# Walnut Blight Control by Pathogen Population Management

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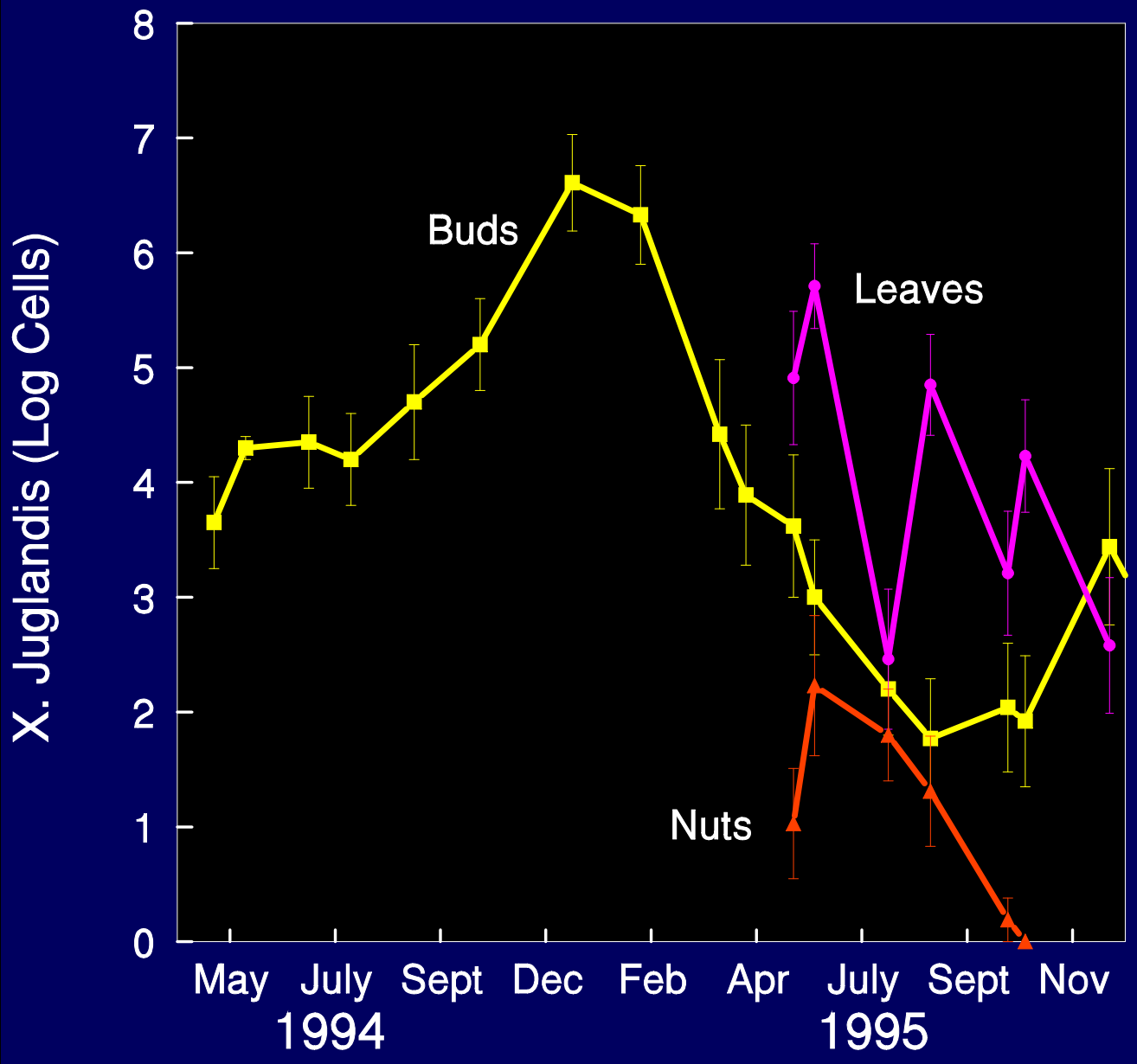
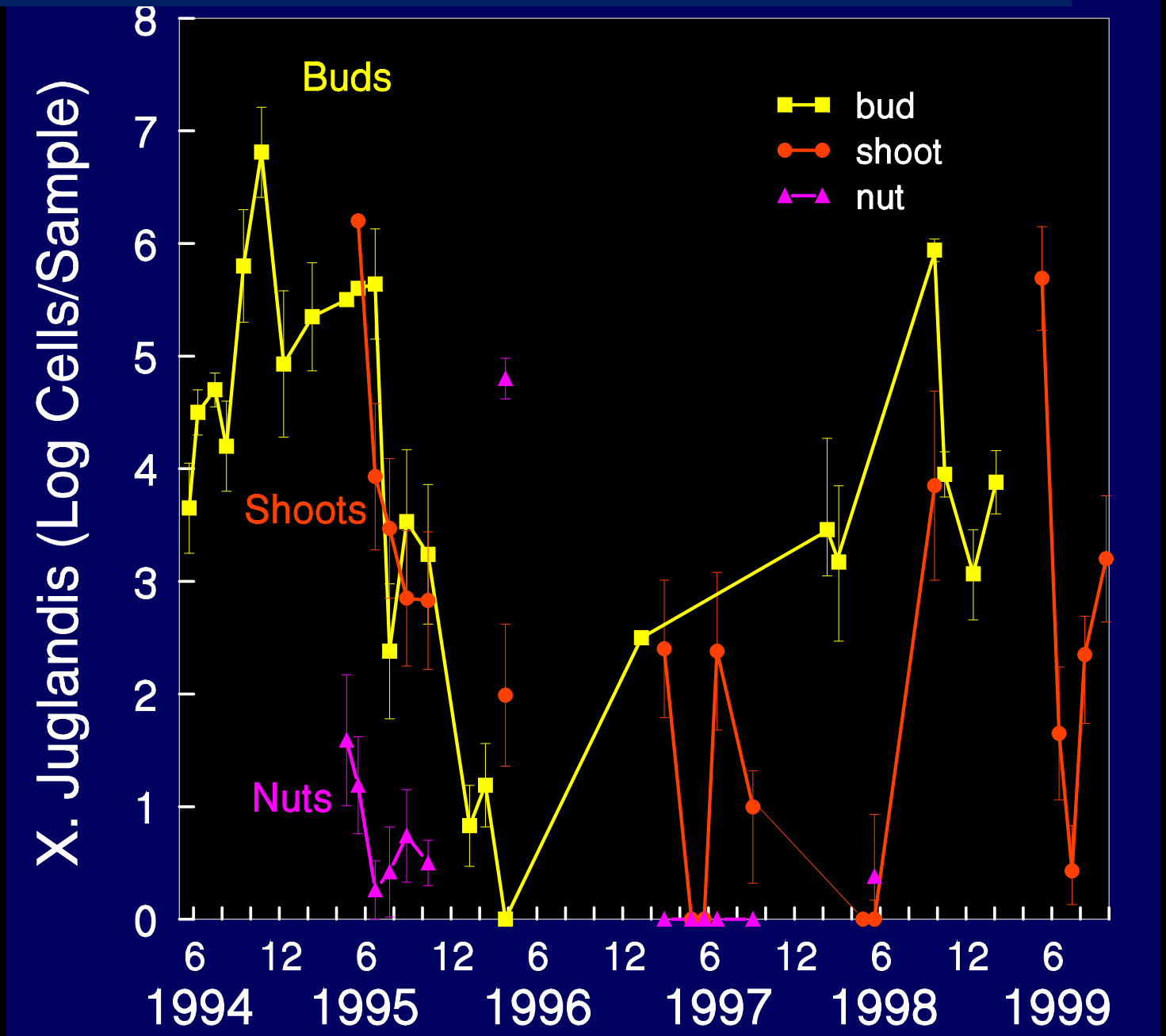
# Pathogen – *Xanthomonas arboricola* pv. juglandis

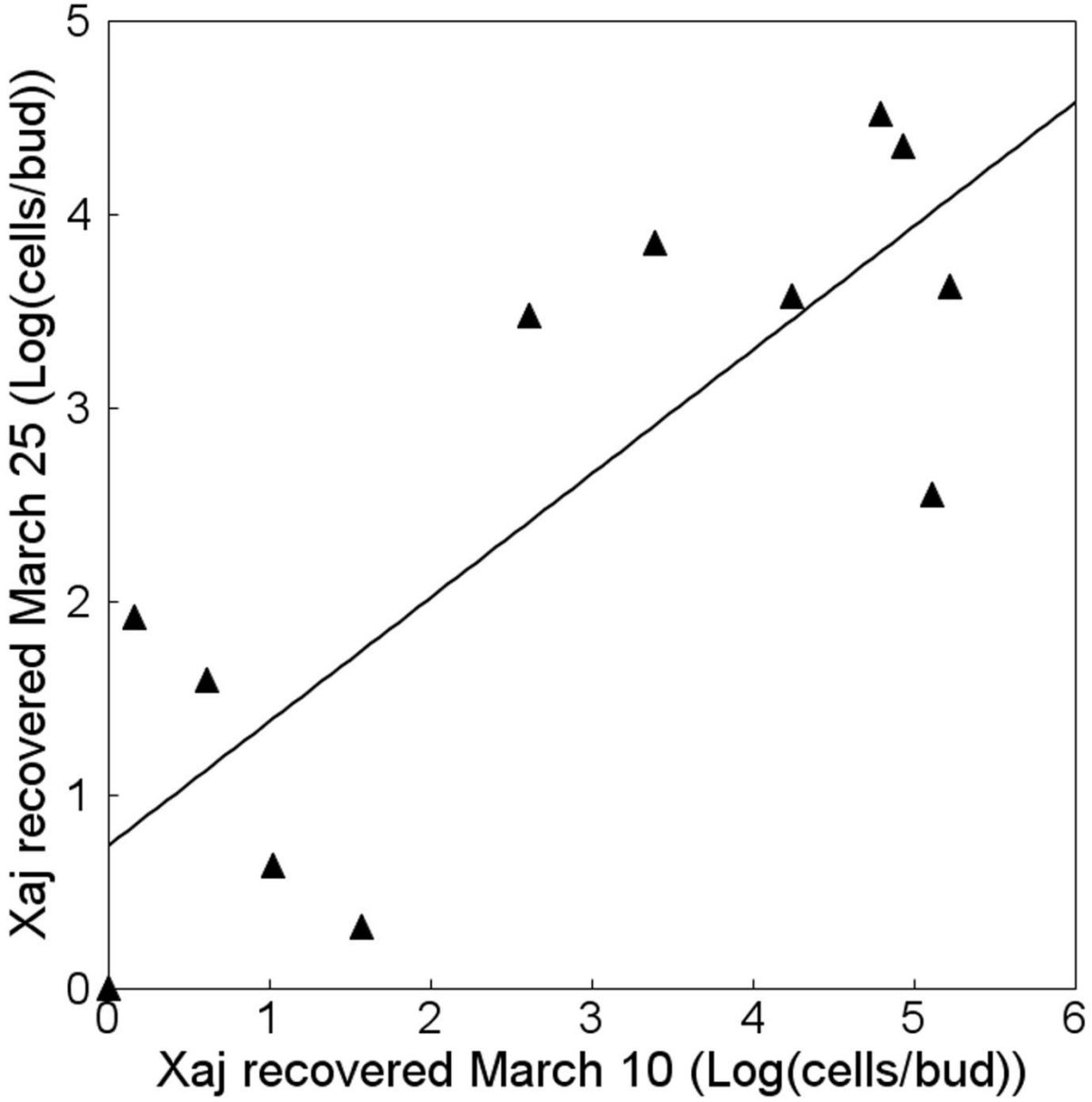
# The pathogen prefers to live in buds



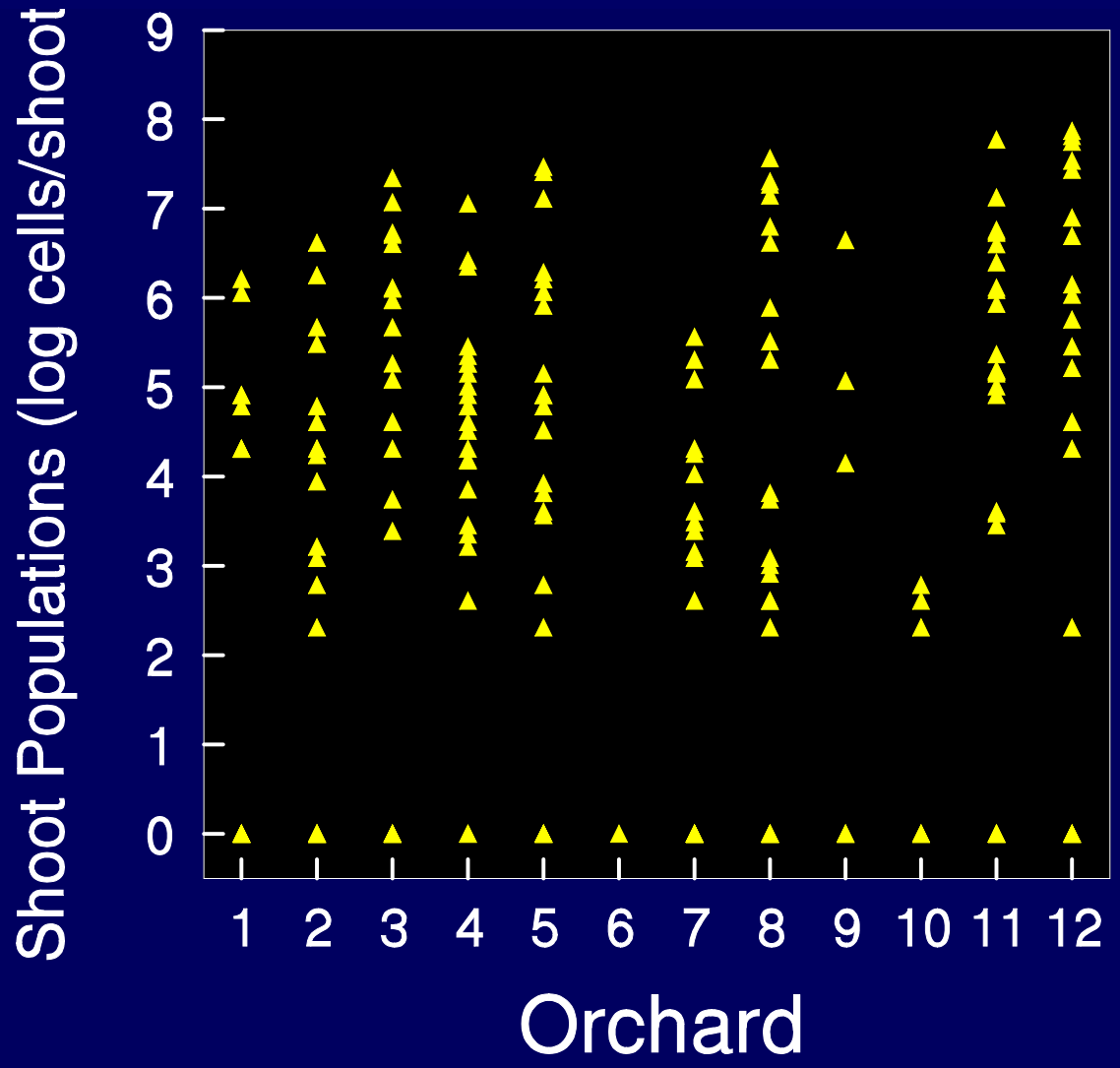
# Pathogen populations change over time



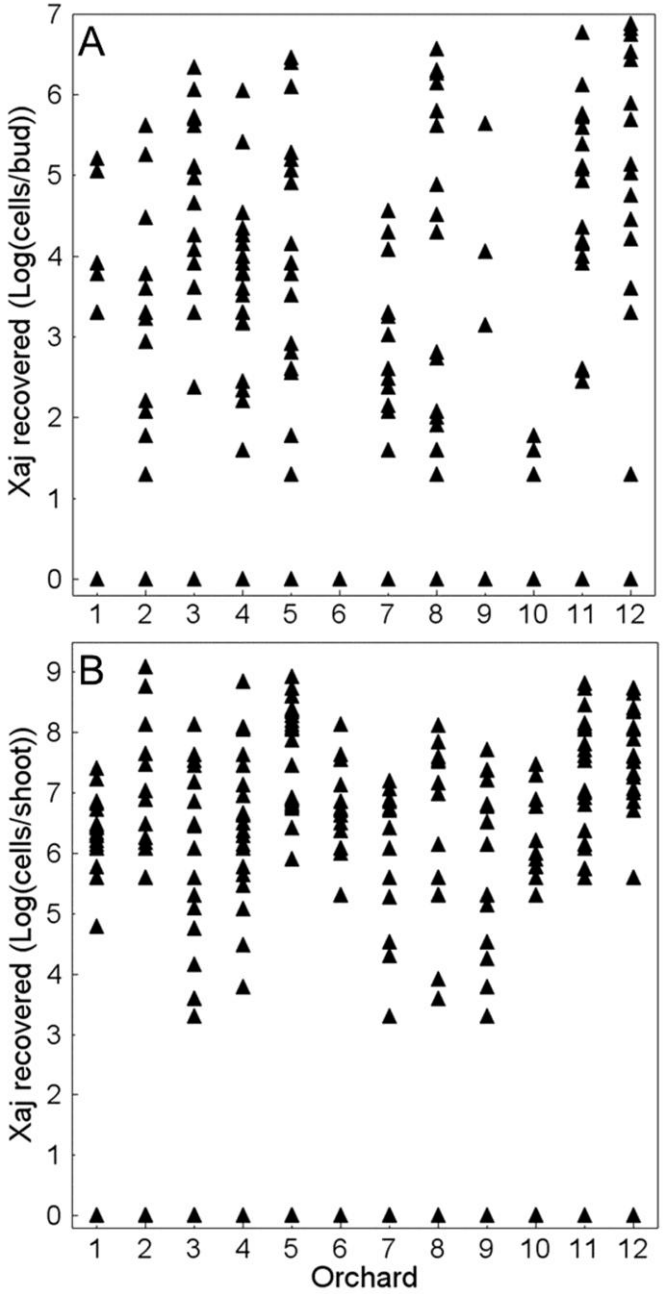
Xaj populations relatively constant with time in dormant buds



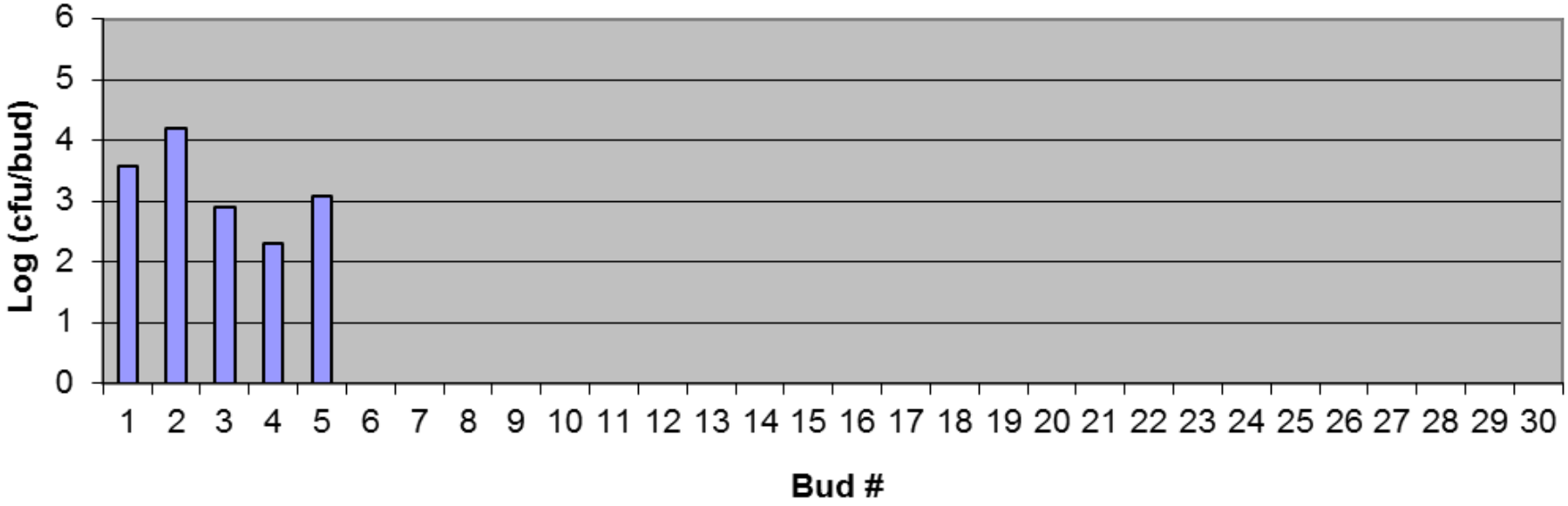
# Pathogen populations vary greatly between orchards and between buds within a given orchard



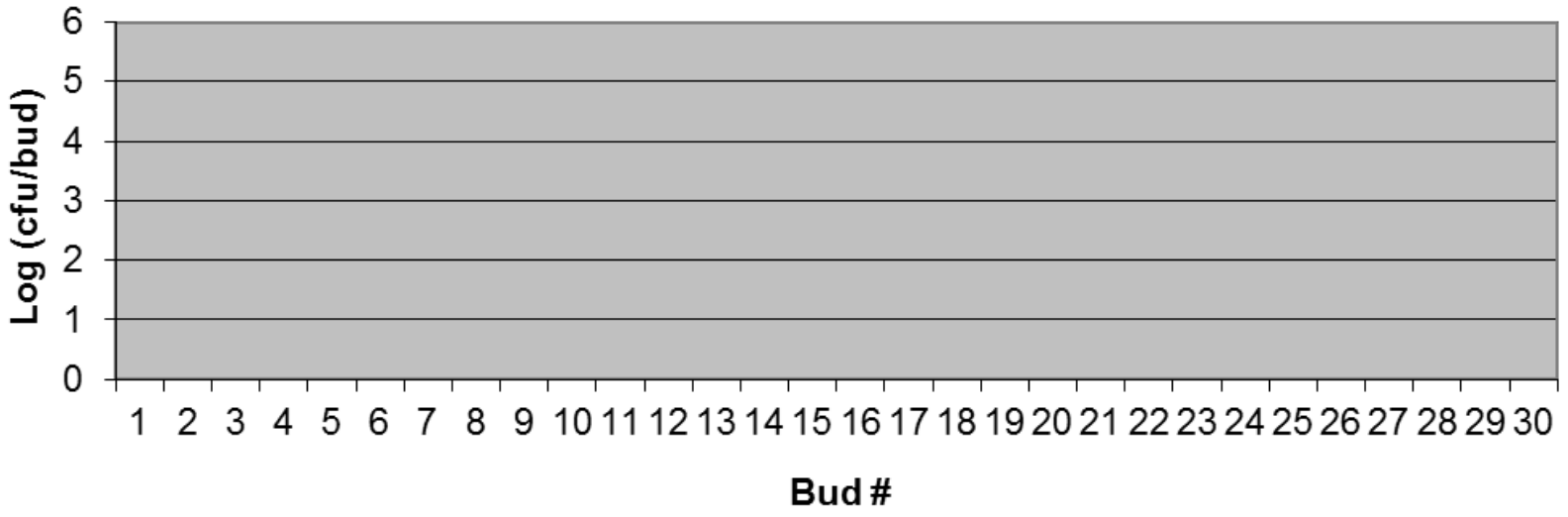
Populations can increase but do not always increase with time after buds open
Always large variation numbers of Xaj



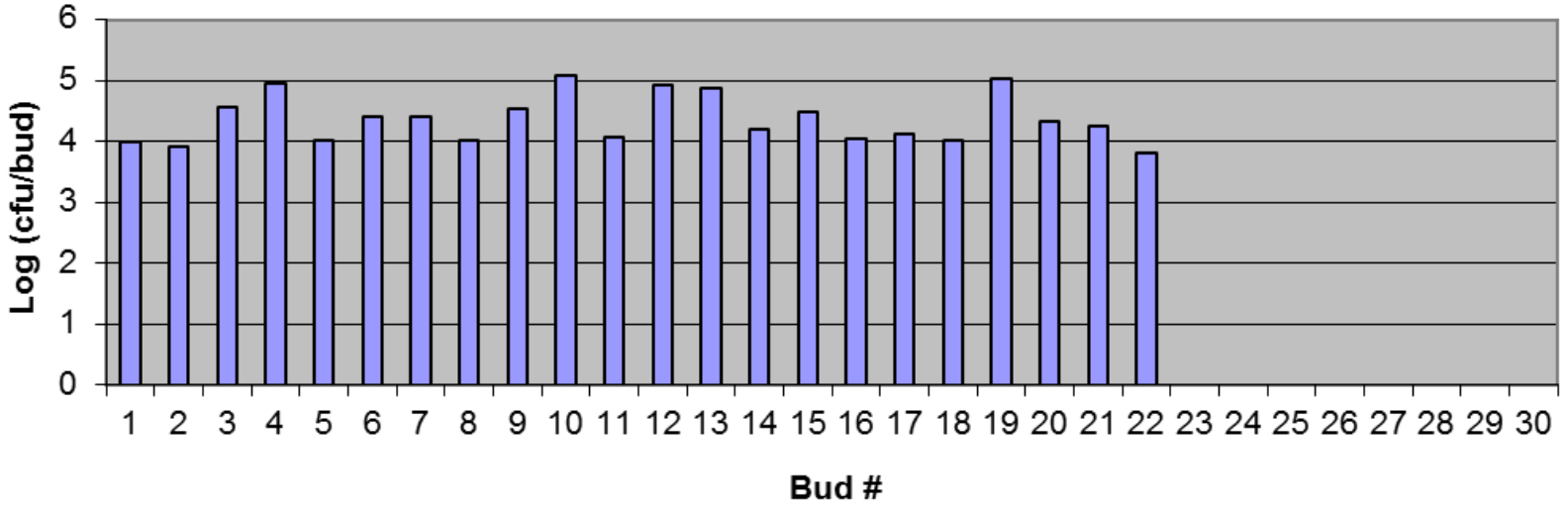
# Tehama County #61



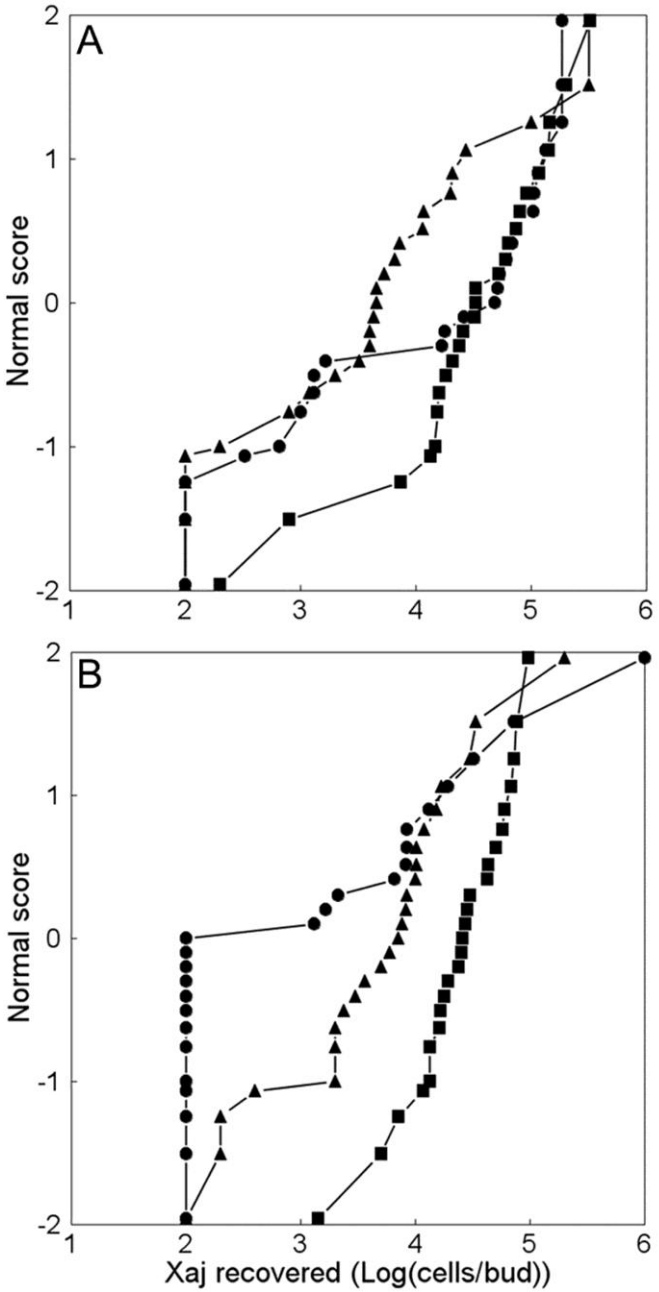
## Tehama County #18



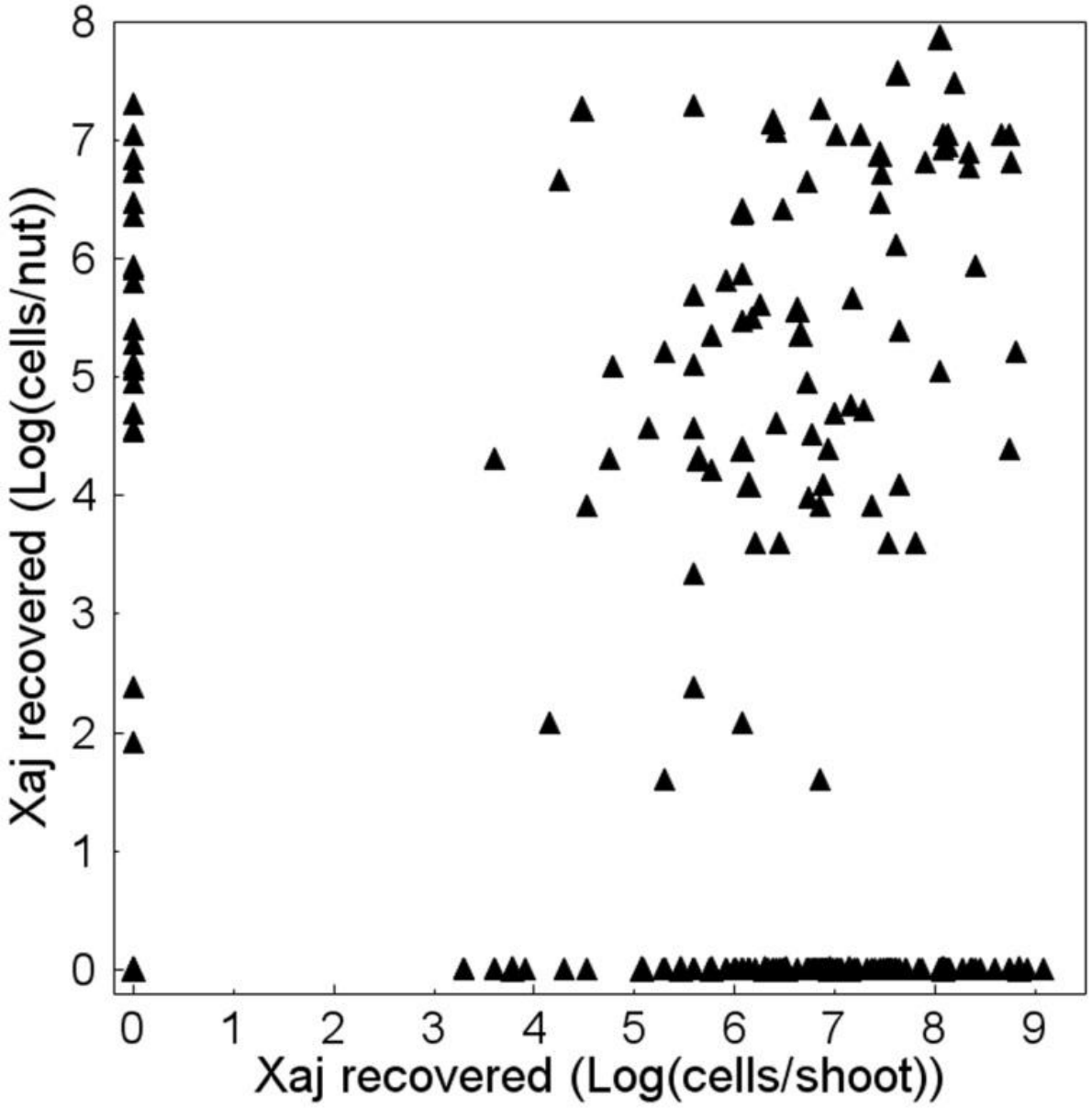

## Tehama County #63



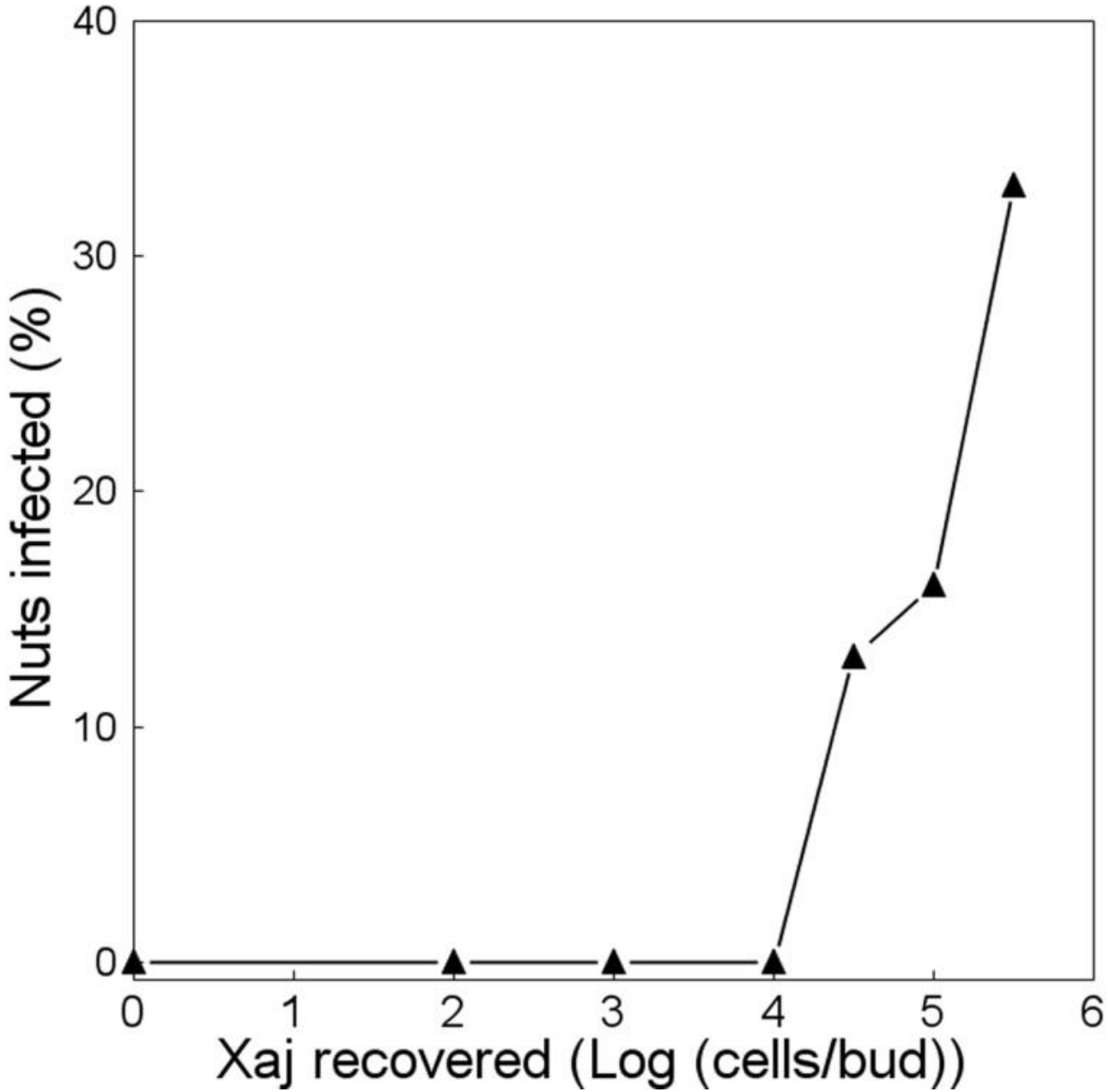
# Xaj populations in buds increase during the summer months



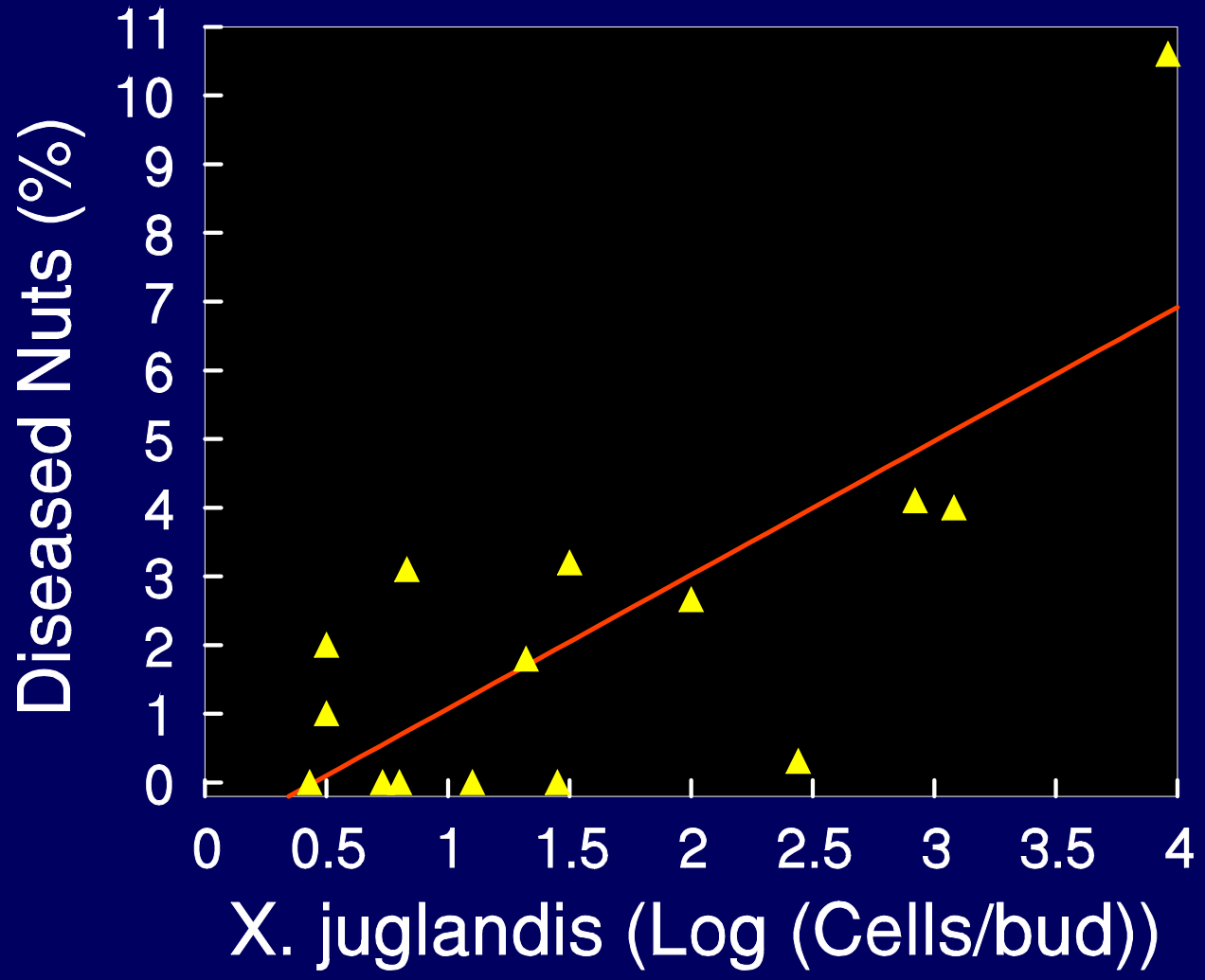
Nuts are very unlikely to become colonized by Xaj unless shoots also colonized



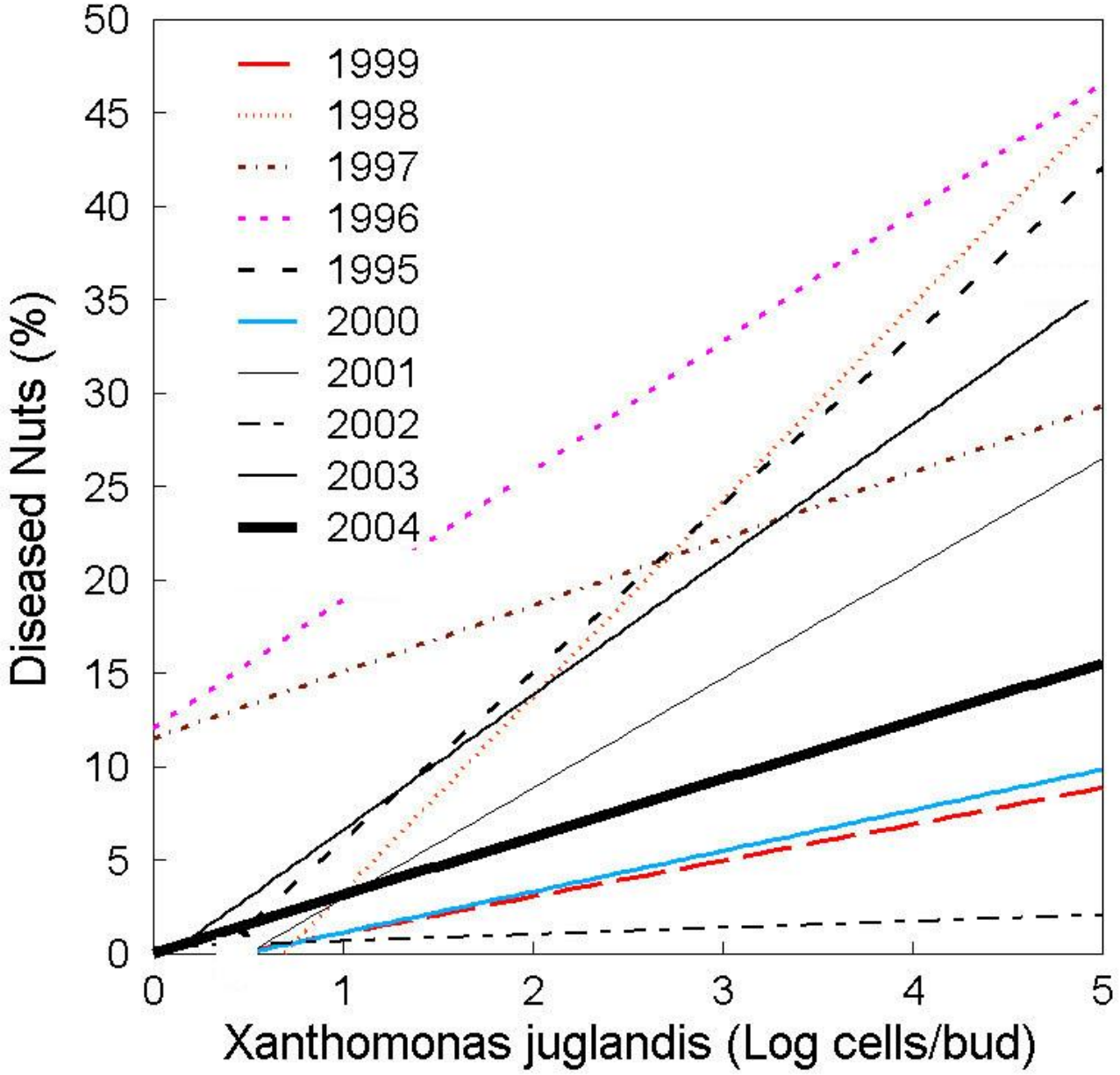
Disease is very unlikely unless Xaj colonizes dormant buds



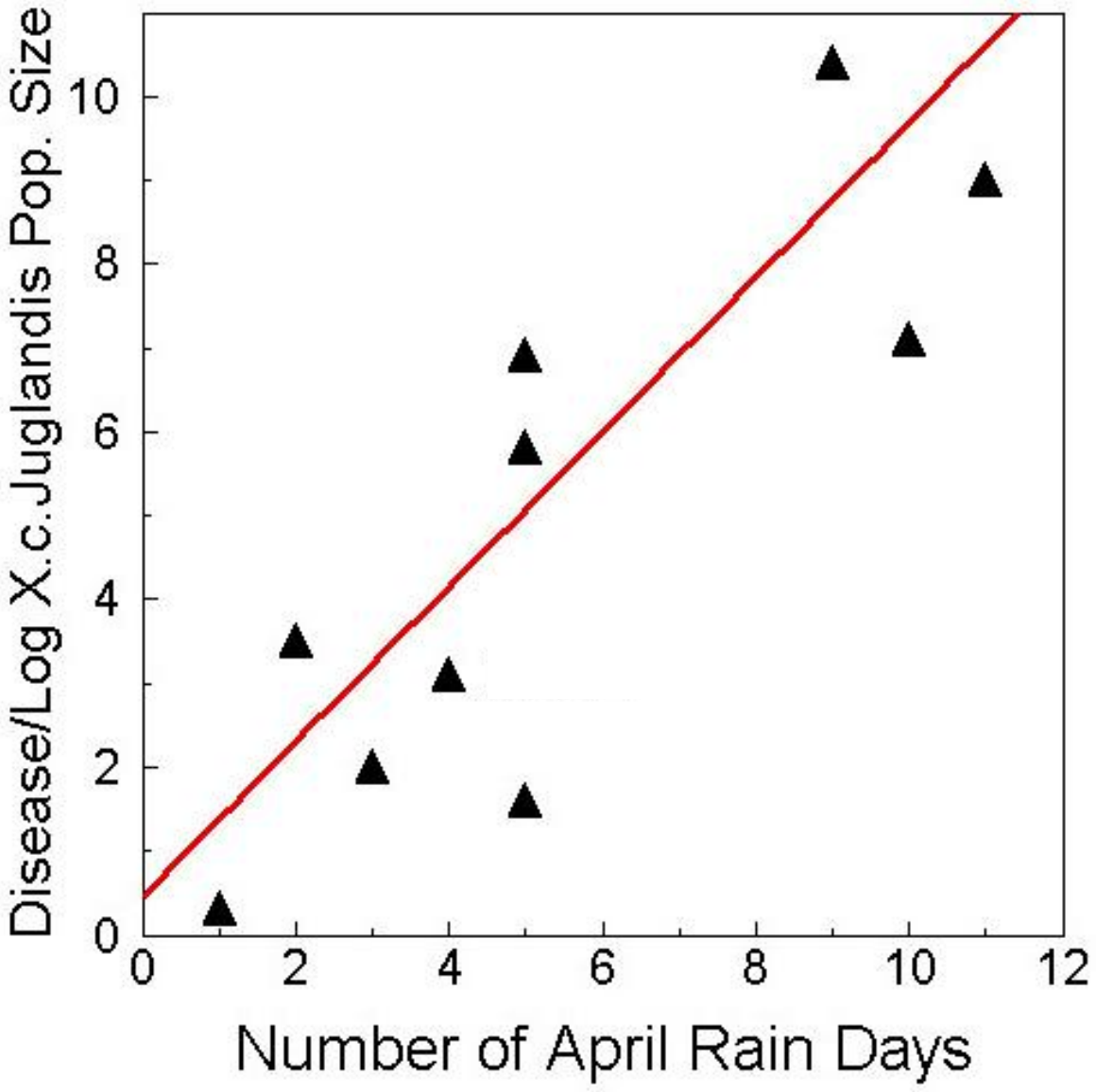
**In a given year, disease incidence is predictable from early season populations of pathogen in buds**



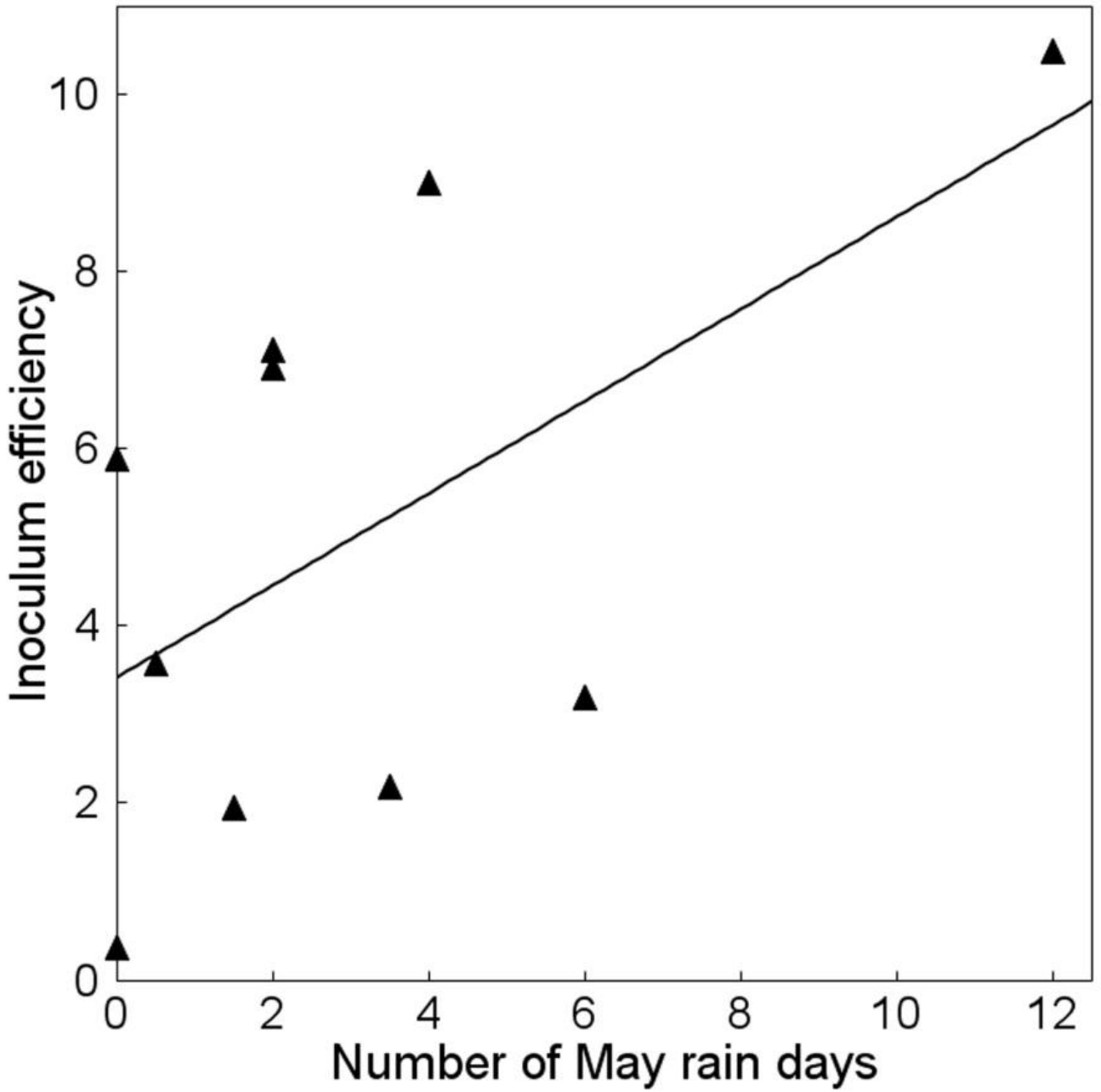
# The “efficiency” with which inoculum leads to disease varies from year to year



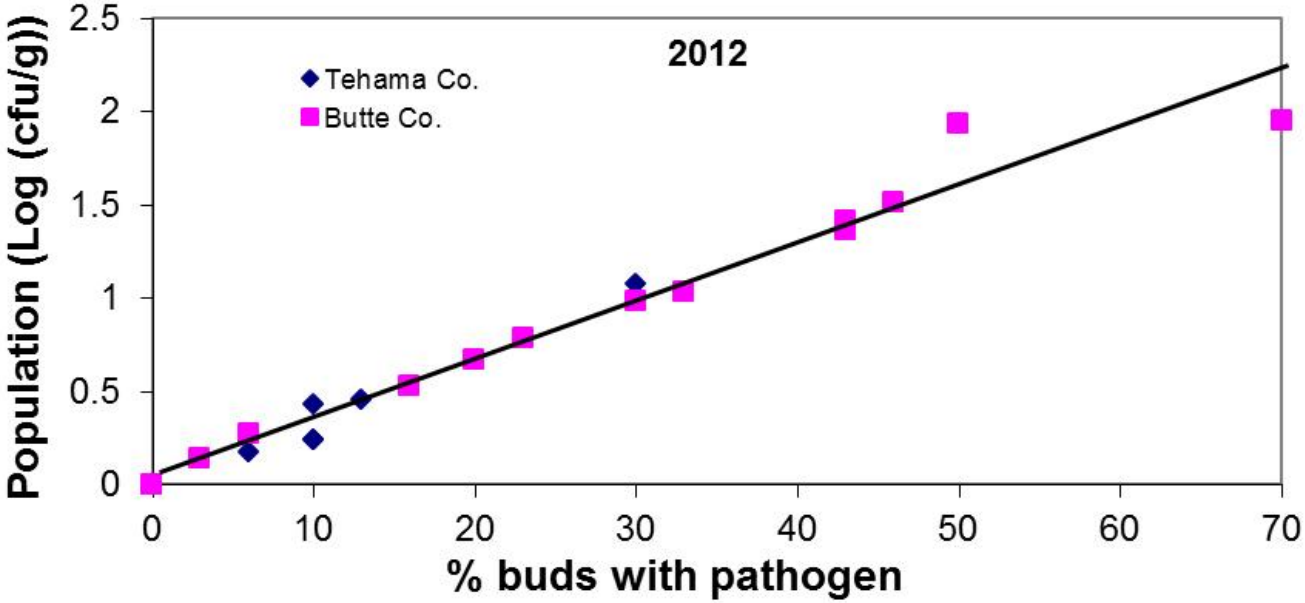
# Early season rain promotes infection if inoculum is present in orchard

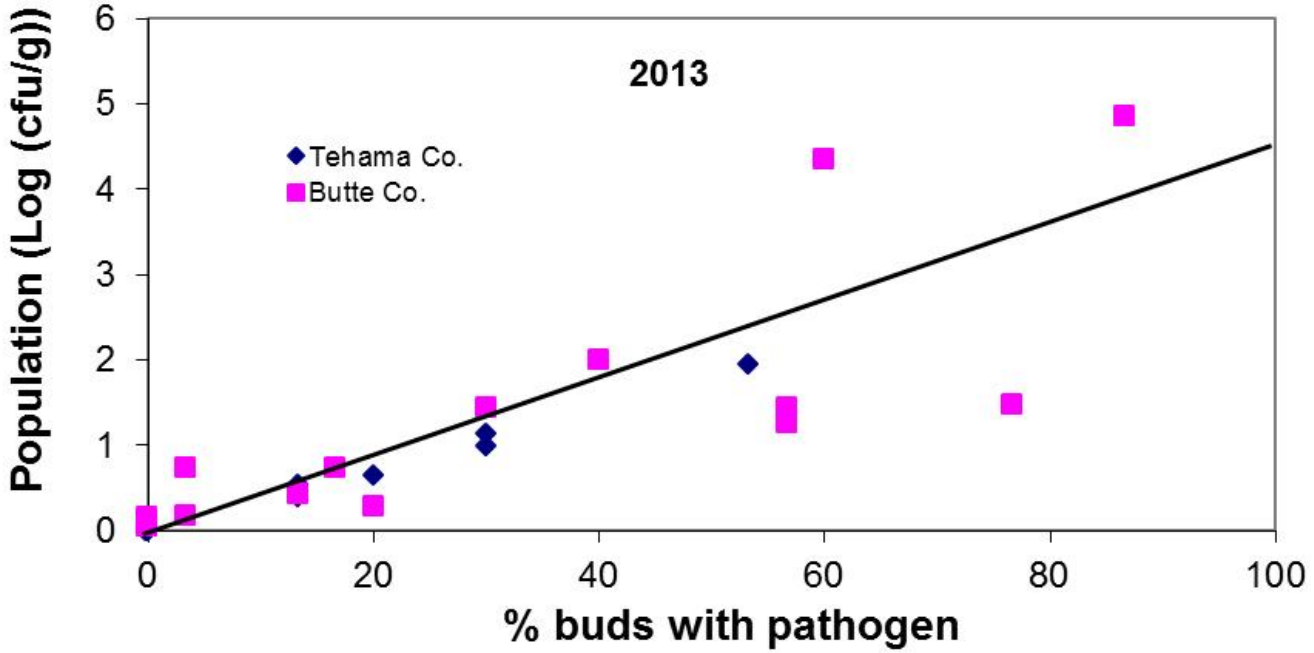


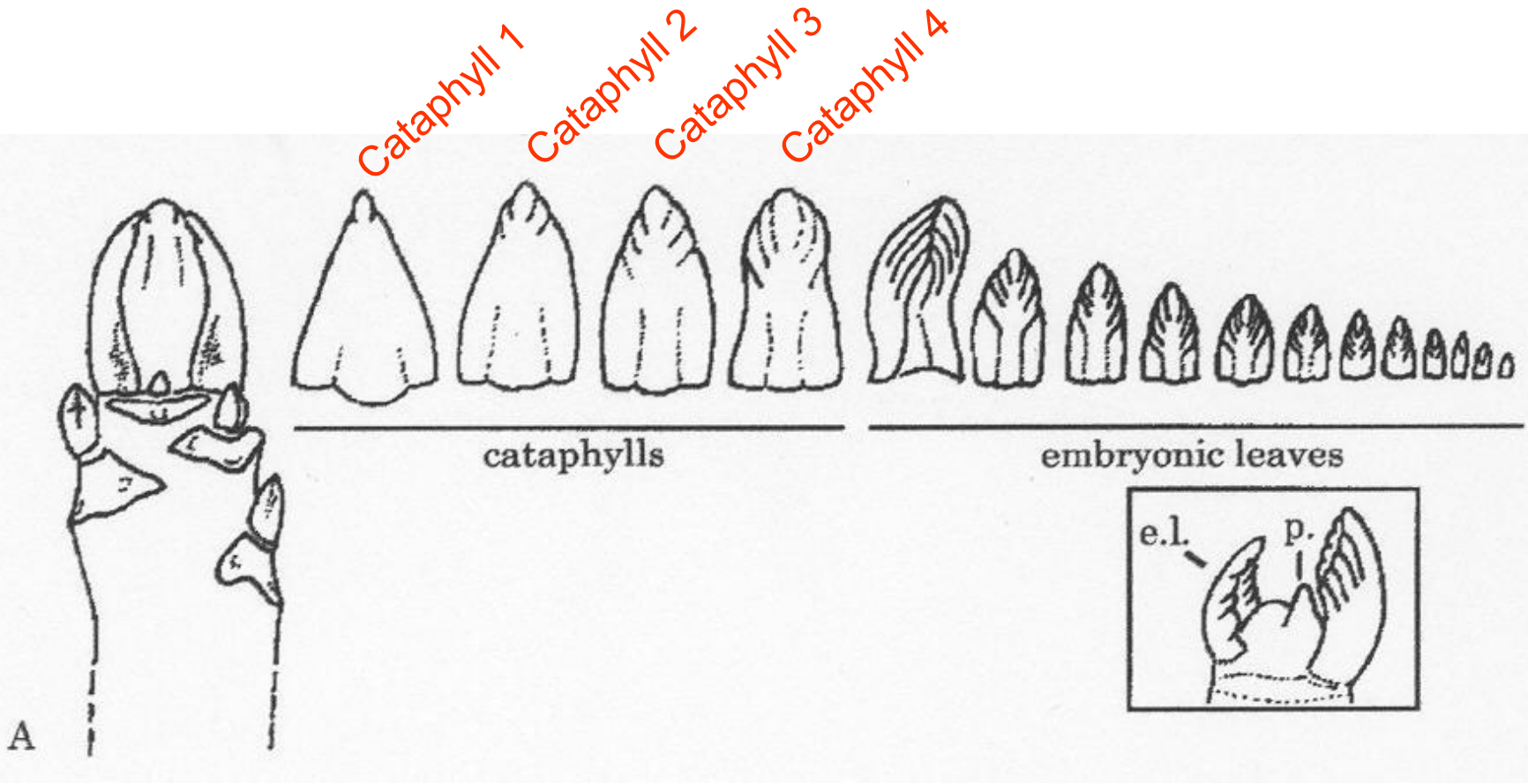
Rain late in spring does not facilitate walnut blight disease

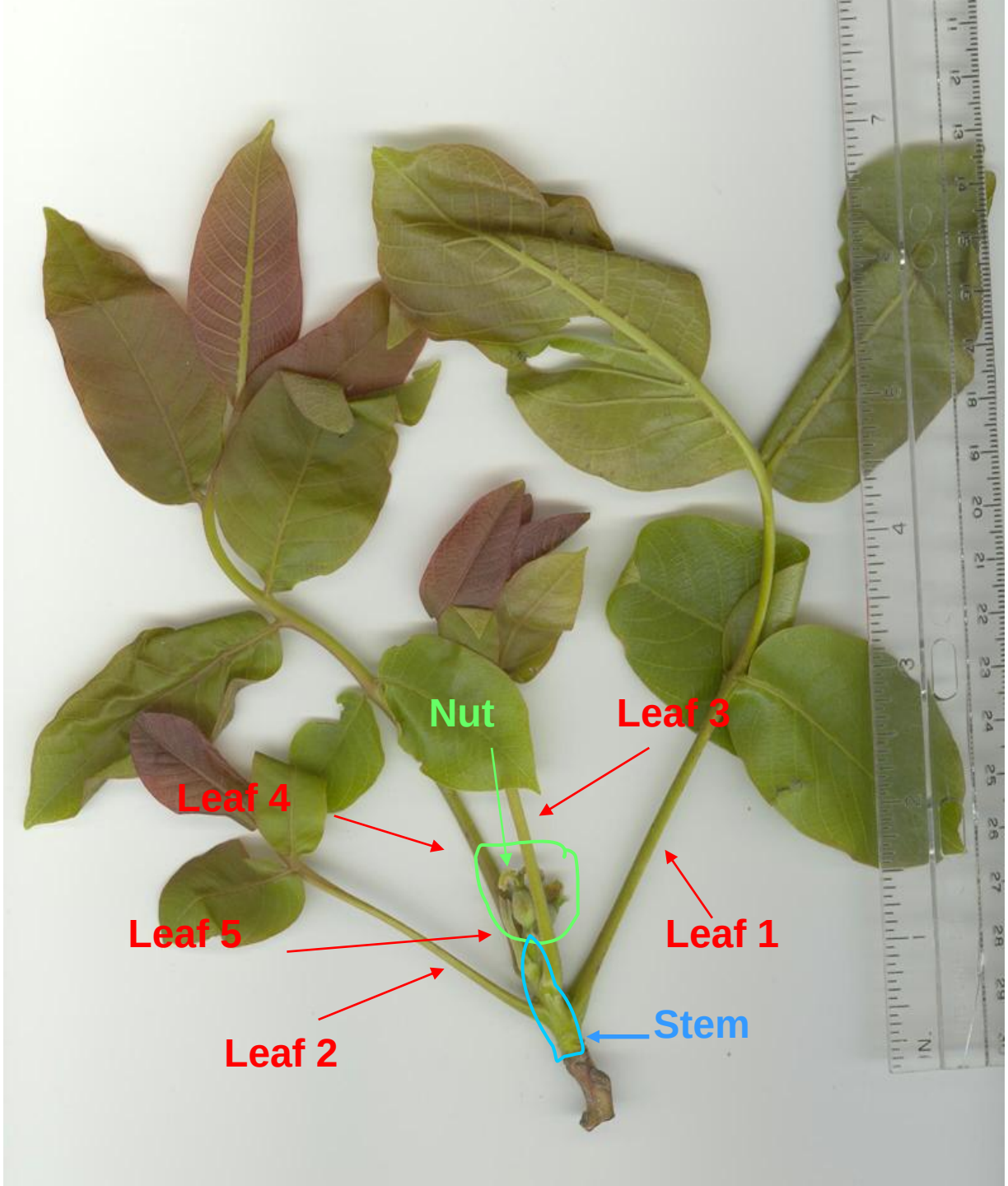


Strong correlation of incidence of bud colonization by Xaj and mean population size – facilitate predictions of disease

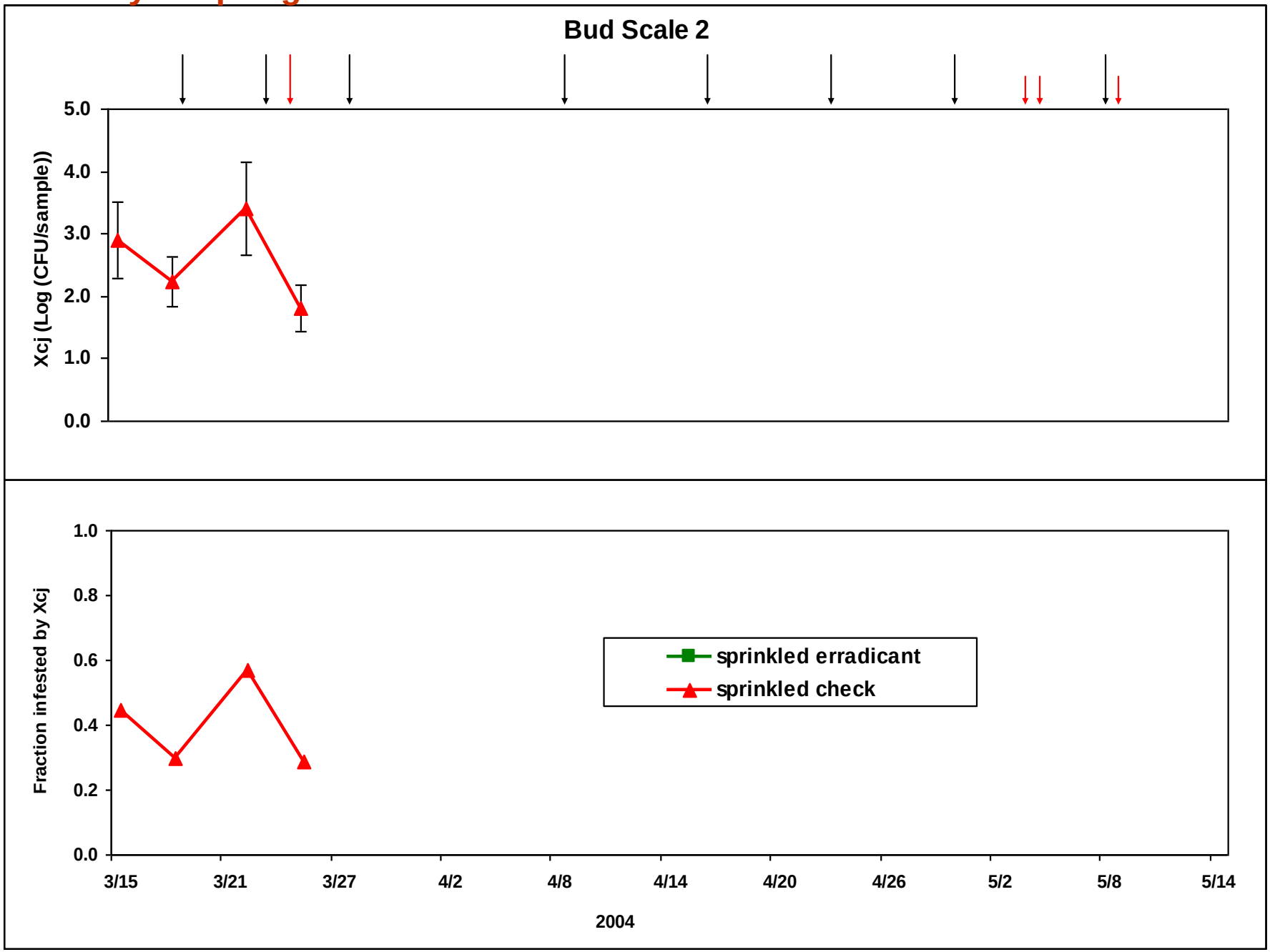


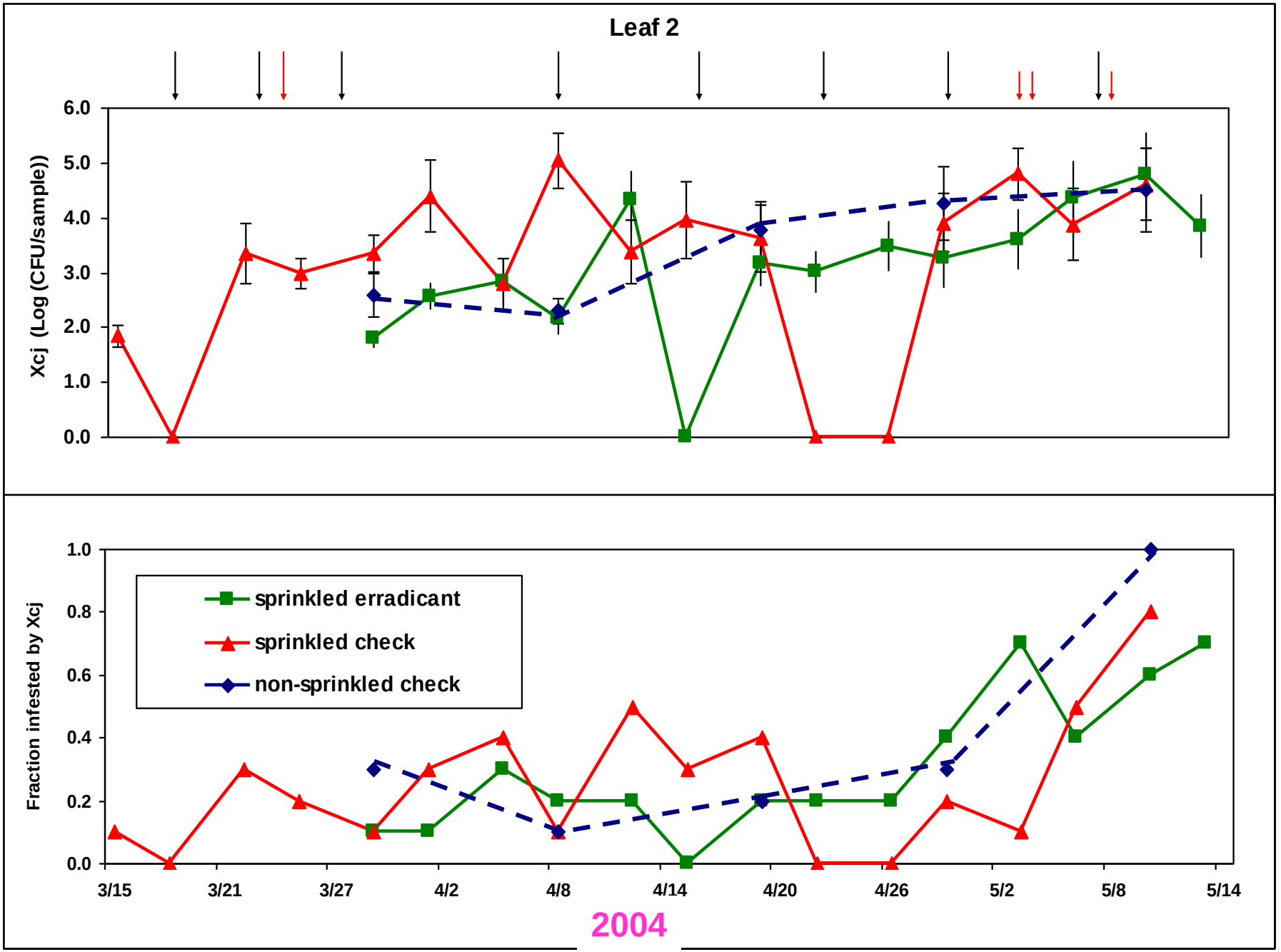

Cataphyll 1
Cataphyll 2
Cataphyll 3
Cataphyll 4
cataphylls
embryonic leaves
e.l.
p.
A


Nut
Leaf 3
Leaf 4
Leaf 5
Leaf 1
Leaf 2
Stem

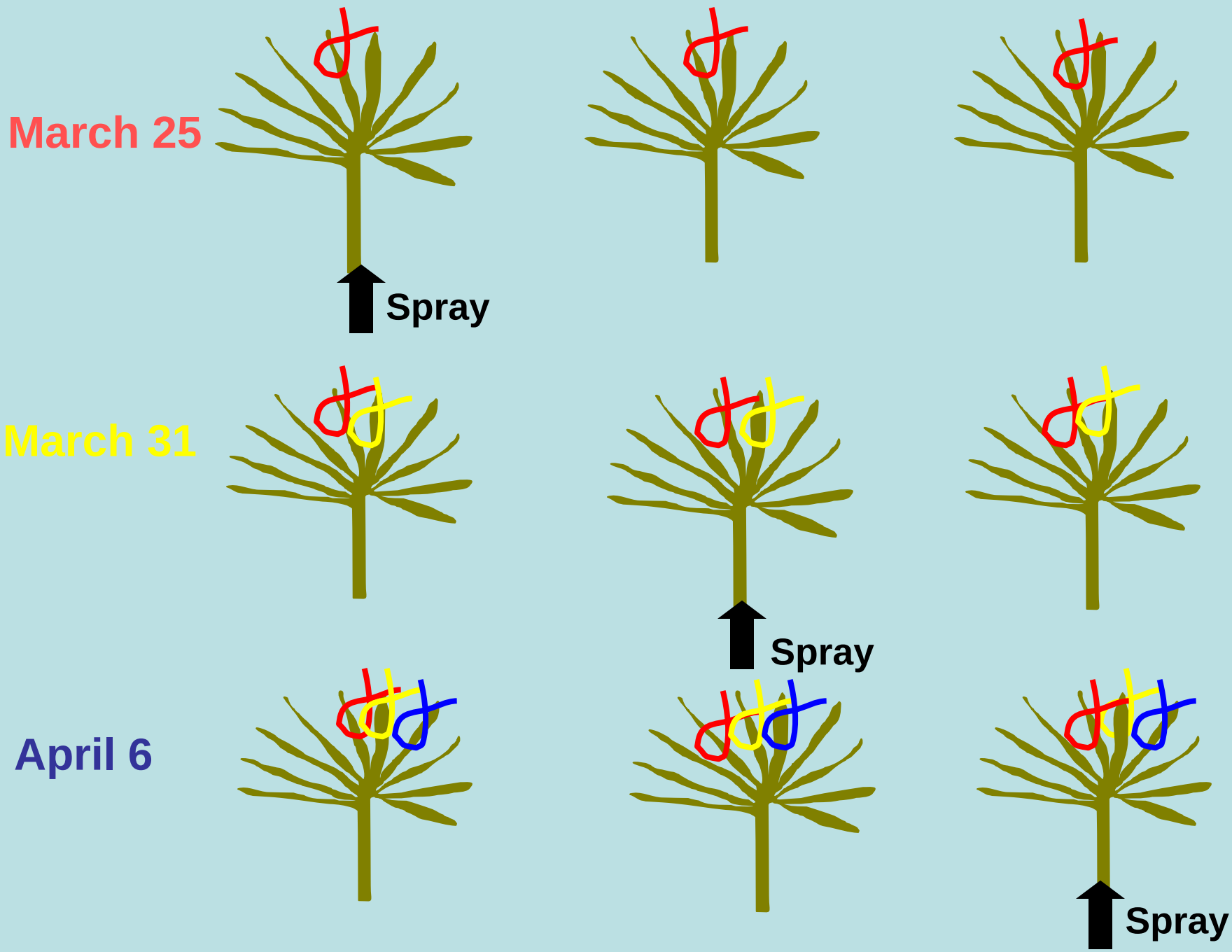
# Bud scales and cataphyls are infested with high numbers of pathogen early in spring



# Newly-emerging leaves are largely free of pathogen shortly after opening




Inoculum


March 25
Spray
March 31
Spray
April 6
Spray

**Sprays made shortly after bud break have largest effect on inhibiting pathogen growth – Prevent growth of inoculum as it spreads from buds**

**Fold- reduction in population size of *Xanthomonas juglandis* on walnut trees treated once at different times relative to bud break with Kocide+Manex**

| Spray timing | Sample date April 7 | April 26 | May 10 | Mean |
|---|---|---|---|---|
| Before Budbreak | 6.0 | | | 1.9 |
| At Budbreak | 44.7 | 16.6 | 9.8 | 25.1 |
| 7 Days after Budbreak | 1.4 | 8.7 | 35.5 | 15.2 |
| 14 Days after Budbreak | | 9.5 | | 9.5 |

# Early sprays have the most impact on disease control

## Incidence of walnut blight on trees treated at various frequencies with Kocide + Manex

| Treatment | Week | | | | | | Disease | Crop | Control | Net | Return on |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Eradicant | 1 | 2 | 3 | 4 | 5 | 6 | (%) | Loss($) | Costs($) | Loss($) | Control Costs($) |
| none | | | | | | | 57.4 a | 1722 | 0 | 722 | --- |
| + | | | | | | | 25.4 b | 762 | 120 | 882 | 8.00 |
| + | + | | | | | | 4.4 c | 132 | 190 | 322 | 8.36 |
| + | + | + | | | | | 4.7 c | 141 | 260 | 401 | 6.08 |
| + | + | + | + | | | | 1.1 c | 33 | 330 | 363 | 5.12 |
| + | + | + | + | + | | | 1.0 c | 30 | 400 | 430 | 4.23 |
| + | + | + | + | + | + | | 1.2 c | 36 | 470 | 506 | 3.58 |
| + | + | + | + | + | + | + | 0.9 c | 27 | 540 | 567 | 3.14 |
| none | + | + | + | + | + | + | 1.1 c | 33 | 420 | 453 | 4.02 |

# Early buds are most likely to be fruitful

**Numbers of nuts harvested from buds tagged on walnut trees as they opened at different times**

| Spray date | # Nuts/500 buds<br>Bud opening date | | | | |
|---|---|---|---|---|---|
| | Closed | Day 0 | Day 7 | Day 14 | Day 21 |
| Day 0 | 108 | 290 | | | |
| Day 7 | 16 | 450 | 256 | | |
| Day 14 | 10 | 373 | 260 | 148 | |
| No Spray | 49 | 267 | 192 | 87 | 7 |

# 2013 Blight Objectives

- Evaluate how many bud samples are necessary to accurately represent pathogen abundance in an orchard.
- Monitor pathogen populations in commercial orchards and utilize those data to make walnut blight spray decisions.
- Use monitoring data to develop a walnut blight bud population history which would indicate if populations are increasing or decreasing in orchards differing in disease control strategies.
- Support commercial labs that wish to offer bud population evaluations to walnut growers.
- Improve our extension efforts to help walnut growers use population information to make management decisions.

# The relatively dry spring in 2013 led to low levels of disease

| Date | Rainfall (in) | Max Temp ( F) | Min Temp ( F) |
|---|---|---|---|
| 3/19 | .06 | 66 | 44 |
| 3/20 | .03 | 63 | 50 |
| 3/31 | .37 | 66 | 50 |
| 4/4 | .23 | 62 | 53 |
| 4/7 | .06 | 68 | 47 |
| 4/8 | .04 | 67 | 40 |
| 5/16 | .08 | 72 | 57 |
| 5/27 | .10 | 69 | 54 |
| 6/10 | .01 | 70 | 57 |
| 6/24 | .04 | 70 | 60 |
| 6/25 | .45 | 75 | 60 |
| | 1.47 | | |

2013 Rainfall and maximum/minimum temperature for the Gerber (CIMIS #8) weather station in Tehama County.

# Pathogen populations and disease are not spatially variable

| Orchard Location and Variety | % Buds with pathogen | | | 2013 Spray Schedule | | | | | 2013 % Blight |
|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2012 | 2013 | | | | | | |
| 2) Lower South, Vina | 16 | 30 | 40 | 3/26[1] | 4/3[2] | 4/12[3] | 4/26[4] | 5/7[4] | 2.34 |
| 3) Lower Middle, Vina | 23 | 10 | 0 | 3/26[1] | 4/3[2] | 4/12[3] | 4/26[4] | 5/7[4] | 1.85 |
| 4) Lower North, Vina | 6 | 16 | 10 | 3/26[1] | 4/3[2] | 4/12[3] | 4/26[4] | 5/7[4] | 1.93 |

Walnut blight population survey information for a Vina variety walnut orchard in Northern Tehama County. 2013 dormant buds infested, the 2013 spray program and the resulting blight damage are listed. Dormant buds were sampled 3/12/13 and blight was visually rated 6/12/13 by counting 1,000 walnuts per location.

Application rates:

[1]BadgeX2 @ 6 lbs/ac, ProStick @ 2.4 lbs/ac, Syl-Coat @ 0.03gal/ac

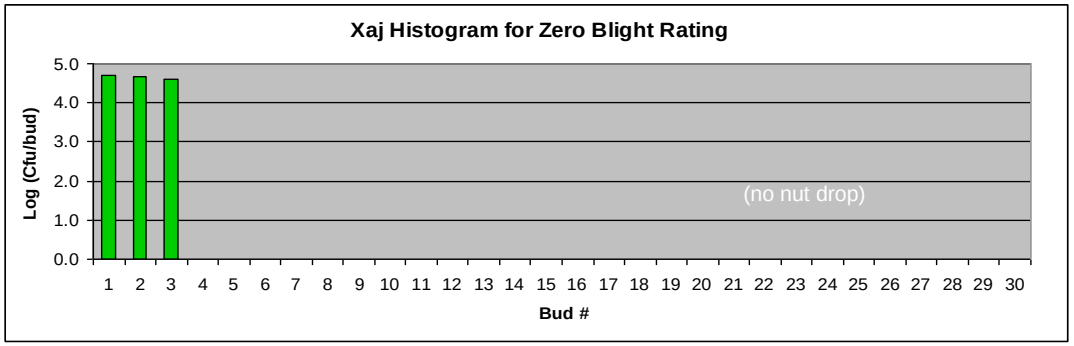
[2]BadgeX2 @ 4 lbs/ac, ProStick @ 2.4 lbs/ac, R-11 @ 12 oz/ac

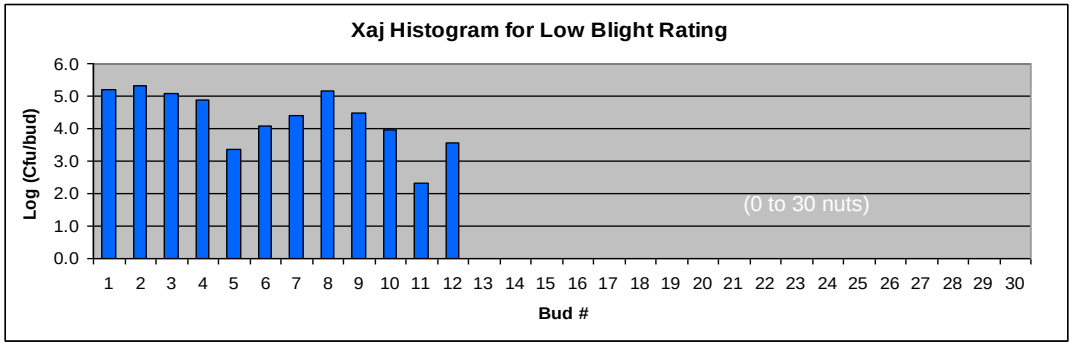
[3]BadgeX2 @ 6 lbs/ac, ProStick @ 2.4 lbs/ac, Syl-Coat @ 4.8 oz/ac

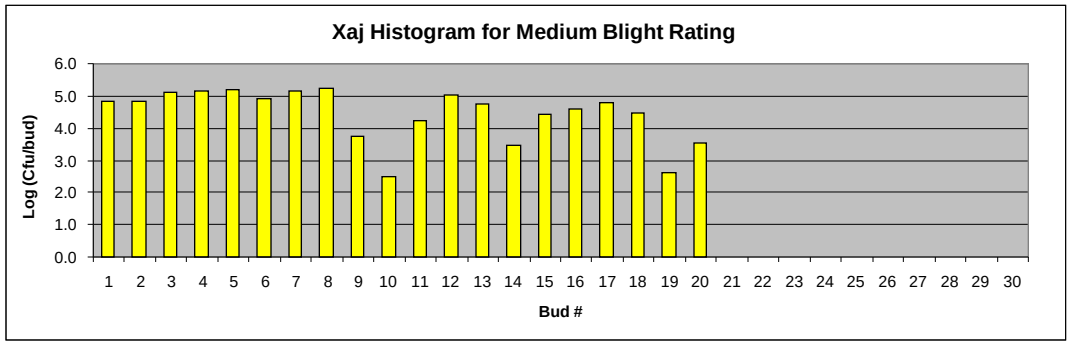
[4]BadgeX2 @ 4 lbs/ac, ProStick @ 2.4 lbs/ac, Syl-Coat @ 3.2 oz/ac

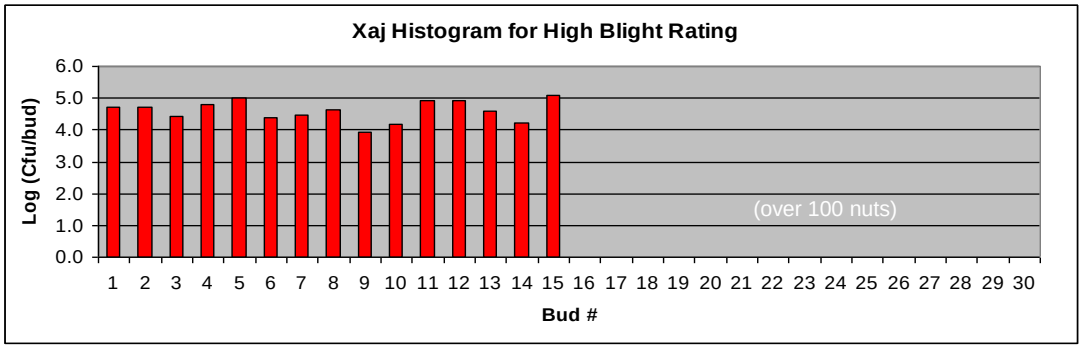
# 2012 Vina

| Tree # | Rating | Tree # | Rating |
|---|---|---|---|
| 69 | L | 34 | M |
| 68 | M | 33 | L |
| 67 | L | 32 | L |
| 66 | L | 31 | M |
| 65 | M | 30 | M |
| 64 | L | 29 | L |
| 63 | H | 28 | L |
| 62 | H | 27 | L |
| 61 | H | 26 | L |
| 60 | H | 25 | Replant |
| 59 | H | 24 | L |
| 58 | H | 23 | M |
| 57 | H | 22 | L |
| 56 | H | 21 | L |
| 55 | M | 20 | 0 |
| 54 | M | 19 | L |
| 53 | L | 18 | L |
| 52 | L | 17 | L |
| 51 | M | 16 | Replant |
| 50 | 0 | 15 | 0 |
| 49 | M | 14 | 0 |
| 48 | L | 13 | 0 |
| 47 | M | 12 | L |
| 46 | M | 11 | 0 |
| 45 | M | 10 | L |
| 44 | L | 9 | 0 |
| 43 | M | 8 | 0 |
| 42 | H | 7 | 0 |
| 41 | Replant | 6 | 0 |
| 40 | L | 5 | L |
| 39 | 0 | 4 | L |
| 38 | M | 3 | Replant |
| 37 | L | 2 | 0 |
| 36 | L | 1 | 0 |
| 35 | L | | |



| Tree # | 2012 Rating | 2013 Rating | Blighted Walnuts 6/21/13 |
|---|---|---|---|
| 69 | L | L | 13 |
| 68 | M | M | 57 |
| 67 | L | M | 63 |
| 66 | L | M | 100 |
| 65 | M | H | 104 |
| 64 | L | M | 39 |
| 63 | H | M | 63 |
| 62 | H | H | 119 |
| 61 | H | H | 146 |
| 60 | H | H | 132 |
| 59 | H | H | 199 |
| 58 | H | M | 96 |
| 57 | H | H | 142 |
| 56 | H | H | 121 |
| 55 | M | H | 147 |
| 54 | M | H | 239 |
| 53 | L | L | 21 |
| 52 | L | Replant | Replant |
| 51 | M | H | 204 |
| 50 | 0 | L | 8 |
| 49 | M | M | 47 |
| 48 | L | M | 31 |
| 47 | M | M | 64 |
| 46 | M | M | 42 |
| 45 | M | L | 22 |
| 44 | L | M | 39 |
| 43 | M | M | 65 |
| 42 | H | M | 92 |
| 41 | Replant | Replant | Replant |
| 40 | L | L | 9 |
| 39 | 0 | L | 7 |
| 38 | M | H | 108 |
| 37 | L | M | 59 |
| 36 | L | L | 16 |
| 35 | L | M | 88 |
| 34 | M | M | 70 |
| 33 | L | M | 41 |
| 32 | L | M | 86 |
| 31 | M | M | 61 |
| 30 | M | M | 50 |
| 29 | L | L | 14 |
| 28 | L | M | 37 |
| 27 | L | L | 25 |
| 26 | L | L | 24 |
| 25 | Replant | Replant | Replant |
| 24 | L | M | 78 |
| 23 | M | H | 123 |
| 22 | L | H | 122 |
| 21 | L | M | 60 |
| 20 | 0 | L | 3 |
| 19 | L | M | 58 |
| 18 | L | L | 15 |
| 17 | L | L | 9 |
| 16 | Replant | Replant | Replant |
| 15 | 0 | L | 14 |
| 14 | 0 | L | 10 |
| 13 | 0 | L | 2 |
| 12 | L | L | 10 |
| 11 | 0 | L | 3 |
| 10 | L | L | 5 |
| 9 | 0 | L | 4 |
| 8 | 0 | L | 5 |
| 7 | 0 | L | 4 |
| 6 | 0 | L | 5 |
| 5 | L | 0 | 0 |
| 4 | L | L | 3 |
| 3 | Replant | Replant | Replant |
| 2 | 0 | L | 12 |
| 1 | 0 | L | 1 |

# Tree-to-tree heterogeneity remained in 2013

**Blight data - 7/13/2012**

**Walnuts were visually rated on the ground under each tree.**

| | Total | Tree Total | % |
|---|---|---|---|
| 0 = No dropped nuts | 13 | 65 | 20.00% |
| L = Less than 30 dropped nuts | 28 | 65 | 43.08% |
| M = 30 - 100 dropped nuts | 15 | 65 | 23.08% |
| H = Over 100 dropped nuts | 9 | 65 | 13.85% |
| Replants | 4 | | |

**Blight data - 6/21/2013**

**Walnuts were counted on the ground under each tree.**

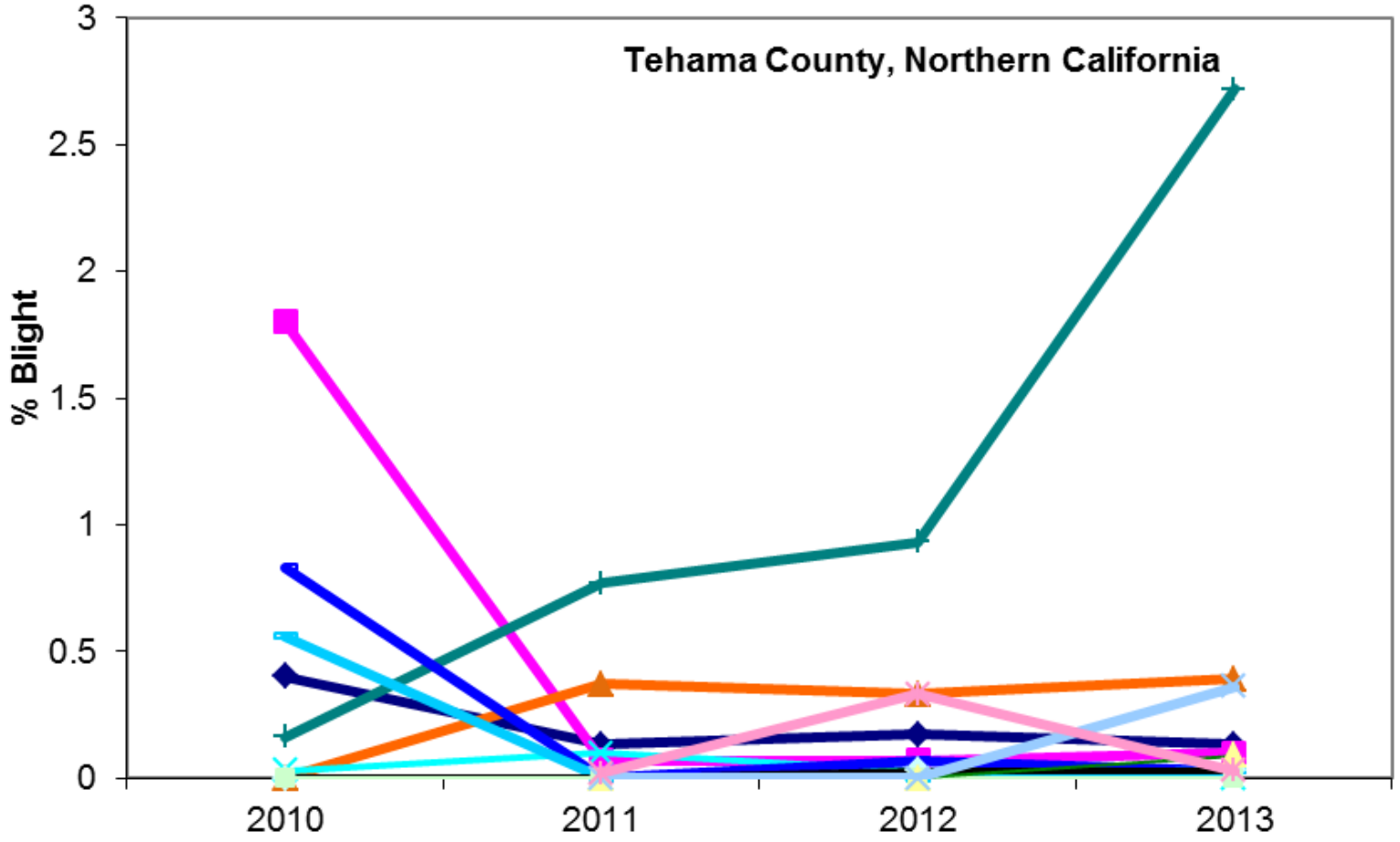
| | Total | Tree Total | % |
|---|---|---|---|
| 0 = No dropped nuts | 1 | 64 | 1.56% |
| L = Less than 30 dropped nuts | 26 | 64 | 40.63% |
| M = 30 - 100 dropped nuts | 24 | 64 | 37.50% |
| H = Over 100 dropped nuts | 13 | 64 | 20.31% |
| Replants | 5 | | |

Walnut blight transect for a Vina orchard in Tehama County. Blight drop under each tree was visually rated 7/13/2012. “0” represents no blighted walnuts on the ground. “L” is less than 30 dropped walnuts. “M” represents 30 to 100 dropped walnuts. “H” indicates more than 100 dropped walnuts per tree. For 2013, the actual number of blighted walnuts per tree were counted 6/21/13.

# Good disease control in Tehama county orchards with low pathogen

| Orchard | % Buds with Pathogen | | | 2013 Spray Mix 8lbs. Nu-Cop 50DF, 2.4 lbs. Manzate Pro-stick, 4 oz. Sylcoat, 1 lb. Zinc Sulfate | 2013 Spray Mix 6 lbs. Nu-Cop 50DF, 2.4 lbs. Manzate Pro-stick, 4 oz. Sylcoat, 5 lbs. Potassium Nitrate | 2013 % Blight |
|---|---|---|---|---|---|---|
| | 2011 | 2012 | 2013 | | | |
| 1) Howard | 13 | 6 | 20 | 4/1, 4/6, 4/11 | 4/18, 5/3, 5/9 | .13 |
| 2) Howard | 70 | 10 | 13 | 4/1, 4/6, 4/11 | 4/18, 5/3, 5/9 | .10 |
| 3) Chandler | 20 | 30 | 30 | 4/6, 4/11, 4/17 | 5/2, 5/8 | .39 |
| 4) Hartley | 3 | 0 | 0 | 4/2, 4/6, 4/10 | 4/17, 5/2, 5/9 | 0 |
| 5) Chandler | 3 | 10 | 0 | 4/7, 4/9, 4/17 | 4/30, 5/7 | 0 |
| 6) Howard | 10 | 10 | 0 | 4/3, 4/8, 4/15 | 5/1, 5/8 | 0 |
| 7) Chandler | 93 | 0 | 53 | 4/7, 4/11, 4/17 | 5/3, 5/9 | 2.7 |
| 8) Howard | 3 | 13 | 30 | 4/2, 4/10, 4/18 | 5/4, 5/11 | .03 |
| 9) Howard | 0 | 0 | 0 | 4/2, 4/10, 4/16 | 4/27, 5/8 | .03 |
| 10) Chandler | 0 | 0 | 0 | 4/2, 4/12 | 5/5*, 5/13* | .03 |
| 11) Chandler | 10 | 0 | 0 | 4/5, 4/10, 4/18 | 5/2*,5/9* | 0 |
| 12) Howard | 6 | – | 0 | 4/3, 4/7, 4/12 | 4/18, 5/2, 5/10 | .09 |
| 13) Chandler | 10 | – | 0 | 4/6, 4/12, 4/18 | 4/26*, 5/8* | .36 |
| 14) Chandler | 30 | – | 13 | 4/5, 4/12, 4/18 | 5/1*, 5/9* | .03 |

2013 walnut blight population survey information for fourteen orchards in Tehama County. The percent dormant buds with pathogen, 2013 spray program and the resulting blight damage are listed left to right. All sprays were half sprays (every other row alternating) by ground application. Spray dates followed by (*) included 14.5 oz. pristine with the blight spray. Dormant buds were collected 3/28/13 and blight was visually rated 6/7/13 by visually counting 3000 walnuts per orchard.

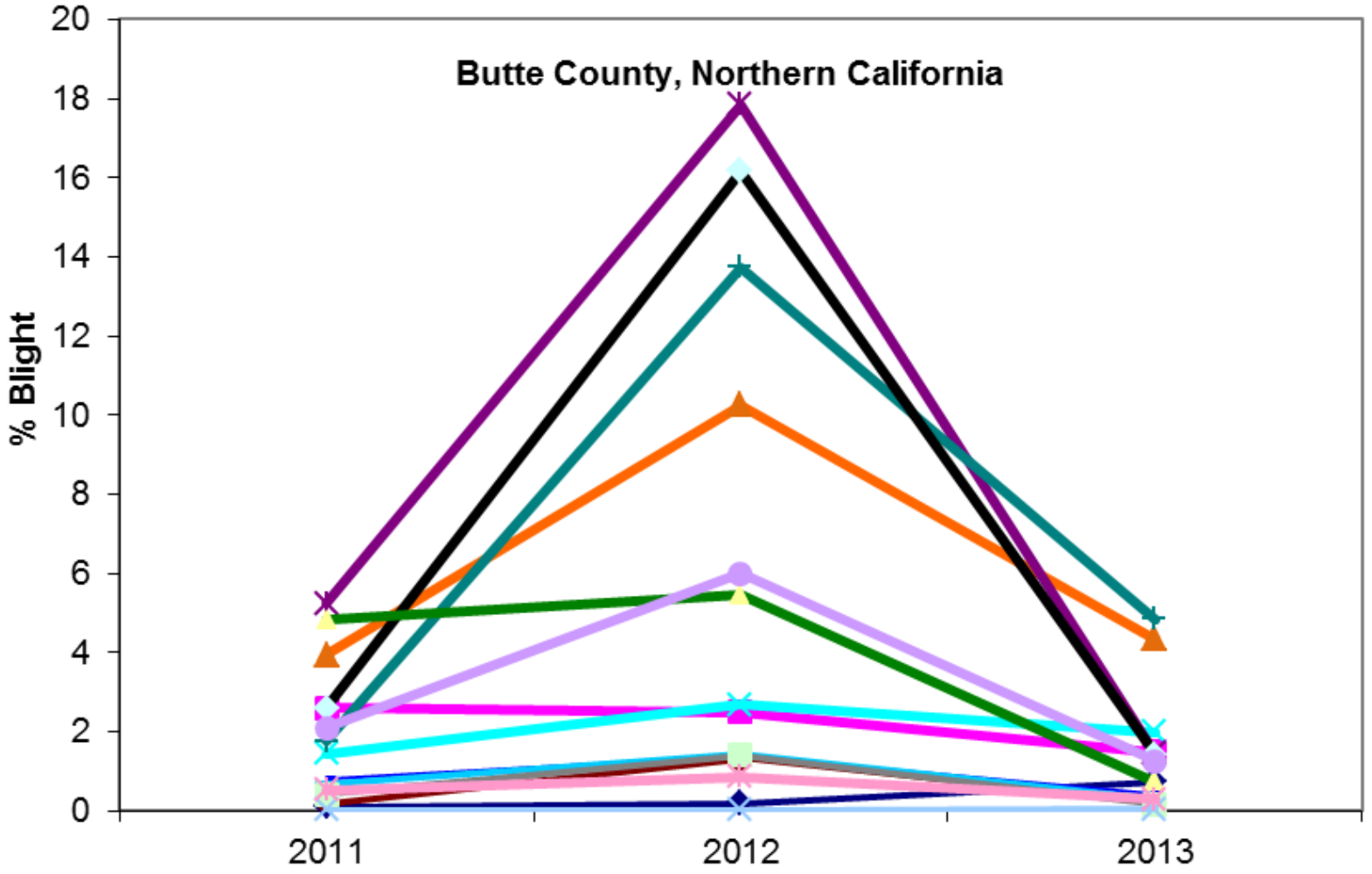



Walnut Blight damage for 14 walnut orchards in Tehama County from 2010 to 2013. Blight damage is increasing in one orchard with a history of high initial inoculum.

# Reasonable disease control in orchards with higher pathogen

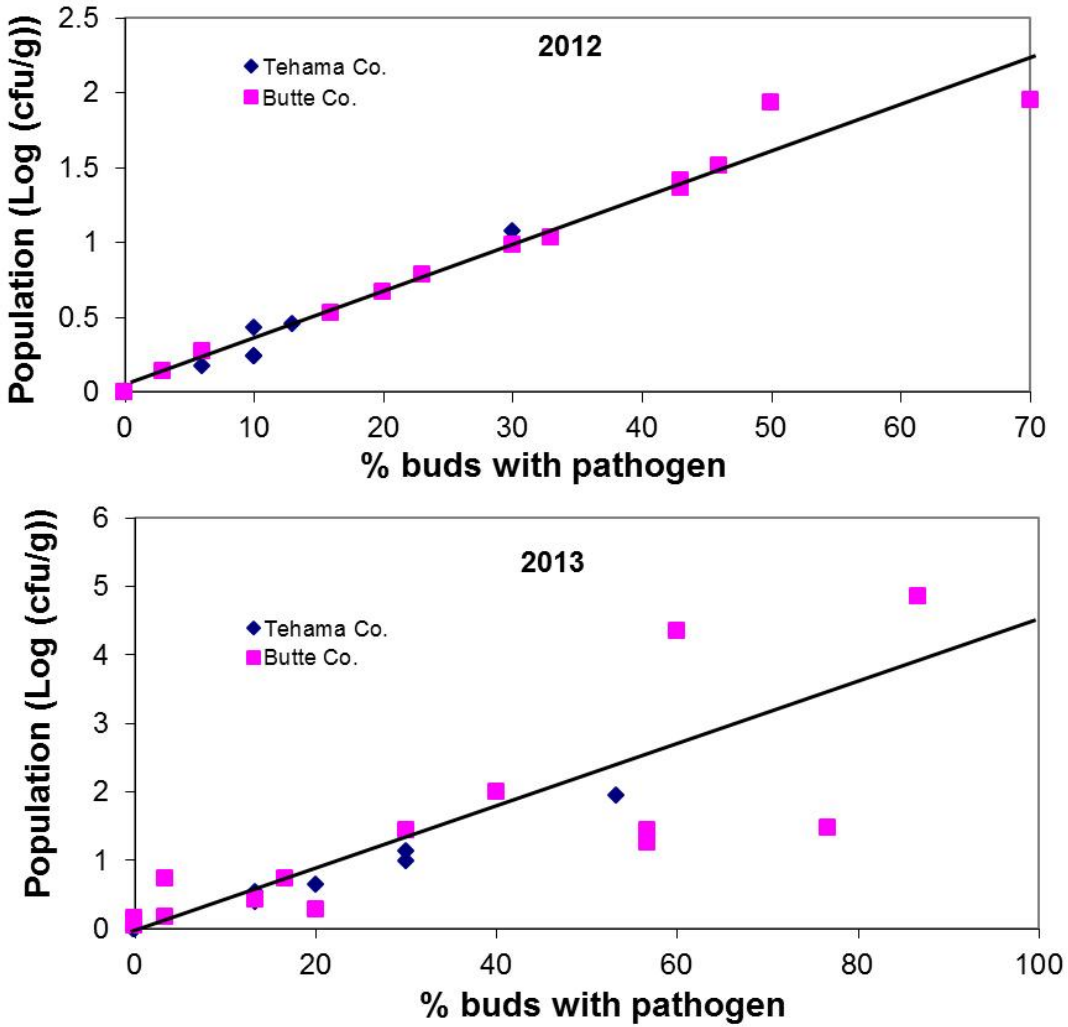
| Orchard | % Buds with Pathogen | | | 2013 Spray Schedule | | | | | | 2013 % Blight |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2012 | 2013 | | | | | | | |
| 1) Hartley | 16 | 0 | 16 | 4/5 – A N,M,S | 4/12 – G N,M,S,Z,L | 5/9 – G N,M,S,Z | | | | .73 |
| 2) Chandler | 0 | 46 | 76 | 4/2 – GH N,M,S,Z,L | 4/10 – GH N,M,S,Z,L | 4/19 – GH N,M,S,Z,L | 5/6 – A N,M,S,Z,H | | | 1.48 |
| 3) Chandler | 73 | 43 | 60 | 4/3 – GH N,M,S,Z,L | 4/11 – GH N,M,S,Z,L | 4/18 – GH N,M,S,Z,L | 5/7 – A N,M,S,Z,H | 5/24 – G N,M,S | | 4.35 |
| 4) Chandler | 56 | 33 | 40 | 4/1 – GH N,M,S,Z,L | 4/6 – GH N,M,S,Z,L | 4/15 – GH N,M,S,Z,L | 5/8 – G N,M,S,Z | | | 1.99 |
| 5) Ashley | 0 | 70 | 30 | 3/19 – GH N,M,S,Z,L | 3/25 – GH N,M,S,Z,L | 4/1 – G N,M,S,Z,L | 4/9 – G N,M,S,Z,L | 4/20 – A N,M,S,PC | 5/8 – G N,M,S,Z | 1.44 |
| 6) Howard | 20 | 16 | 3 | 3/27 – GH N,M,S,Z,L | 4/4 – GH N,M,S,Z,L | 4/12 – GH N,M,S,Z,L | 4/17 – GH N,M,S,Z,L | 5/6 – GH N,M,S,Z,H | 5/13 – GH N,M,S,Z | .17 |
| 7) Chandler | 46 | 30 | 86 | 4/5 – A N,M,S | 4/11 – GH N,M,S,Z,L | 4/20 – GH N,M,S,Z,L | 5/7 – A N,M,S,Z,H | 5/25 – G N,M,S | | 4.85 |
| 8) Howard | 40 | 6 | 13 | 3/26 – GH N,M,S,Z,L | 4/3 – GH N,M,S,Z,L | 4/10 – GH N,M,S,Z,L | 4/19 – GH N,M,S,Z,L | 5/6 – G N,M,S,Z,L | | .43 |
| 9) Howard | 16 | — | — | 3/27 – GH N,M,S,Z,L | 4/4 – GH N,M,S,Z,L | 4/12 – GH N,M,S,Z,L | 4/18 – GH N,M,S,Z,L | 5/4 – G N,M,S,Z,H | | .29 |
| 10) Vina | 60 | 43 | 56 | 3/25 – GH N,M,S,Z,L | 4/2 – GH N,M,S,Z,L | 4/10 – G N,M,S,Z,L | 4/21 – A N,M,S,PC | 5/8 – G N,M,Z,S | | 1..43 |
| 11) Howard | 53 | 20 | 0 | 3/25 – GH N,M,S,Z,L | 4/1 – GH N,M,S,Z,L | 4/6 – GH N,M,S,Z,L | 4/15 – GH N,M,S,Z,L | 5/7 – G N,M,S,Z,L | 5/24 – G N,M,S | .16 |
| 12) Howard | 40 | 23 | 3 | 3/25 –GH N,M,S,Z,L | 4/1 – GH N,M,S,Z,L | 4/6 – GH N,M,S,Z,L | 4/15 – GH N,M,S,Z,L | 5/7 – G N,M,S,Z,L | 5/24 – G N,M,S | .74 |
| 13) Tulare | 0 | 0 | 0 | 3/27 – GH N,M,S,Z,L | 4/3 – GH N,M,S,Z,L | 4/13 – GH N,M,S,Z,L | 4/20 – GH N,M,S,Z,L | 5/10 – G N,M,S,Z | | .05 |
| 14) Vina | 3 | 3 | 20 | 3/26 – GH N,M,S,Z,L | 4/2 – GH N,M,S,Z,L | 4/10 – GH N,M,S,Z,L | 4/19 – GH N,M,S,Z,L | 5/13 – G N,M,S,Z | | .29 |
| 15) Chandler | 83 | 50 | 56 | 4/1 – GH N,M,S,Z,L | 4/5 – GH N,M,S,Z,L | 4/15 – GH N,M,S,Z,L | 5/7 – A N,M,S,Z | 5/24 – G B,M,S | | 1.25 |

Improved spray programs plus a low disease pressure year resulted in much better disease control in 2013



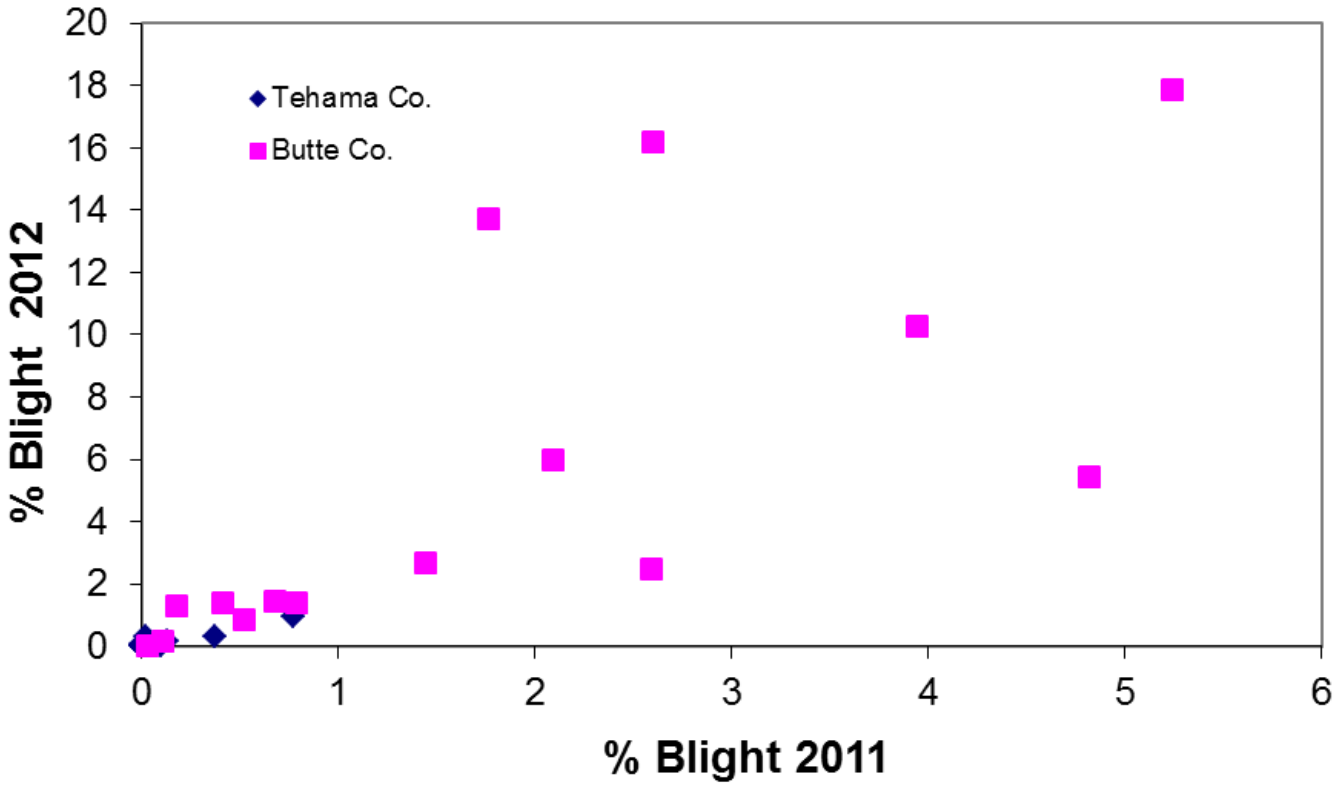

Walnut Blight damage for 15 walnut orchards in Butte County from 2011 to 2013.

# Disease prediction can be made based on more easily measured incidence of infestation rather than average population size



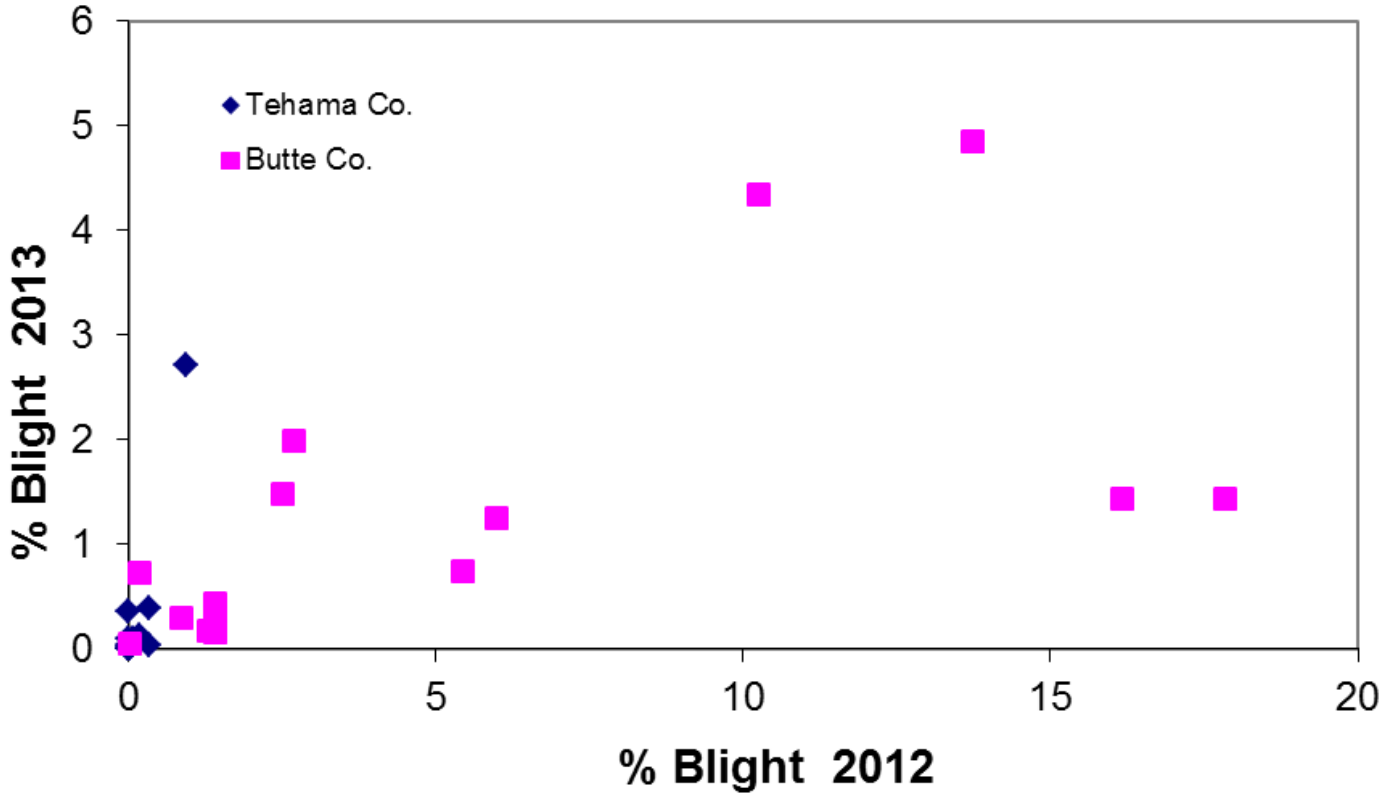

Relationship of % buds with pathogen and the associated bud population. Very strong correlation of incidence of bud infestation with average population size of pathogen –The lines drawn represent the linear regressions Y=0.0308X + 0.055 ($R^2$=0.967) (2012); and Y=0.0398x + 0.067 ($R^2$=0.626) (2013).

The incidence of blight in one year is somewhat predictive of disease incidence in the following year when considered over many orchards.



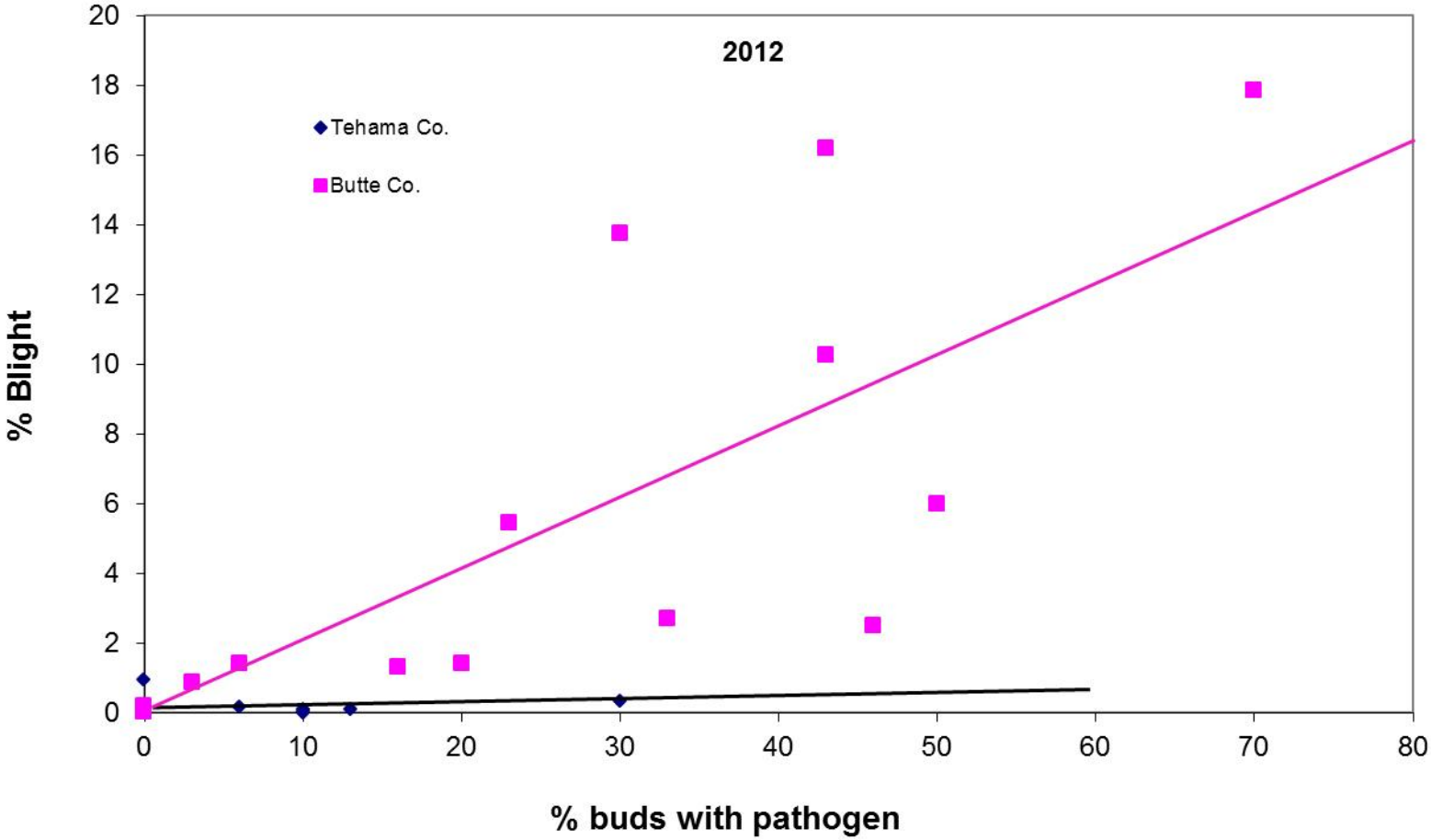

Relationship of previous year percent blight damage to current year blight damage for 2011 and 2012.

The incidence of blight in one year is somewhat predictive of disease incidence in the following year when considered over many orchards.



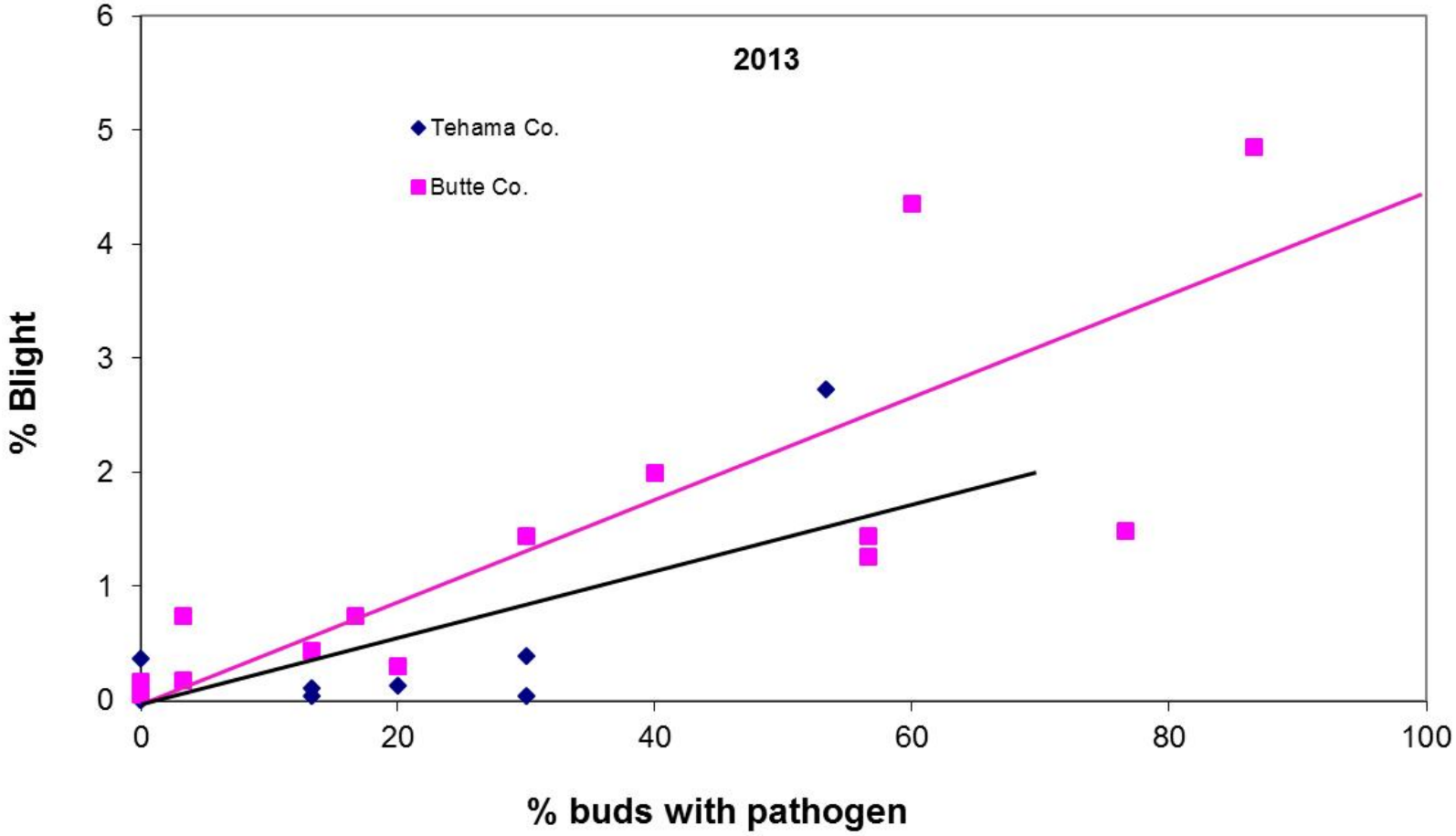

Relationship of previous year percent blight damage to current year blight damage for 2012 and 2013. The incidence of blight in one year is somewhat predictive of disease incidence in the following year when considered over many orchards.

# Strongest predictions of disease based on pathogen abundance




Relationship between the percent of buds infested with pathogen and the incidence of walnut blight damage for 30 orchards in Butte and Tehama counties in 2012. The lines drawn represent the linear regression Y=0.218x – 0.28 ($R^2$=0.56); and Y=0.001x + 0.14 ($R^2$=0.001) for orchards in Butte and Tehama counties, respectively.

# Strongest predictions of disease based on pathogen abundance

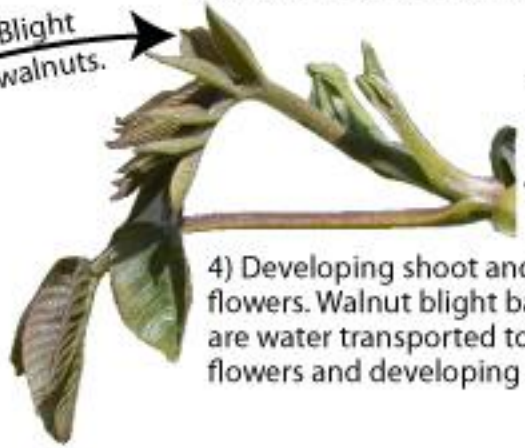



Relationship between the percent of buds infested with pathogen and the incidence of walnut blight damage for 30 orchards in Butte and Tehama counties in 2013. The lines drawn represent the linear regressions Y=0.039x + 0.067 ($R^2$=0.626); and Y=0.032x – 0.096 ($R^2$=0.58) for orchards in Butte and Tehama counties, respectively.

# Disease Cycle for Walnut Blight caused by *Xanthomonas arboricola pv juglandis*

Richard P. Buchner and Steve E. Lindow

Bacteria splashed onto developing shoots and walnut flowers. Blight treatments protect green tissue, flowers and developing walnuts.



4) Developing shoot and walnut flowers. Walnut blight bacteria are water transported to walnut flowers and developing nuts.

Applied sprays protect developing walnuts.

Infection results in blighted walnuts.

3) Young shoots emerging through the cataphylls ("prayer stage"). Walnut blight bacteria are water transported from the outer bud scales to the newly emerging leaves.

5) Blighted walnut

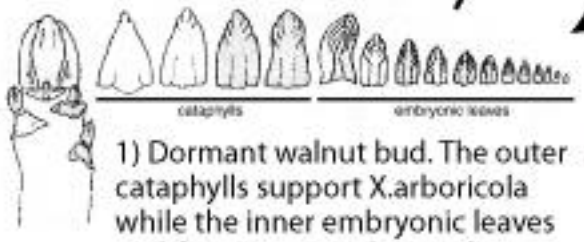
8) Healthy, non blighted walnut

2) Many but not all, buds swell and begin to open in the spring. X.arboricola reside in the outer bud scales "waiting" for transport to green tissue.

2b) Some buds remain closed and potentially harbor inoculum for subsequent years.

6) If frequent rains and favorable conditions exist, secondary inoculum can lead to additional crop damage and inoculum build up (poly cyclic phase)

9) Initial blight bacteria are the primary source of inoculum. With low inoculum, disease epidemics are less likely and protected walnuts remain disease free (mono cyclic phase).




1) Dormant walnut bud. The outer cataphylls support X.arboricola while the inner embryonic leaves and flowers are pathogen free.

7) Disease epidemics result in high bacterial populations in developing buds and subsequent high inoculum for the following year.

10) Low disease incidence results in low bacterial population in developing buds and subsequent low inoculum for the following year.