.1 b	58.8	28.7 b	57	24	236 c	0.267 b
Two-sided root pruning	Untreated	41.6 c	43.4	54.7 a	85.8	45.1 a	93	37	253 b	0.49 a
Two-sided root pruning	Two-sided root pruning	50.1 b	32.3	54.7 a	85.4	49.5 a	85	41	273 a	0.447 a
Pr(>F)		<.001	0.0585	<.001	0.0616	0.0314	0.0513		<.001	<.001

*letters signify significant difference with LSD test, all values are means of 4 replicates, n=25

**analysis of variance pr(>f).05

As might be expected from the moderate vegetative stress induced by root pruning, first-year (2013) fruit set and yield were not negatively affected, irrespective of the level of root pruning (Table 3). Fruit size of root pruned treatments, however, was smaller; possibly due to a shortage of carbon (as presumed to be the case in experiment 1). In year 2 (2014), we split the replicates in half (4 contiguous trees per rep); one half was re-root pruned to the same level while the other half was left untreated. In addition, double-sided root pruning was applied to trees previously untreated in year 1.

Shoot growth of trees untreated in year 2, recovered fully in the second year (Fig 4, right). Trees pruned to the same level in consecutive years had a similar 20% reduction in shoot growth. Trees root pruned for the first time in their 5th leaf showed less overall shoot growth than other treatments (Fig 4, right). Bloom, fruit set and yield were all markedly increased by double-sided root pruning, but only when applied the previous year (Table 3). Projected per-acre production was increased by ~70% for these treatments relative to controls (from 24 bins to 41 bins). Fruit size or quality (data not shown) were unaffected by root pruning in year 2. These data support application of root pruning to young plantings to improve early production. We continue to evaluate the benefits of annual root pruning.

Objective 3:
2012 Planting: The 2012 planting to compare bi-axe and single axe training systems using multiple in-row tree spacing (2, 4 and 6 ft. for Bartlett, and 4 and 8 ft. for 'd'Anjou x 12 ft. alley spacing) needed to be restarted in 2013 due to excessively poor vigor and tree health. 2014 tree growth responded well to pruning, but production was delayed. Trunk size was only slightly smaller for bi-axe trees (compared to single axe) probably because bi-axe trees were developed by heading; a technique which generated vigorous axes. Bartlett trees were slightly smaller at the 2 ft. spacing compared to wider spacings. 'd'Anjou' tree size was not influenced by spacing. This is likely due to the wider spacings of 'd'Anjou', compared to Bartlett, and the poor growth in the formative years (i.e., no root competition yet). Bartlett trees have just now filled their space at the 2 ft. spacing. Minimum yield was recorded for Bartlett trees (~10 fruits per tree) equating to ~ 2.4, 1.5 and 1 bins per acre for the 2, 4 and 6 ft. spacing, respectively (data not shown).

2013 Planting: The performance of 'd'Anjou' trees is being evaluated on OH×F 87, OH×F 69 and Pyro 2-33 at three levels of training (V, single axe, bi-axe) and three levels of intra-row spacing (3, 4.5, and 6 ft.) at Hood River, OR. Alley spacing is 12 ft. resulting in a range of tree densities per acre of 605, 807, and 1,210. Tree growth and development (branching) was excellent after 2 years. Much of the uniformity among reps (see photos) of the bi-axe trees can be attributed to the nursery practice of chip budding scion buds opposite one another, as opposed to establishing the bi-axe by heading in the field. All trees reached the top wire (8 ft.) by August, 2014. Tree height will be managed at 10 ft. Trunk cross-sectional area of bi-axe trees was 40% smaller than single axe trees (whether planted to a V or vertical; Table 3). These data show the vigor control achieved by dividing vigor over two axes. Trees on Pyro 2-33 remained smaller than either of the OH×F clones (i.e., trees on Pyro 2-33 were significantly smaller at planting). Effects of inter-row spacing on trunk size were not significant, but 'd'Anjou' trees planted at 3' spacing were numerically smaller than those at 4.5 or 6 ft. Trees planted at 3 ft. have just filled their space. Bi-axe trees also resulted in significantly higher flower clusters per tree than either of the single axe training systems. While flower density was quite low, the results suggest a potential improvement in precocity of bi-axe trees.

Training. Individual axes of bi-axe trees were tied to bamboo (fastened to wires). Initially, bi-axe trees planted at 6 ft. in-row spacing were spread at ~45 degree angles until reaching the second wire (~5 ft.) then trained vertical. At 3 ft. spacing, axes were not spread as wide and were tied to a vertical position after the first wire (~2.5 ft.). The objective of changing the angle of the axes was to fill space. Trees in the V training system (each pole tipped 10 degrees from vertical) were attached to the wires in spring of 2014. Adjacent trees were tipped opposite one another. For trees in the 6' spacing, 3 leaders (palmette) per tree were trained to fill space (i.e., 12 ft. between trees on the same plane). V-trained trees at 3 and 4.5 ft. spacing were maintained as central leaders. The single axe trees were trained as spindles. All systems were pruned in the dormant period. For all systems, shoots in the top 25% of the tree were snapped at roughly 1/3rd of their length (a technique of S. Musacchi). All limbs that exceeded ~50% of the trunk diameter were removed with a bevel cut (i.e., Dutch cut). Shortening (heading) was only performed on primary scaffolds that were deemed too vigorous. The primary criterion for heading was the presence of weak or blind nodes within the basal foot of the scaffold. The objective was to invigorate these nodes by heading in order to maintain fruiting potential at the base of limbs. Otherwise no other limbs were headed. All new shoots that developed in the spring were either tied, tooth-picked or clothes-pinned to establish wide-branched angles (30 to 45 degrees from horizontal). Throughout the season, wide branch angles were encouraged by bending, tying to wires, spreading and/or hop clipping (for those limbs oriented into the alley).

Table 3. Effect of rootstock, training system and in-row spacing on 2nd leaf 'd'Anjou' tree growth & flowering.

Treatment Effects	Trunk size: Above graft union (cm^2)	Trunk size: Below graft union (cm^2)	Flower clusters no./tree
Rootstock			
OH×F 69	11.6	24 a	2.2
OH×F 87	11	21.2 ab	1.6
Pyro 2-33	9	20.1 b	1.6
Training system			
Bi-axe	7.2 b	21.9	3.5 a
Single-axe	12.6 a	22.5	1.1 b
V	11.8 a	21	0.8 b
In-row spacing			
3 ft.	9.9	20.5	1.6
4.5 ft.	10.9	22.4	2
6 ft.	10.8	22.5	1.6

Executive Summary:

PGR Experiments

Eight trials were conducted to evaluate ReTain on pear fruit set and production; 60% of the trials resulted in significantly greater fruit set or yield, 40% did not. When effective, yield improvements ranged from a three-fold increase to only modest, numerical gains. For 'd'Anjou', ReTain was only effective when applications were made ~10 to 14 days after bloom, at a rate of 1 pouch per acre. Applications near full bloom were ineffective. In fact, bloom applications only improved fruit set for 'Comice' in one of three trials. 'Comice' is purported to have a short ovule longevity period. In that trial, however, applications made 2 weeks after bloom had a significantly greater response.

The rate of ethylene production of untreated 'd'Anjou' and 'Comice' flowers steadily increased from bloom (near 0), peaking around 14 days after bloom, and returning to ~0 by 30 d after bloom. ReTain markedly reduced, but did not completely inhibit, ethylene production of flowers and fruitlets. Differences in the absolute rate of ethylene were observed between 2013 and 2014. Plausibly, a critical level of ethylene contributes to fruit abscission, and to be effective, ReTain applications should be applied just prior to this peak. Further work is required to better understand the relationship. Interestingly, fruits harvested from ReTain treatments had equivalent seed counts as untreated fruits.

Ethephon applications (300 ppm) ~45 d after full bloom significantly improved return bloom, fruit set and yield of 'd'Anjou' trees the year after application.

Root Pruning Experiments

Root pruning was applied to orchards between 2012 (6th leaf d'Anjou') and 2014 (4th and 5th leaf 'd'Anjou'). In all trials, root pruning reduced vegetative growth (between 20% and 40%). Reduction in shoot length and trunk growth was positively related to tree age and the severity of pruning (two sides elicited a stronger response than one).

Root pruning was too severe on 6th leaf trees, resulting in reduced yield and fruit size the year of application. Root pruning was not re-applied to this orchard, but vegetative growth and fruit size remained restricted through 2014. In contrast, shoot length of trees pruned in their 4th leaf recovered fully the year subsequent to application (when not root pruned again), but trunks remained significantly smaller.

In all trials, double-sided root pruning consistently improved return bloom, fruit set, yield, and yield efficiency the year after application. In 2014, trees root-pruned in their 4th leaf (2013) had ~65% greater yield than controls (i.e., 41 bins per acre vs. 24 bins per acre) with no negative effect on fruit size or quality.

Root pruning in consecutive years reduced shoot length by 20% and increased yields by ~70% compared to untreated trees.

Training Systems

In 2013, a rootstock trial was planted to evaluate the performance of 'd'Anjou' on OH x F 87, OH x F 69 or Pyro 2-33 at three different training systems (V, bi-axe, single-axe) and three different in-row spacings (3, 4.5 and 6 ft.). After the 2nd leaf, trees on Pyro 2-33 were significantly smaller than OH x F 87 or OH x F 69. Individual axes of bi-axe trained trees were 40% smaller than single axe trees, irrespective of rootstock.