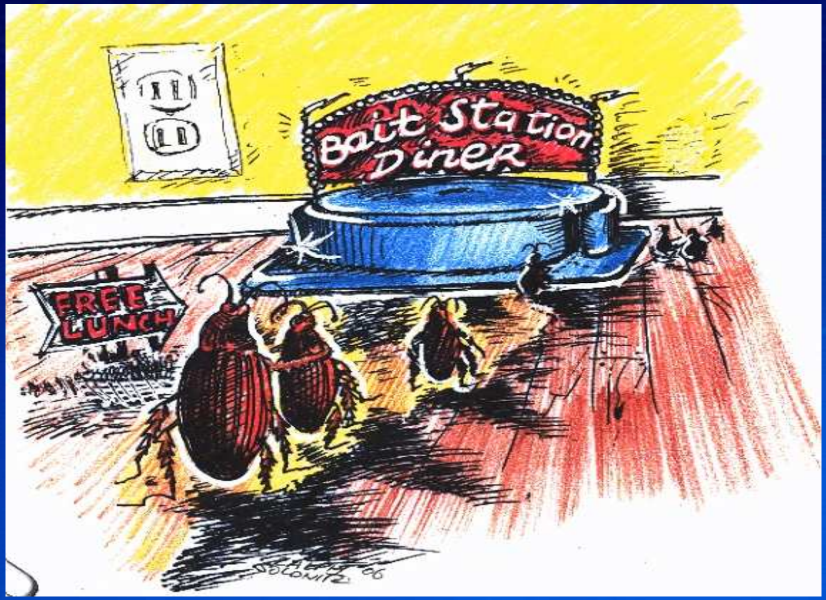
Scent of a Woman:

Application of Cockroach Pheromone as Bait



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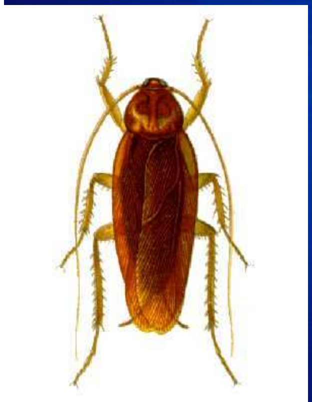
Objectives

- Investigate the feasibility of using the pheromone blattellaquinone to increase the effectiveness of roach bait products
  - Population model that describes how roaches proliferate in an environment to be targeted by roach bait
  - Necessities for industrial scale pheromone and gel synthesis
  - Utility functions that represent anticipated consumer satisfaction with a given product

The Roach Problem

- Roaches are a major source of home infestations.
  - The German cockroach (*Blattella germanica*) is the most abundant out of 4000 species
  - American cockroach (*Periplaneta americana*)
  - Asian cockroach (*Blattella asahinai*)



American Roach

1 inch long

Asian Roach

½-5/8 inch long

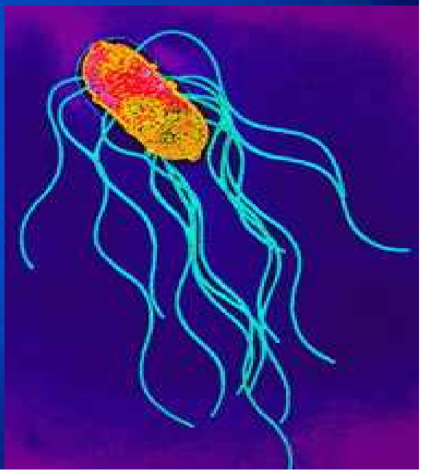
German Roach

½-5/8 inch long

The Roach Problem

- Roaches feast on garbage, feces
  - Carry at least 100 species of bacteria
    - *Salmonella, E. coli, Shigella*, etc.
  - Carrier of house dust mites
    - Powerful allergen

House dust mite



Salmonella bacterium

Why won't they just die??

- Can go for a month without food and can hold its breath for 45 minutes
- Nocturnal creatures
- Have an amazing reproductive capacity
  - One cockroach can produce up to 300,000 roaches per year
  - From babies to adults in 3-4 months

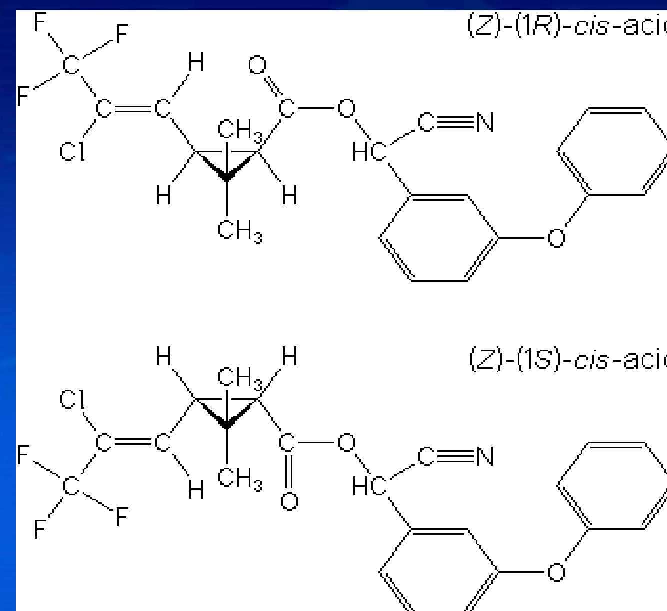
Methods of Extermination

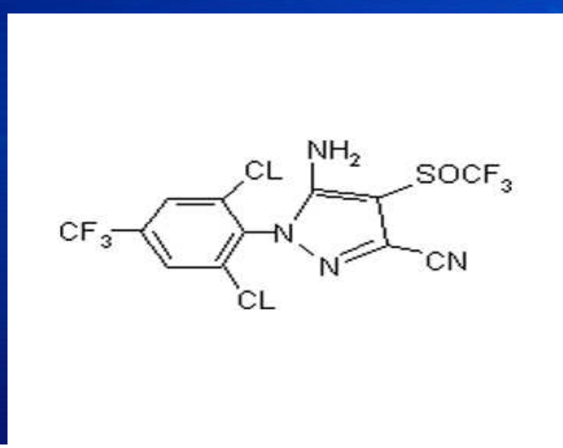
- Clean out
  - Residual Pesticides
  - Crack and Crevice work (C&C)
  - Foggers/Aerosols
- Roach Bait
  - Bait stations (indoor)
  - Bait gels (indoor)
  - Granular baits (outdoor)
  - Insect Growth Regulators (IGR)
  - Pheromone traps

Roach Poisons

Boric acid powder is applied to infested areas. The particles cling to the insects' legs and cause fatal chemical burns.

Pyrethroid nerve poisons are a common class of insecticides used to kill roaches.



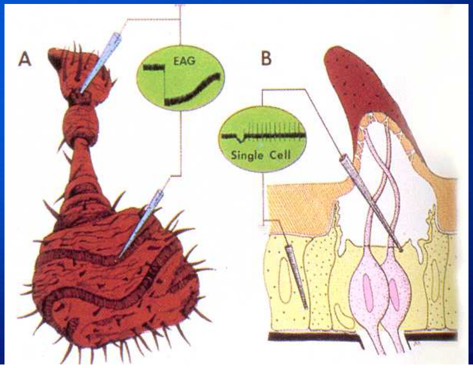


Fipronil is fatal after about 72 hours allowing the poison to spread throughout the roach population.

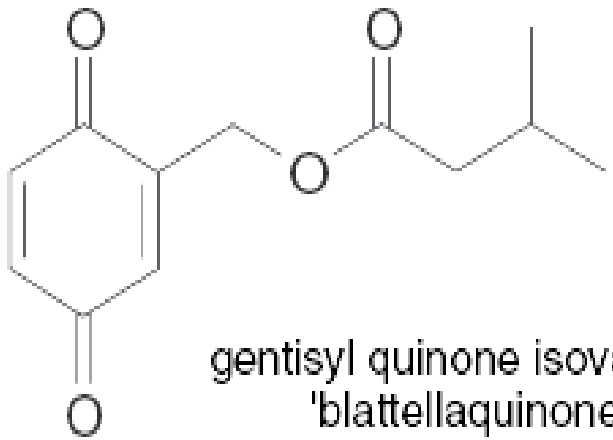
Isolation of New Pheromone

- Research project at Cornell University
  - Nojima, Schal, Webster, Santangelo, Roelofs
- German roach pheromone isolated using various techniques
  - Gas-chromatographic electroantennogram detector (GC-EAD)
  - Silica gel separation
  - NMR Characterization
  - High Performance liquid Chromatography (HPLC)
  - GC-mass spectrometry

Electroantennogram



Blattellaquinone



gentisyl quinone isovalerate
'blattellaquinone'

- Same as natural pheromone
  - Supported by NMR
- Roaches very responsive
  - Lab tested
    - 10-100ng attracted 60% of males in lab
  - Field tested
    - Roach-infested pig farm
    - 10-1000μg trapped 10-30 roaches per night
- Very promising as an attractant

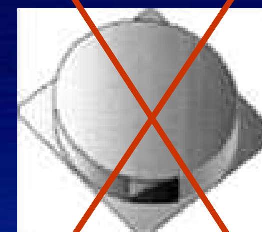
Roach Trap Market

- Competitors
  - Maxforce (Bait Stations, Bait Gels, Granular Baits)
  - Avert (Aerosol Bait)
  - Siege (Aerosol Bait)
  - Niban (Granular Bait)
  - Baygon (Granular Bait)
- Area of Focus
  - Southwest U.S.

Roach Trap Design

Aerosol forms don't get the roaches where they are hiding

Granular forms can't be eaten by the roach nymphs



Bait stations have to be placed very carefully or they become a hazard to children and pets

Roach bait gels are the best option because they don't have any of the other methods' drawbacks

Roach Bait Gel

- Blattellaquinone
  - The sex pheromone will increase attraction to the bait among the males
- Traditional bait attractants
  - A traditional attractant (Maltose) is added to attract females and nymphs as well
- Fipronil
  - The bait is laced with this poison. Roaches are cannibalistic and consume their own excrement so the poison will spread.

Utility Functions

What makes you happy?....

Physical Properties

- Durability
  - How long before the roach problem returns?
  - Based on a population model.
- Speed
  - How long does it take to reduce or eliminate the infestation?
  - Based on a population model.
- Odor
  - How badly does it smell?
- Toxicity
  - Is it safe for pets and people?

Consumer Survey

The following survey regards your preferences for an off-the-shelf roach killer product. In other words, if you found out that you had a roach problem in your home and you wanted to fix it yourself instead of spending the extra money for a pest control service, what attributes would you be looking for? Please answer the following questions as honestly as possible. This survey is confidential.

1) **Rank the following categories from most important "1" to least important "4" in a roach removal product:**
    a. Durability (How long is it before the roach problem returns?)
    b. Speed (How long does it take to reduce or eliminate the infestation?)
    c. Odor (How badly does it smell?)
    d. Toxicity (Is it safe for pets and people?)

2) **How satisfied would you be if the product permanently killed all the roaches the first time you used it?**

1	2	3	4	5
(not satisfied)				(very satisfied)

3) **How satisfied would you be if the product killed enough roaches so that you didn't see them anymore, but you had to repeat the process every 3-6 months?**

1	2	3	4	5
(not satisfied)				(very satisfied)

4) **How satisfied would you be if the product killed enough roaches so that you didn't see them anymore, but they were back within a month?**

1	2	3	4	5
(not satisfied)				(very satisfied)

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5) **How satisfied would you be if the product eliminated your infestation in 24-48 hours?**

1	2	3	4	5
(not satisfied)				(very satisfied)

6) **How satisfied would you be if the product eliminated your infestation in 3-4 days?**

1	2	3	4	5
(not satisfied)				(very satisfied)

Beta Function

Beta Function: measures how much more the consumer will prefer the new product given equal prices.

$$\beta = \frac{S_2}{S_1}$$

S_1 is the % satisfaction for our product and S_2 is the % satisfaction for our main competitor's (Maxforce).

w_i is the weight of the parameter and y_i is the normalized un-weighted % satisfaction.

$$S_i = \sum w_i y_i$$

y_i values are obtained from the utility functions.

Survey Results

DURABILITY	Satisfaction Ratings per survey #									
	1	2	3	4	5	6	7	8	9	10	Average
Permanent roach death	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
3-6 month roach lull	60%	80%	60%	20%	60%	100%	60%	60%	100%	40%	64%
1 month roach reprieve	0%	0%	0%	0%	0%	80%	40%	40%	40%	20%	22%

SPEED	Satisfaction Ratings per survey #										
	1	2	3	4	5	6	7	8	9	10	Average
24-48hr elimination	100%	100%	80%	80%	100%	100%	100%	100%	100%	80%	94%
3-4 day elimination	100%	40%	60%	60%	80%	80%	80%	80%	60%	60%	70%
5-7 day elimination	80%	0%	40%	40%	60%	40%	40%	60%	40%	40%	44%
1-2 week elimination	60%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%

ODOR	Satisfaction Ratings per survey #										
	1	2	3	4	5	6	7	8	9	10	Average
slight odor	40%	50%	80%	50%	50%	40%	50%	80%	50%	50%	54%
odorless	100%	100%	100%	100%	100%	80%	100%	100%	100%	90%	97%
moderate odor	20%	0%	30%	50%	30%	30%	30%	40%	30%	40%	30%
overpowering stench	0%	0%	0%	40%	0%	20%	0%	20%	0%	20%	10%
pleasant fragrance	40%	40%	90%	100%	60%	100%	90%	60%	70%	50%	70%

TOXICITY	Satisfaction Ratings per survey #										
	1	2	3	4	5	6	7	8	9	10	Average
slightly toxic	60%	0%	60%	0%	20%	100%	40%	40%	80%	20%	42%
moderately toxic	40%	0%	40%	0%	0%	40%	20%	20%	40%	0%	20%
extremely toxic	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%
non-toxic	80%	80%	80%	80%	80%	100%	100%	100%	100%	100%	90%

Weights

- Indicate how important each attribute is to the consumers.

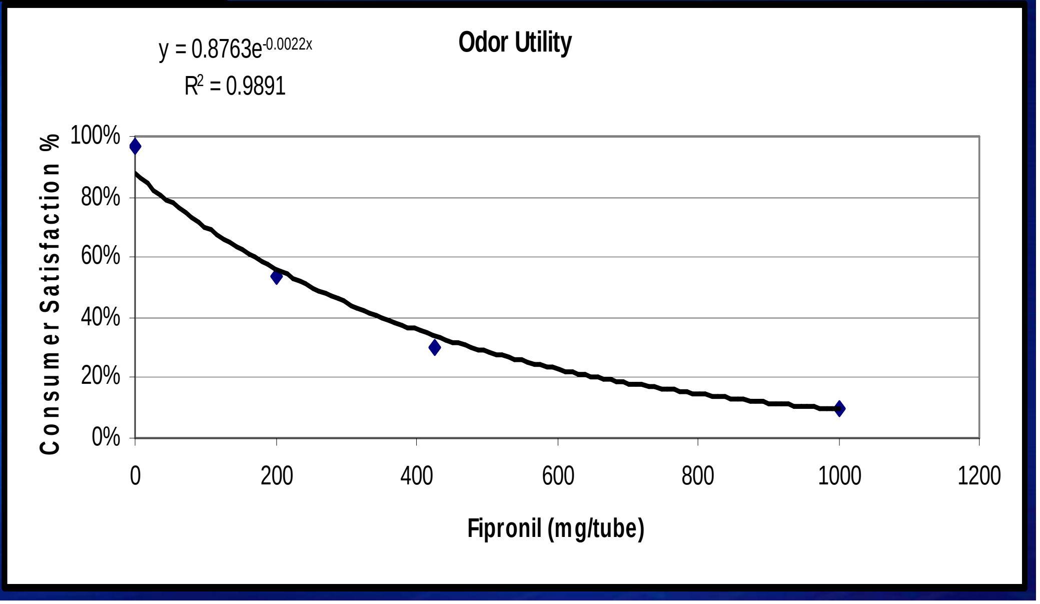
$$S_i = \sum w_i y_i$$

	1	2	3	4	5	6	7	8	9	10	Average weight
Durability	40%	10%	40%	20%	20%	10%	10%	10%	20%	10%	19%
Speed	20%	30%	30%	30%	30%	40%	40%	40%	30%	40%	33%
Odor	10%	20%	10%	10%	10%	30%	30%	20%	10%	20%	17%
Toxicity	30%	40%	20%	40%	40%	20%	20%	30%	40%	30%	31%

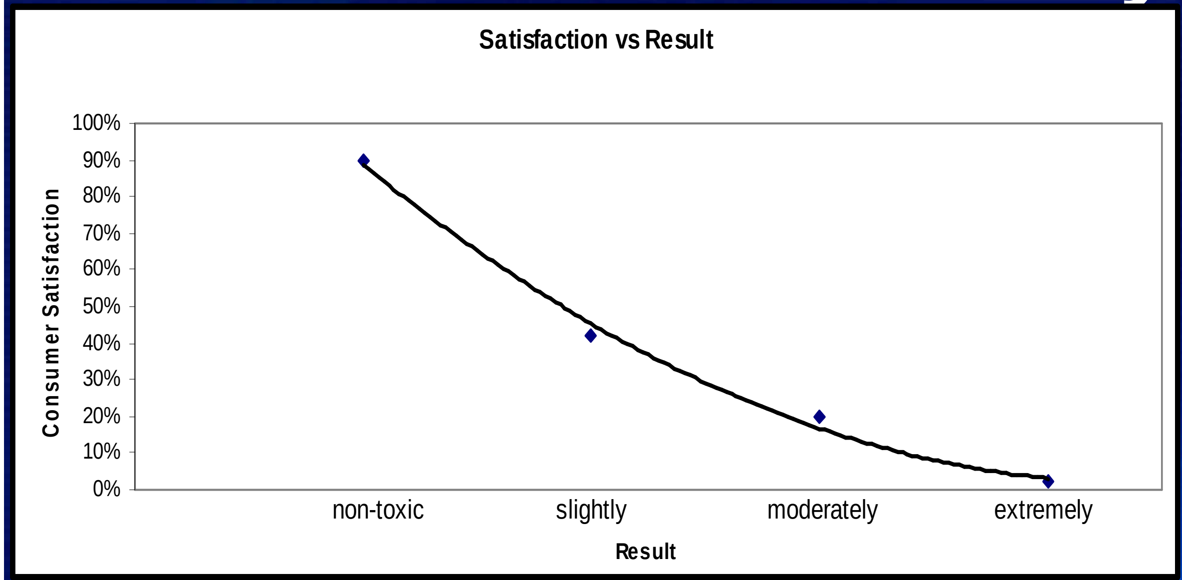
Consumers felt that speed and toxicity were the two most important aspects of the product.

Odor

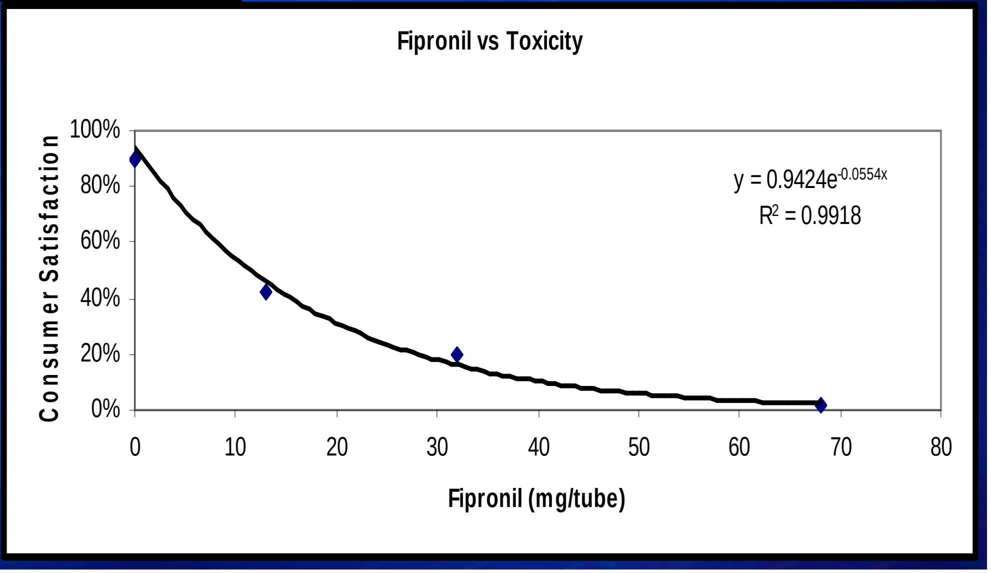
POISON	Fipronil (mg/tube)	Avg. Satisfaction
slight odor	100	54%
odorless	0	97%
moderate odor	300	30%
overpowering stench	1000	10%



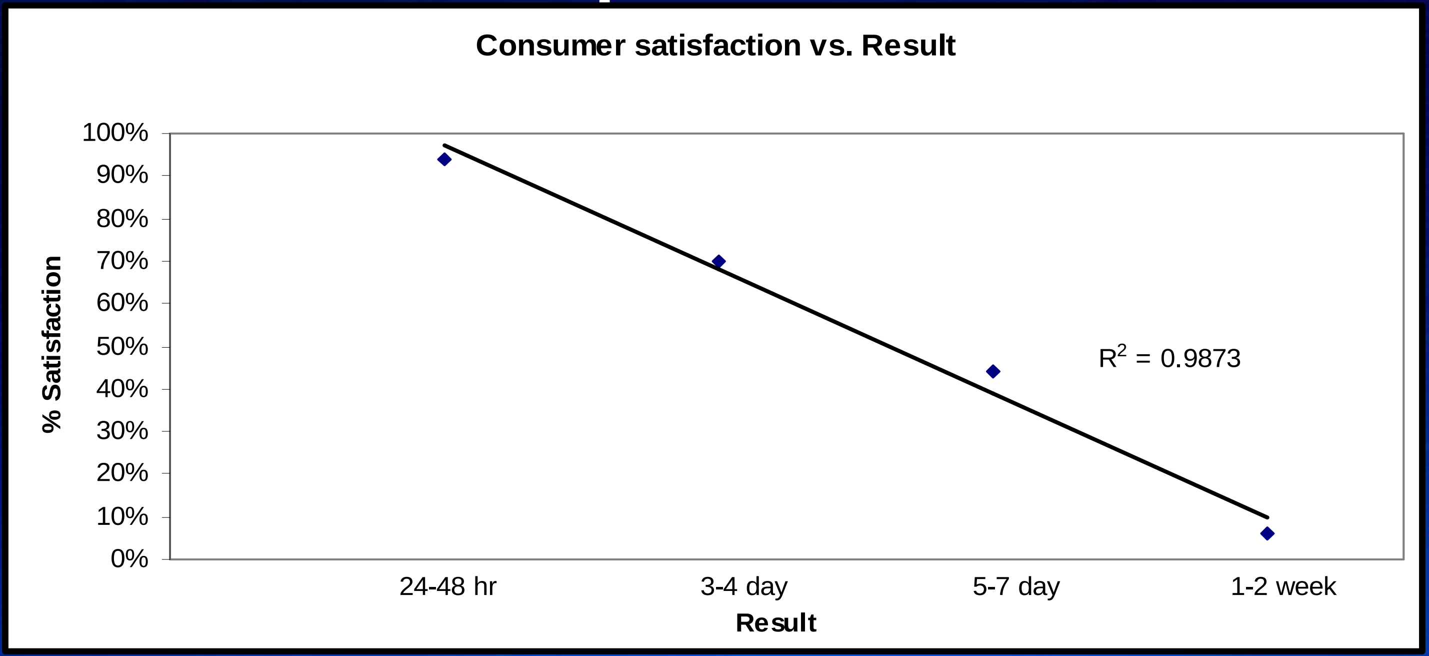
Toxicity



POISON	Fipronil (mg/tube)	Avg. Satisfaction
slightly toxic	11.34	42%
moderately toxic	34	20%
extremely toxic	68	2%
non-toxic	0	90%

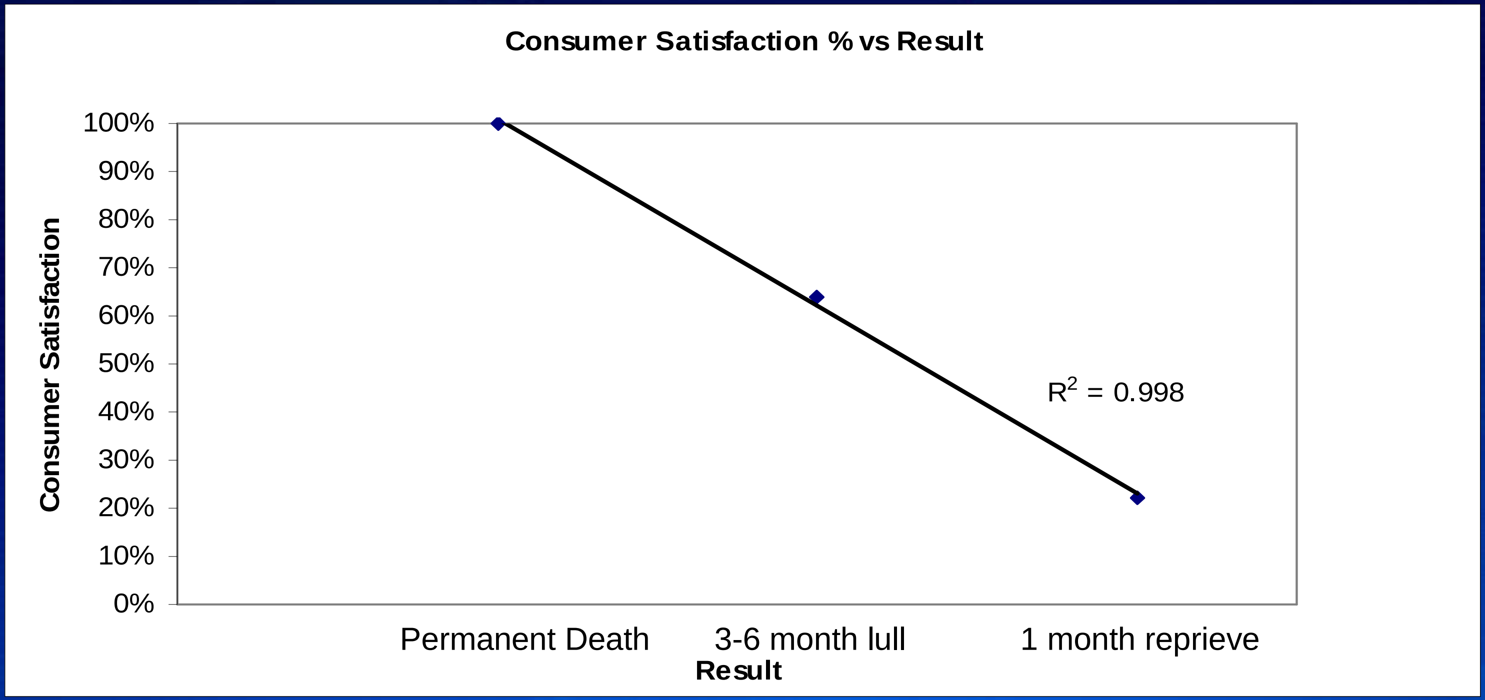


Speed



- Depends on:
  - Maltose
  - Fipronil
  - Blattellaquinone

Durability



- Depends on:
  - Maltose
  - Fipronil
  - Blattellaquinone

Population Model

Population Model

- Need a model to represent a cockroach infestation
- Observe the effects of product composition on population
  - Pheromone, maltose, fipronil
- Determine amounts of each to eliminate population

Population Model

- Basic Equation

$$\frac{dN_t}{dt} = \{Birth\ Rate\} - \{Death\ Rate\}$$

- When Death Rate > Birth Rate, population will die

Population Model

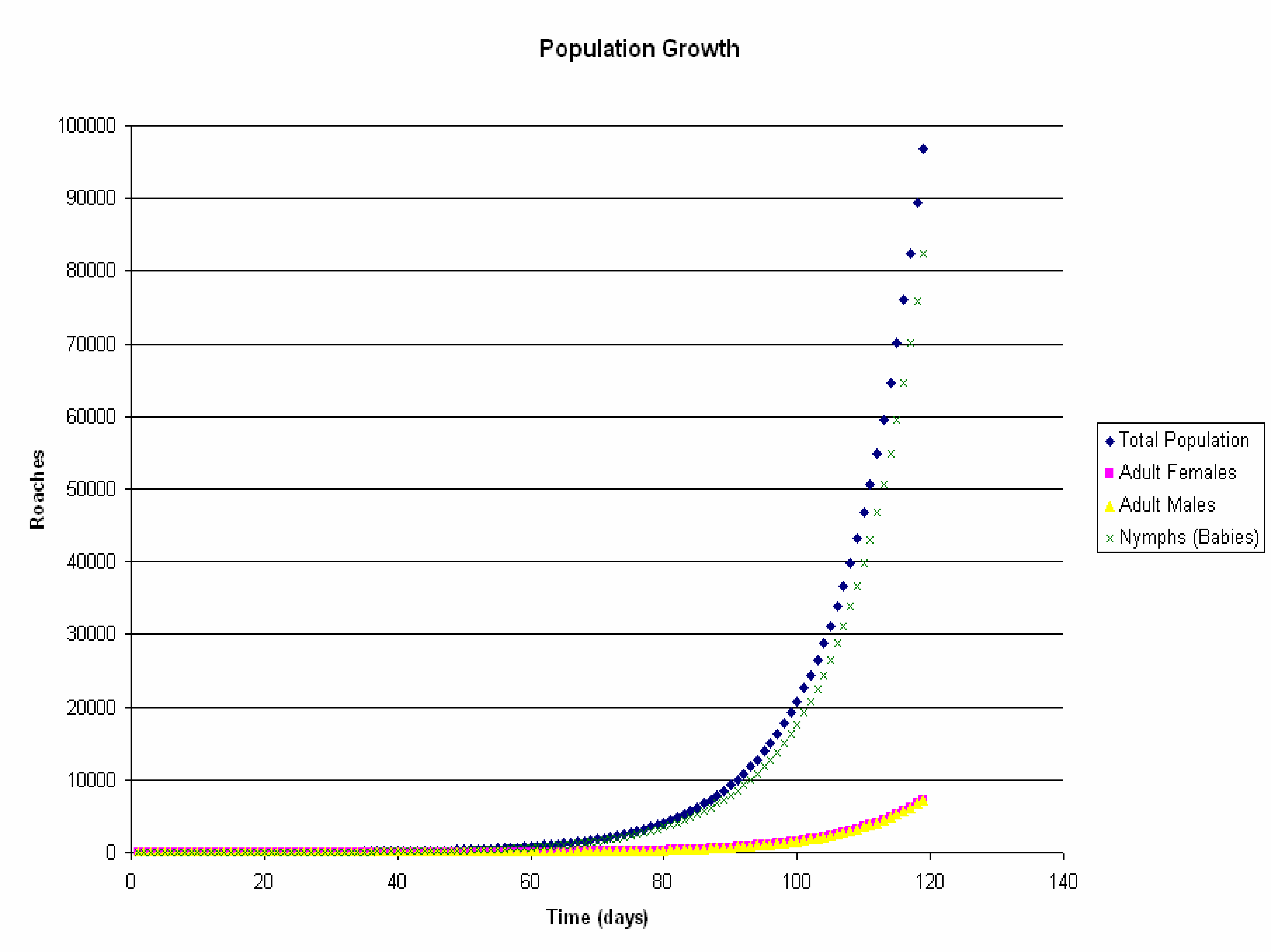
- Total Population
  - Adults: Males & Females
  - Nymphs (babies)
  - Three different growth equations

Population Model

$$\frac{dBabies}{dt} = (\#\,Females)\left(\frac{\#\,EggsLaid}{Female \cdot Time}\right)(SexRatio) - k_m\left(Babies\right)$$

$$\frac{dAdultMales}{dt} = \frac{k_m\left(Babies\right)}{2} - \left(NaturalDeathRate\right)\left(Males\right)$$

$$\frac{dAdultFemales}{dt} = \frac{k_m\left(Babies\right)}{2} - \left(NaturalDeathRate\right)\left(Females\right)$$



Population Growth
Roaches
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
20
40
60
80
100
120
140
Time (days)
Total Population
Adult Females
Adult Males
Nymphs (Babies)

Population Model

- Growth rate is uninhibited
  - Population goes to infinity
- Need to account for limited food, space

Population Model

$$\frac{d(AdultMales)}{dt} = \frac{km(Babies)}{2} - k_{naturaldeath}(AdultMales)$$

- $k_{\text{lack of food}}$ = rate of death due to starvation

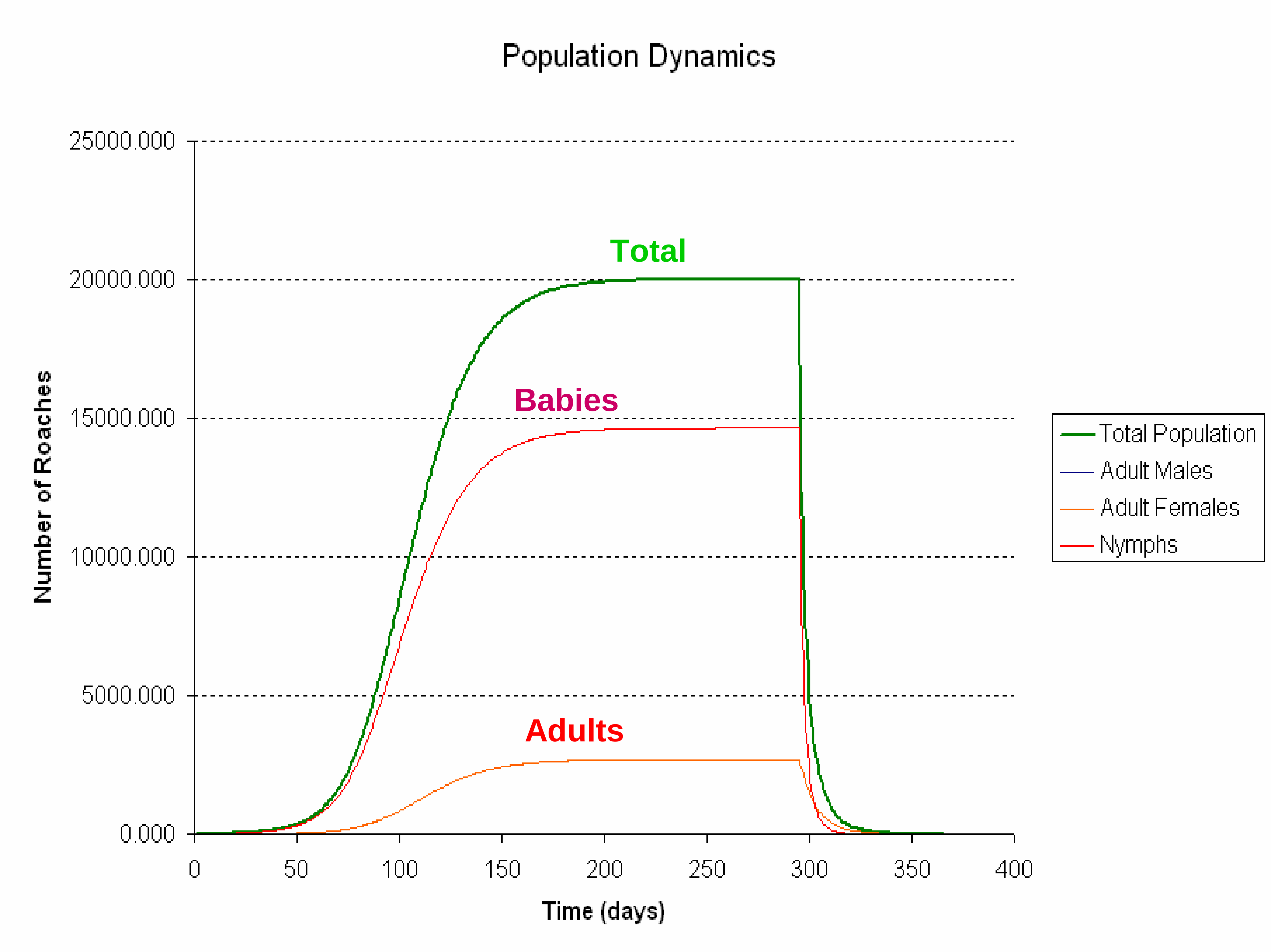
$$\frac{d(Food)}{dt} = -k_{consumptionrate} * (TotalRoaches)$$

- $k_{\text{crowding effects}}$ = rate of roaches leaving
  - Proportional to how much space is available

Population Model

- Apply each term to each roach type

- Assume:
  - Population distribution in eggs is equal
    - Half males, half females
  - Adults & Nymphs consume food equally
  - Cannibalism does not extend lifetime

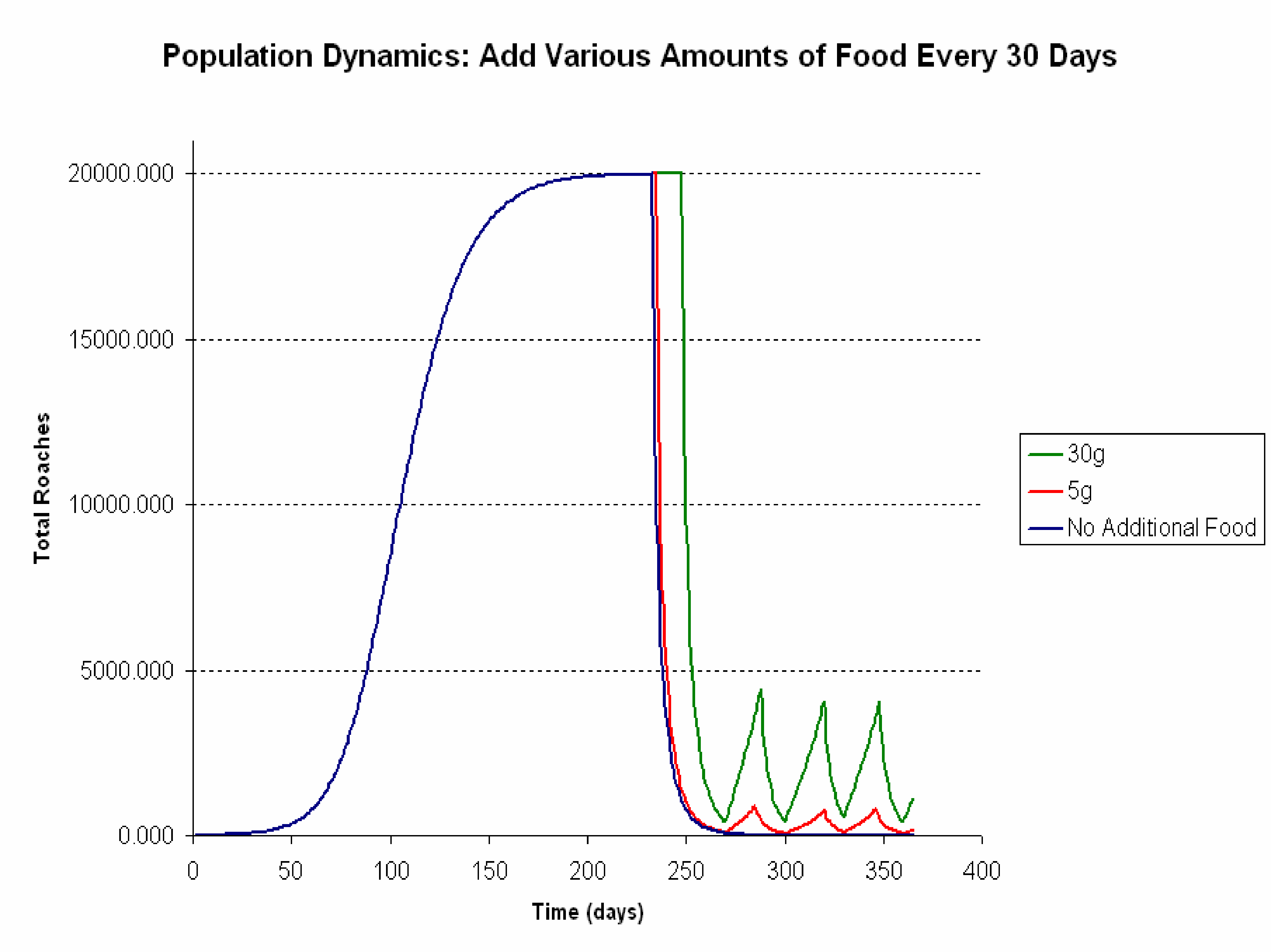


Population Dynamics
Total
Babies
Adults
Number of Roaches
Time (days)
25000.000
20000.000
15000.000
10000.000
5000.000
0.000
0
50
100
150
200
250
300
350
400
Total Population
Adult Males
Adult Females
Nymphs

Population Model

- Lets make things interesting…

Population Model	
Constants	
Maturation rate	0.016666667
Natural death rate	0.01
Birth rate	1.142857143
Roaches eat 'x' grams/day of Food	0.0008
Roaches contact 'y' grams/day of Bait	0.001
User Inputs	
Add poison on Day	1000
Initial Food Supply (grams)	2000
Add more food every 'x' days	30
How many grams of food to add?	0
Maximum Population	20000



Population Dynamics: Add Various Amounts of Food Every 30 Days
Total Roaches
20000.000
15000.000
10000.000
5000.000
0.000
0
50
100
150
200
250
300
350
400
Time (days)
30g
5g
No Additional Food

Population Model

- Incorporate gel bait into model
  - Attract roaches with pheromone, maltose
  - Kill roaches with fipronil

- Poison will also spread throughout colony
  - "Secondary Infection"

Population Model

NonInfected	Infected	Secondary Infected
Adult Males (NIM)	Adult Males (IM)	Adult Males (SIM)
Adult Females (NIF)	Adult Females (IF)	Adult Females (SIF)
Babies (NIB)	Babies (IB)	Babies (SIB)

Population Model

- Population change depends on 9 equations
  - Change in NIM, IM, SIM, NIF, IF, SIF, NIB, IB, SIB
- All roaches are attracted to food bait
- Only adult males attracted to pheromone

Non-Infected Roach Equations

$$\frac{d(NIM)}{dt} = \frac{km(NIB)}{2} - k_{naturaldeath}(NIM) - k_{lack\ of\ food} NIM - k_{crowding\,effects} NIM$$

$$- k_{pheromone} NIM - k_{maltose} NIM - k_{\sec} NIM \left(\frac{Infected_{Total}}{TotalRoaches} \right)$$

- $K_{pheromone}$ – proportional to blattellaquinone concentration
- $K_{maltose}$ – proportional to maltose concentration
- $K_{secondary}$ – proportional to # of infected roaches in colony

Population Model

$$\frac{d(NIF)}{dt} = \frac{km(NIB)}{2} - k_{naturaldeath}(NIF) - k_{lack\ of\ food}NIF - k_{crowdingeffects}NIF - k_{maltose}NIF - k_{\sec}NIF\left(\frac{Infected_{Total}}{TotalRoaches}\right)$$

$$\frac{d(NIB)}{dt} = k_{BirthRate}(NIF)(SexRatio) - km(NIB) - k_{lack\ of\ food}NIB - k_{crowdingeffects}NIB - k_{maltose}NIB - k_{\sec}NIB\left(\frac{Infected_{Total}}{TotalRoaches}\right)$$

Infected Roach Equations

$$\frac{dIM}{dt} = \left(k_{pher} NIM\right) + \left(k_{maltose} NIM\right) - \left(k_{fipronil} IM\right)$$

$$\frac{dIF}{dt} = \left(k_{maltose} NIF\right) - \left(k_{fipronil} IF\right)$$

$$\frac{dIB}{dt} = \left(k_{maltose} NIB\right) - \left(k_{fipronil} IB\right)$$

Secondary Infection Equations

$$\frac{dSIM}{dt} = k_{\sec}(NIM)\left(\frac{Infected_{Total}}{TotalRoaches}\right) - k_{fipronil,\sec}(SIM)$$

$$\frac{dSIF}{dt} = k_{\sec}(NIF)\left(\frac{Infected_{Total}}{TotalRoaches}\right) - k_{fipronil,\sec}(SIF)$$

$$\frac{dSIB}{dt} = k_{\sec}(NIB)\left(\frac{Infected_{Total}}{TotalRoaches}\right) - k_{fipronil,\sec}(SIB)$$

Population Model

Constants	
Maturation rate	0.016666667
Natural death rate	0.01
Birth rate	1.142857143
Roaches eat 'x' grams/day of Food	0.0008
Roaches contact 'y' grams/day of Bait	0
User Inputs	
Add poison on Day	1000
Initial Food Supply (grams)	3000
Add more food every 'x' days	10
How many grams of food to add?	0
Maximum Population	20000
Gel Tube Composition - User Inputs	
Total Gel (grams)	65
Blatellaquinone (μg)	0.0125
Fipronil (g) [max at .06]	0.06
Maltose	0
Carrageenan	64.93999999

Microsoft Excel - cockroach model_4_29_ vary pheromone.xls

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B23 =B19-(B20*0.000001)-B21-B22

	E	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
37		NonInfected				Infected				Secondary Infected				Totals		
38		Adults		Babies	Total	Adults		Babies	Total	Adults		Babies	Total			
39		Male	Female			Male	Female			Male	Female					
40	**Nt**	NIM	NIF	NIB	Total	IM	IF	IBM	It	SIM	SIF	SIB	St	Male	Female	Babies
41	**2.000**	1.000	1.000	0.000	2.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.00
42	**3.123**	0.990	0.990	1.143	3.123	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.990	0.990	1.14
43	**4.234**	0.990	0.990	2.255	4.234	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.990	0.990	2.25
44	**5.345**	0.998	0.998	3.349	5.345	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.998	0.998	3.34
45	**6.466**	1.016	1.016	4.434	6.466	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.016	1.016	4.43
46	**7.607**	1.043	1.043	5.521	7.607	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.043	1.043	5.52
47	**8.778**	1.079	1.079	6.621	8.778	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.079	1.079	6.62
48	**9.989**	1.123	1.123	7.743	9.989	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.123	1.123	7.74
49	**11.249**	1.176	1.176	8.896	11.249	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.176	1.176	8.89
50	**12.569**	1.239	1.239	10.092	12.569	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.239	1.239	10.09
51	**13.959**	1.310	1.310	11.338	13.959	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.310	1.310	11.33
52	**15.428**	1.392	1.392	12.645	15.428	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.392	1.392	12.64
53	**16.989**	1.483	1.483	14.022	16.989	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.483	1.483	14.02
54	**18.652**	1.585	1.585	15.481	18.652	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.585	1.585	15.48
55	**20.428**	1.698	1.698	17.032	20.428	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.698	1.698	17.03
56	**22.331**	1.823	1.823	18.685	22.331	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.823	1.823	18.68
57	**24.374**	1.961	1.961	20.453	24.374	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.961	1.961	20.45
58	**26.570**	2.111	2.111	22.347	26.570	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.111	2.111	22.34
59	**28.934**	2.276	2.276	24.381	28.934	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.276	2.276	24.38
60	**31.482**	2.457	2.457	26.569	31.482	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.457	2.457	26.56
61	**34.231**	2.654	2.654	28.924	34.231	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.654	2.654	28.92
62	**37.200**	2.868	2.868	31.464	37.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.868	2.868	31.46
63	**40.407**	3.101	3.101	34.204	40.407	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.101	3.101	34.20
64	**43.874**	3.355	3.355	37.163	43.874	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.355	3.355	37.16
65	**47.623**	3.631	3.631	40.360	47.623	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.631	3.631	40.36
66	**51.678**	3.931	3.931	43.816	51.678	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.931	3.931	43.81
67	**56.067**	4.257	4.257	47.553	56.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.257	4.257	47.55

Population Model / Population Model (2) / Population Model (3) / Main Chart / Population Model (4) / Chart4 / Pop Chart / Pop

Ready Max=20000

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Microsoft Excel - cockroach model_4_29_ vary pheromone.xls

B23 =B19-(B20*0.000001)-B21-B22

	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM
37															
38															
39															
40	dNIM/dt	dNIF/dt	dNIB/dt	dIM/dt	dIF/dt	dIB/dt	dSIM/dt	dSIF/dt	dSIB/dt	dNt/dt	dFood/dt	Food Amount (g	Food Added	Capacity Factor	Poisoned?
41	-0.010	-0.010	1.143	0.000	0.000	0.000	0.000	0.000	0.000	1.123	-0.002	3000.000	0	75854.129	0
42	0.000	0.000	1.112	0.000	0.000	0.000	0.000	0.000	0.000	1.112	-0.002	2999.998	0	75854.129	0
43	0.009	0.009	1.093	0.000	0.000	0.000	0.000	0.000	0.000	1.111	-0.003	2999.996	0	75854.129	0
44	0.018	0.018	1.085	0.000	0.000	0.000	0.000	0.000	0.000	1.121	-0.004	2999.993	0	75854.129	0
45	0.027	0.027	1.087	0.000	0.000	0.000	0.000	0.000	0.000	1.141	-0.005	2999.988	0	75854.129	0
46	0.036	0.036	1.100	0.000	0.000	0.000	0.000	0.000	0.000	1.171	-0.006	2999.983	0	75854.129	0
47	0.044	0.044	1.122	0.000	0.000	0.000	0.000	0.000	0.000	1.211	-0.007	2999.977	0	75854.129	0
48	0.053	0.053	1.154	0.000	0.000	0.000	0.000	0.000	0.000	1.260	-0.008	2999.970	0	75854.129	0
49	0.062	0.062	1.195	0.000	0.000	0.000	0.000	0.000	0.000	1.320	-0.009	2999.962	0	75854.129	0
50	0.072	0.072	1.246	0.000	0.000	0.000	0.000	0.000	0.000	1.390	-0.010	2999.953	0	75854.129	0
51	0.081	0.081	1.307	0.000	0.000	0.000	0.000	0.000	0.000	1.470	-0.011	2999.943	0	75854.129	0
52	0.091	0.091	1.378	0.000	0.000	0.000	0.000	0.000	0.000	1.561	-0.012	2999.932	0	75854.129	0
53	0.102	0.102	1.459	0.000	0.000	0.000	0.000	0.000	0.000	1.663	-0.014	2999.919	0	75854.129	0
54	0.113	0.113	1.550	0.000	0.000	0.000	0.000	0.000	0.000	1.777	-0.015	2999.906	0	75854.129	0
55	0.125	0.125	1.653	0.000	0.000	0.000	0.000	0.000	0.000	1.903	-0.016	2999.891	0	75854.129	0
56	0.137	0.137	1.768	0.000	0.000	0.000	0.000	0.000	0.000	2.043	-0.018	2999.875	0	75854.129	0
57	0.151	0.151	1.894	0.000	0.000	0.000	0.000	0.000	0.000	2.196	-0.019	2999.857	0	75854.129	0
58	0.165	0.165	2.034	0.000	0.000	0.000	0.000	0.000	0.000	2.364	-0.021	2999.837	0	75854.129	0
59	0.180	0.180	2.188	0.000	0.000	0.000	0.000	0.000	0.000	2.548	-0.023	2999.816	0	75854.129	0
60	0.197	0.197	2.356	0.000	0.000	0.000	0.000	0.000	0.000	2.749	-0.025	2999.793	0	75854.129	0
61	0.214	0.214	2.540	0.000	0.000	0.000	0.000	0.000	0.000	2.968	-0.027	2999.768	0	75854.129	0
62	0.233	0.233	2.740	0.000	0.000	0.000	0.000	0.000	0.000	3.207	-0.030	2999.740	0	75854.129	0
63	0.254	0.254	2.959	0.000	0.000	0.000	0.000	0.000	0.000	3.467	-0.032	2999.710	0	75854.129	0
64	0.276	0.276	3.197	0.000	0.000	0.000	0.000	0.000	0.000	3.749	-0.035	2999.678	0	75854.129	0
65	0.300	0.300	3.456	0.000	0.000	0.000	0.000	0.000	0.000	4.056	-0.038	2999.643	0	75854.129	0
66	0.326	0.326	3.737	0.000	0.000	0.000	0.000	0.000	0.000	4.388	-0.041	2999.605	0	75854.129	0
67	0.353	0.353	4.042	0.000	0.000	0.000	0.000	0.000	0.000	4.749	-0.045	2999.564	0	75854.129	0

Population Model / Population Model (2) / Population Model (3) / Main Chart / Population Model (4) / Chart4 / Pop Chart / Pop

Ready Max=20000

Microsoft Excel - cockroach model_4_29_ vary pheromone.xls

B23 =B19-(B20*0.000001)-B21-B22

	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY
37													
38													
39						**Bait Degradation**							
40	Poisoned?	Fraction NIM pher	%NIM food	%NIF	%NIB	dBait/dt	Total Bait	Blatellaquinone (µg)	Fipronil	Fipronil (ppm)	%Mortality	Maltose	
41	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
42	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
43	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
44	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
45	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
46	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
47	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
48	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
49	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
50	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
51	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
52	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
53	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
54	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
55	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
56	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
57	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
58	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
59	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
60	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
61	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
62	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
63	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
64	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
65	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
66	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	
67	0	0.000	0.000	0.000	0.000	0.000	65.000	0.0125	0.06	923.0769	84.1420	0	

Population Model / Population Model (2) / Population Model (3) / Main Chart / Population Model (4) / Chart4 / Pop Chart / Pop

Ready Max=20000

icrosoft Visual Basic - cockroach model_4_29_ Bait Degrade.xls - [Module1 (Code)]

File Edit View Insert Format Debug Run Tools Add-Ins Window Help

Type a question for help

Ln 7, Col 1

General) dNIM

```
Function dNIM(km, NIB, NIM, k_natdeath, maxpop, poison, pher_per, food_per, food, Nt, It, Fip)

'Once the poison is added, the infection rates are activated'
If (poison <= 0) Then k_pher = 0 Else k_pher = pher_per
If (poison <= 0) Then k_malt = 0 Else k_malt = food_per
If (poison <= 0) Then k_sec = 0 Else k_sec = 1 / 10

'When food runs out, the "death rate with respect to lack of food" is activated'
If (food > 0) Then kf = 0 Else kf = 1 / 10

'This is the overall equation for change in Non-Infected Males (NIM)'
dNIM = (0.5 * km * NIB) - (k_natdeath * NIM) - (kf * NIM) - (NIM * NIM / maxpop) - (k_pher) * (NIM) - (k_malt * NIM) -

End Function

Function dNIF(km, NIB, NIF, k_natdeath, maxpop, poison, food_per, food, Nt, It, Fip)

If (food > 0) Then kf = 0 Else kf = 1 / 10

If (poison <= 0) Then k_malt = 0 Else k_malt = food_per
If (poison <= 0) Then k_sec = 0 Else k_sec = 1 / 10

dNIF = (0.5 * km * NIB) - (k_natdeath * NIF) - (kf * NIF) - (NIF * NIF / maxpop) - (k_malt * NIF) - (k_sec * NIF * It /

End Function

Function dNIB(birth_rate, NIF, km, NIB, maxpop, poison, food_per, food, Nt, NIM, It, Fip)

If (NIM <= 0.5) Then Males = 0 Else Males = NIM
SexRatio = Males / NIF

If (SexRatio >= 1) Then SR = 1 Else SR = SexRatio
If (food > 0) Then k_birth = birth_rate Else k_birth = 0
If (food > 0) Then kf = 0 Else kf = 1 / 5

If (poison <= 0) Then k_malt = 0 Else k_malt = food_per
If (poison <= 0) Then k_sec = 0 Else k_sec = 1 / 10
```

Microsoft Visual Basic - cockroach model_4_29_ Bait Degrade.xls - [Module1 (Code)]

File Edit View Insert Format Debug Run Tools Add-Ins Window Help

Type a question for help

Ln 7, Col 1

(General) dNIM

```
Function dIMR(poison, pher_per, food_per, NIM, IMR, Mortality)

'pher_per is a function of Blattellaquinone amount'

k_fip = Mortality

If (poison <= 0) Then dIMR = 0 Else dIMR = pher_per * NIM + food_per * NIM - (k_fip * IMR)

End Function

Function dIFR(poison, food_per, NIF, IFR, Mortality)

k_fip = Mortality
If (poison <= 0) Then dIFR = 0 Else dIFR = (pher_per * NIF) + (food_per * NIF) - (k_fip * IFR)

End Function

Function dIB(poison, food_per, NIB, IB, Mortality)

k_fip = Mortality
If (poison <= 0) Then dIB = 0 Else dIB = (pher_per * NIB) + (food_per * NIB) - (k_fip * IB)

End Function

Function dSIM(NIM, It, Nt, SIM, Mortality)

'k_sec_death is a function of fipronil concentration'

k_sec_infect = 1 / 5
k_sec_death = Mortality / 3

dSIM = k_sec_infect * NIM * (It / Nt) - (k_sec_death * SIM)


End Function
```

Microsoft Visual Basic - cockroach model_4_29_ Bait Degrade.xls - [Module1 (Code)]

File Edit View Insert Format Debug Run Tools Add-Ins Window Help

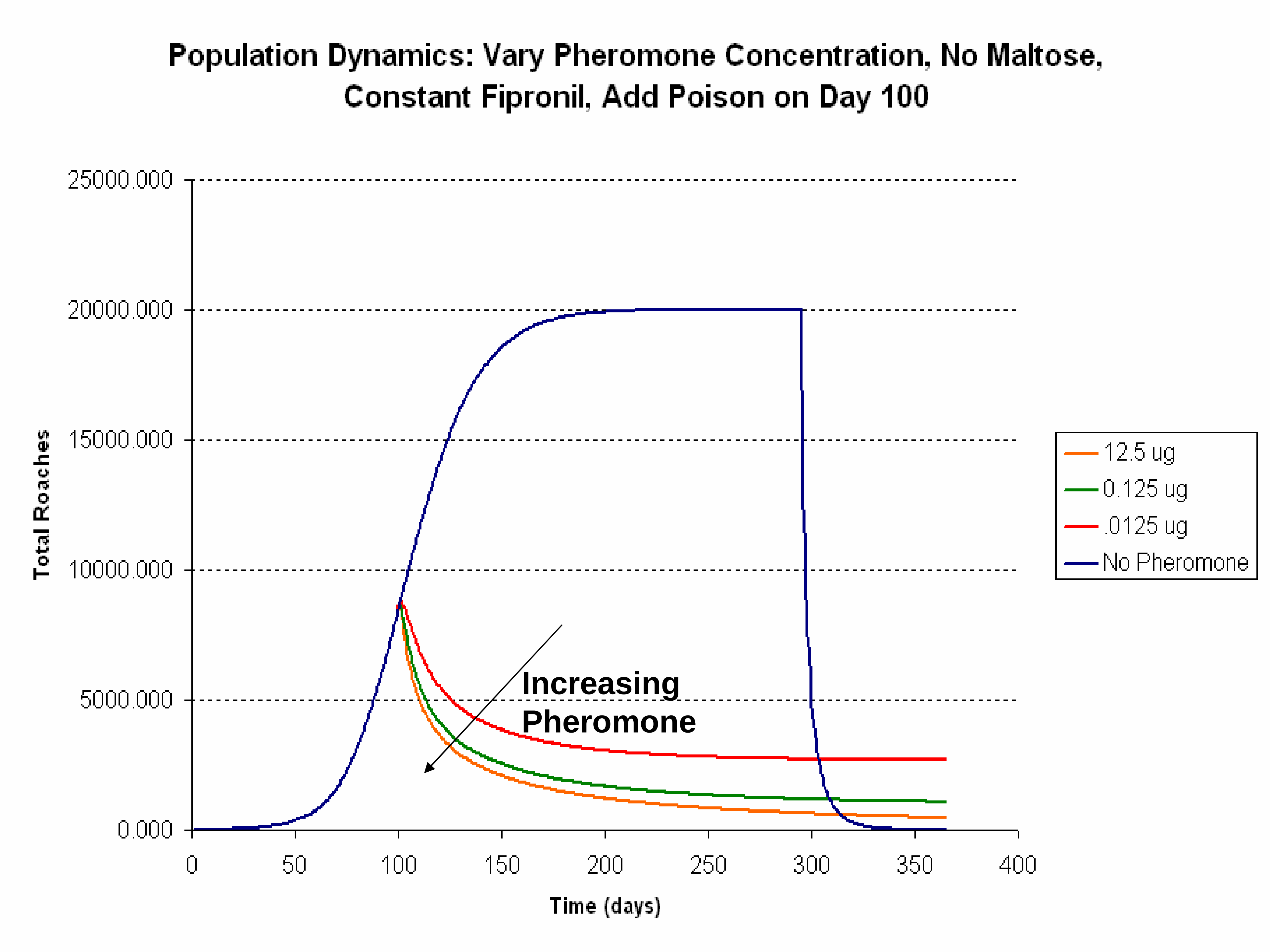
Ln 7, Col 1

(General) | dNIM

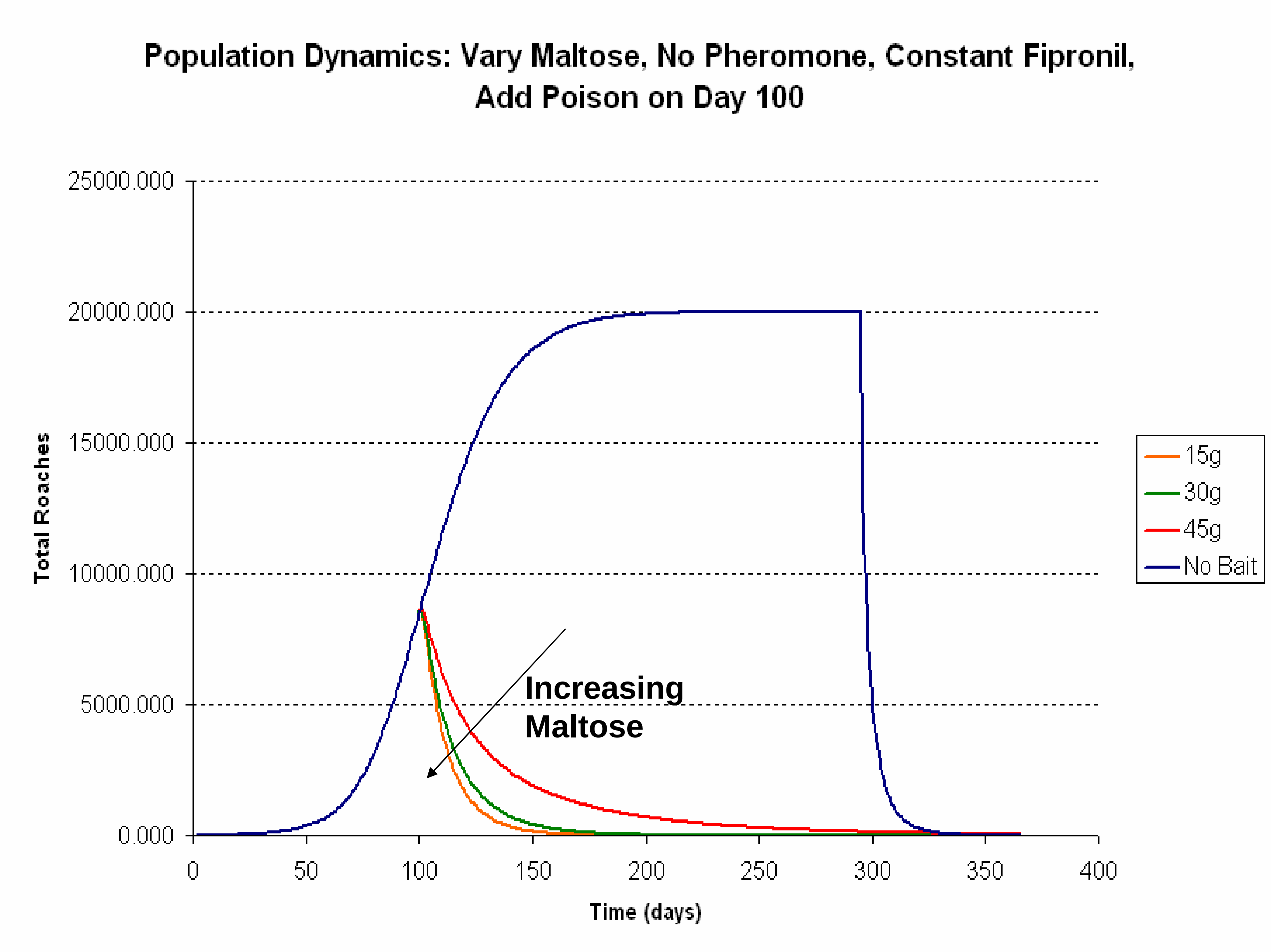
```
k_sec_death = Mortality / 3

dSIF = k_sec_infect * NIF * (It / Nt) - (k_sec_death * SIF)


End Function

Function dSIB(NIB, It, Nt, SIB, Mortality)

k_sec_infect = 1 / 5
k_sec_death = Mortality / 3

dSIB = k_sec_infect * NIB * (It / Nt) - (k_sec_death * SIB)

End Function

Function dFood(EatRate, Roaches)

dFood = -EatRate * Roaches

End Function

Function dBait(checkpoison, EatBait, NIM, NIF, NIB, k_pher, k_malt)

If (checkpoison = 0) Then Eat_rate = 0 Else Eat_rate = EatBait
dBait = -Eat_rate * (k_pher * NIM + k_malt * NIM + k_malt * NIF + k_malt * NIB)


End Function


Function Check(day, numberofdays) 'This code checks to see if a day is a muliple of the numberofdays.  Food can now be 

DayCheck = Int(day / numberofdays)
If (day / numberofdays = DayCheck) Then Check = 1 Else Check = 0
End Function
```

Population Model

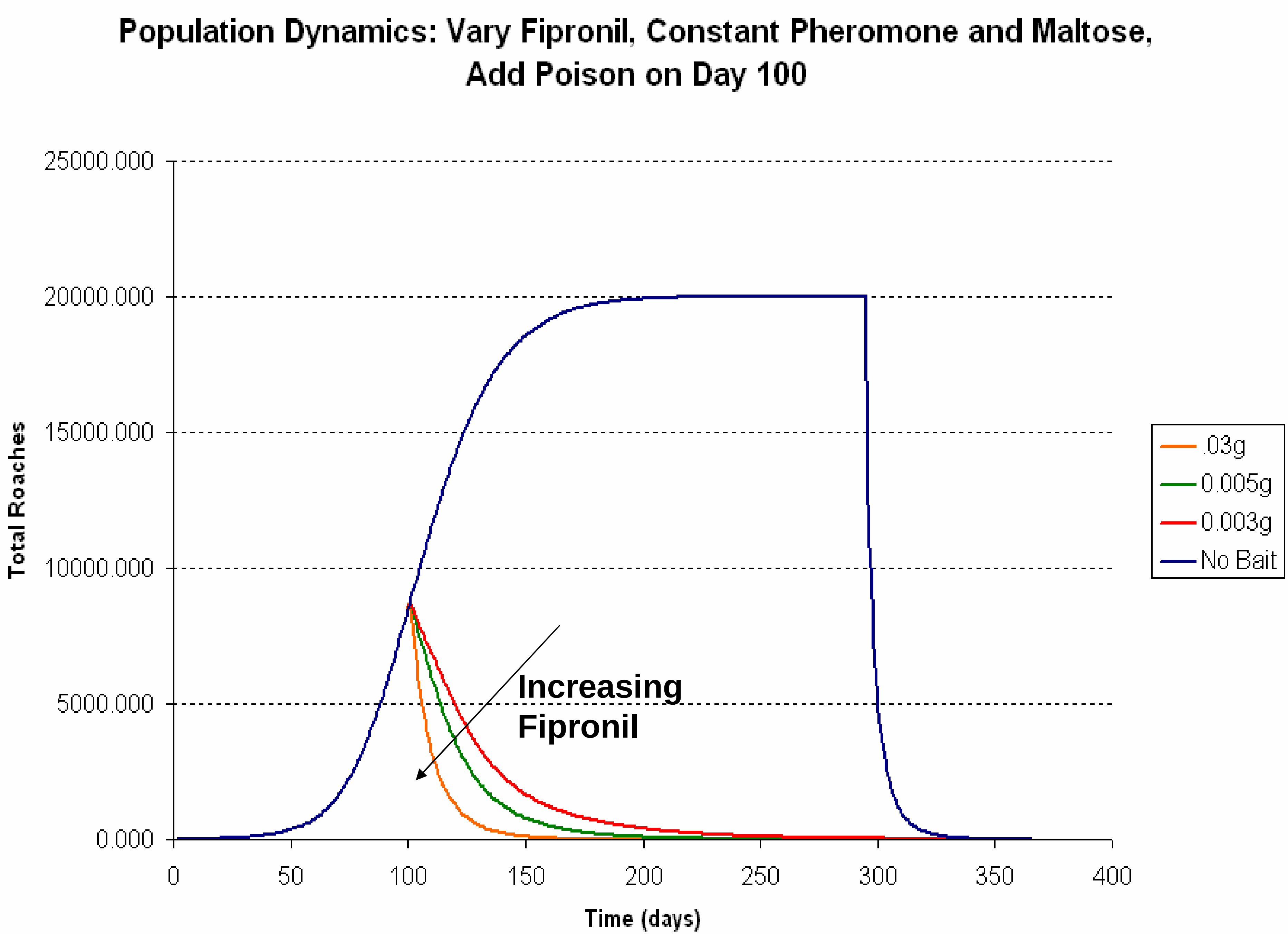
- Vary Pheromone
- Vary Maltose
- Vary Fipronil

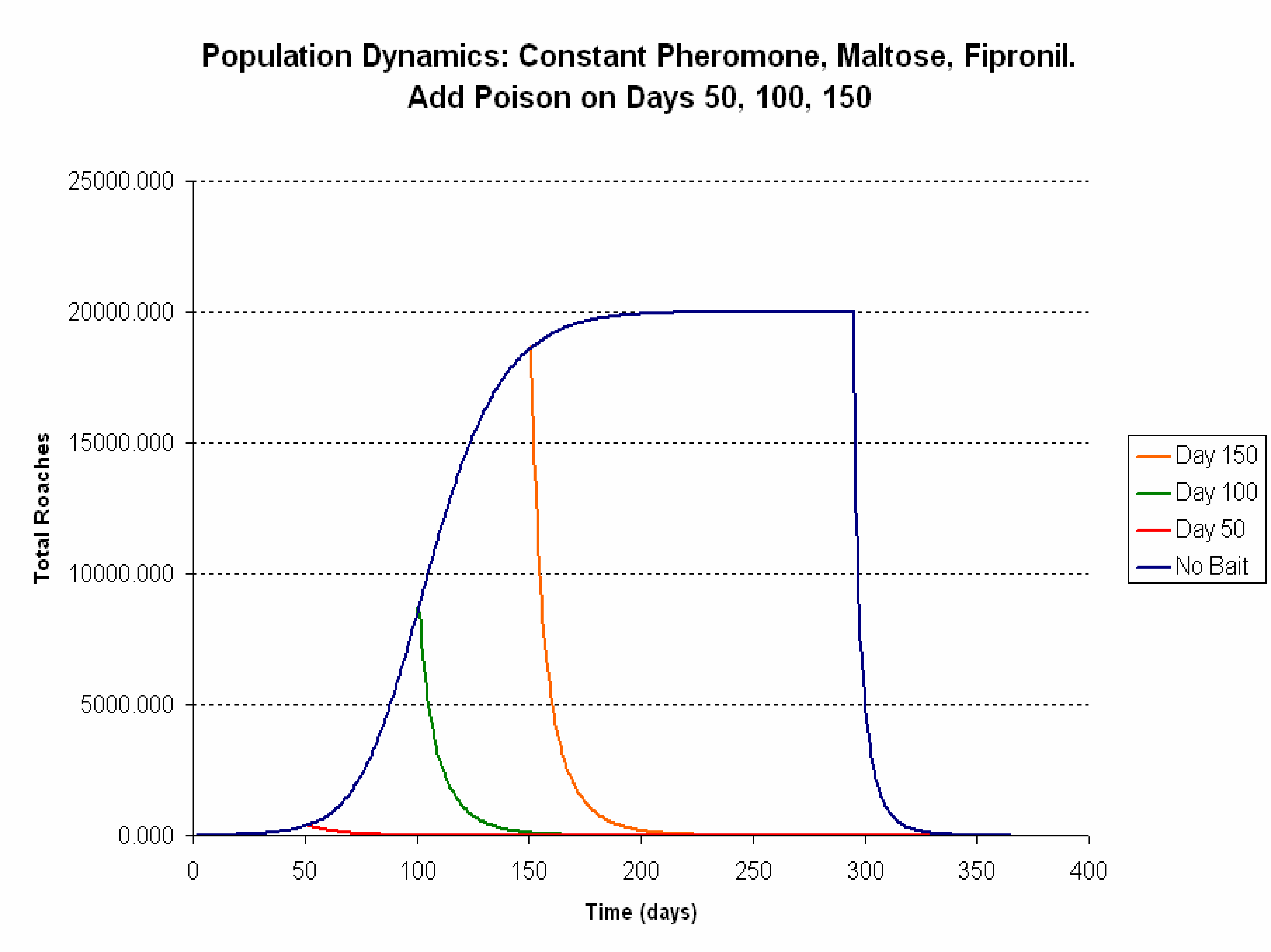


Population Dynamics: Vary Pheromone Concentration, No Maltose, Constant Fipronil, Add Poison on Day 100
Total Roaches
25000.000
20000.000
15000.000
10000.000
5000.000
0.000
0
50
100
150
200
250
300
350
400
Time (days)
Increasing Pheromone
12.5 ug
0.125 ug
.0125 ug
No Pheromone



Population Dynamics: Vary Maltose, No Pheromone, Constant Fipronil, Add Poison on Day 100
25000.000
20000.000
15000.000
10000.000
5000.000
0.000
Total Roaches
0
50
100
150
200
250
300
350
400
Time (days)
15g
30g
45g
No Bait
Increasing Maltose


Population Dynamics: Vary Fipronil, Constant Pheromone and Maltose, Add Poison on Day 100
25000.000
20000.000
15000.000
10000.000
5000.000
0.000
Total Roaches
0
50
100
150
200
250
300
350
400
Time (days)
Increasing Fipronil
.03g
0.005g
0.003g
No Bait

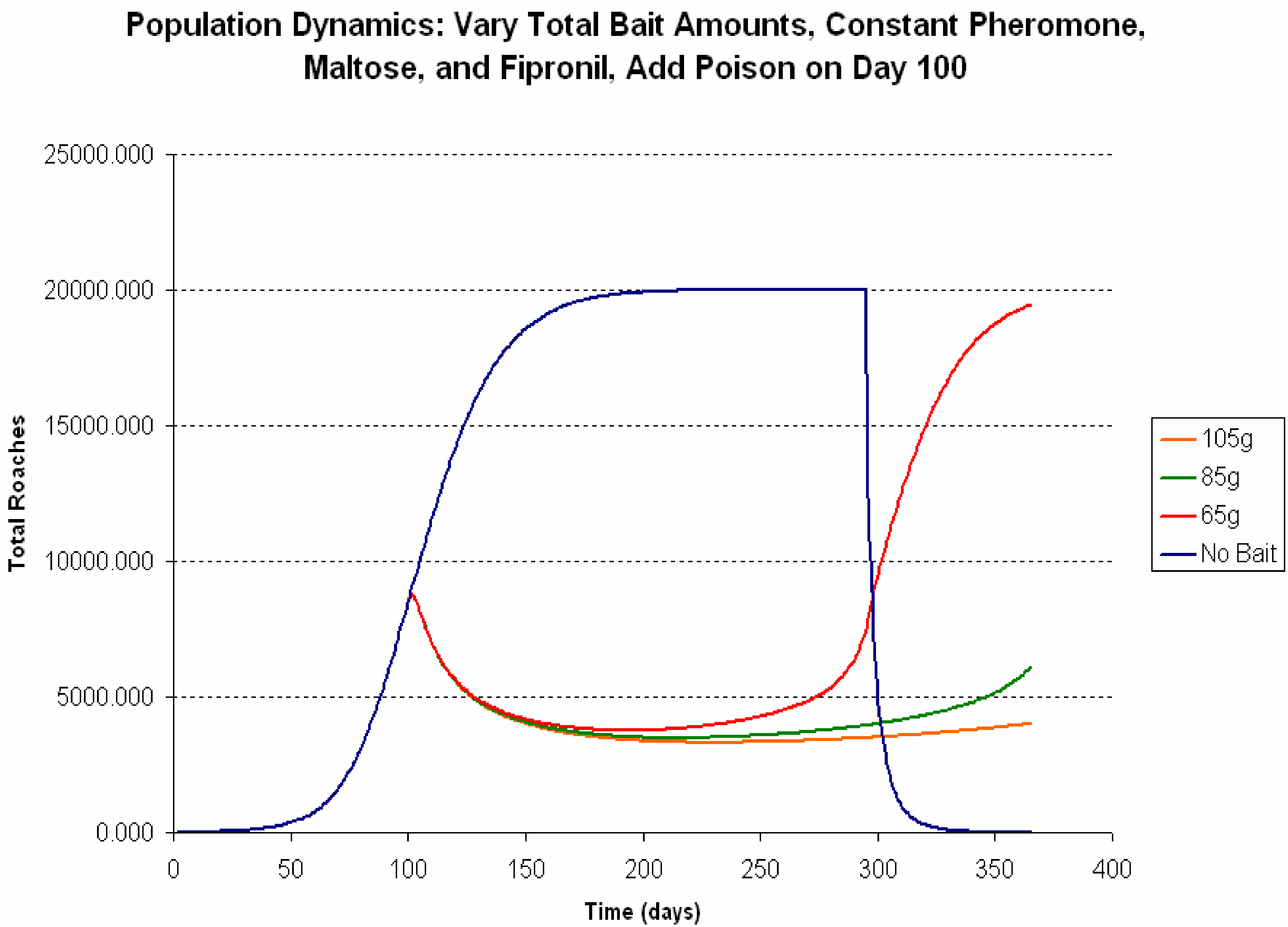


Population Dynamics: Constant Pheromone, Maltose, Fipronil.
Add Poison on Days 50, 100, 150
Total Roaches
25000.000
20000.000
15000.000
10000.000
5000.000
0.000
0
50
100
150
200
250
300
350
400
Time (days)
Day 150
Day 100
Day 50
No Bait

Population Model

- Bait Degradation
  - Roaches will contact, eat gel
  - Gel will diminish

$$\frac{dGel}{dt} = -k_{Bait\,consumption}\left(k_{pheromone}NIM + k_{maltose}(NIM + NIF + NIB)\right)$$

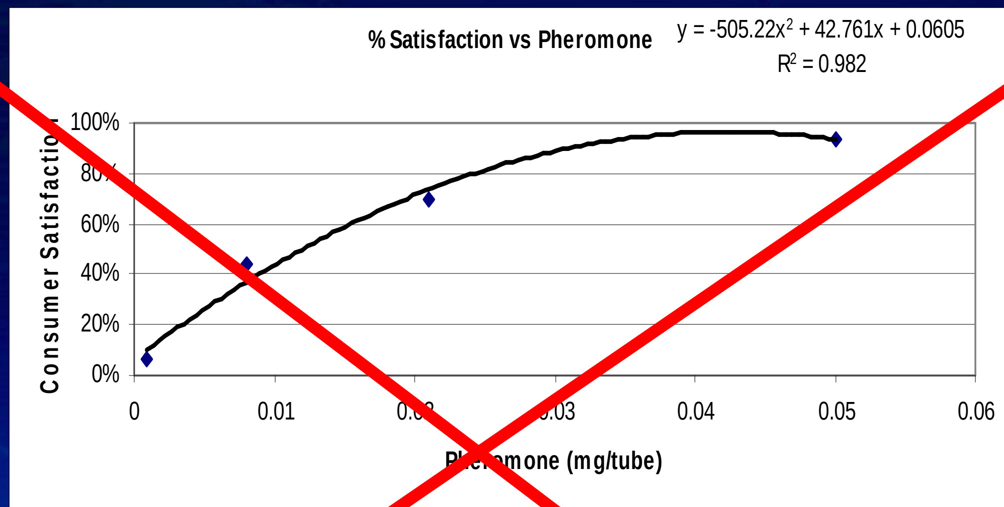


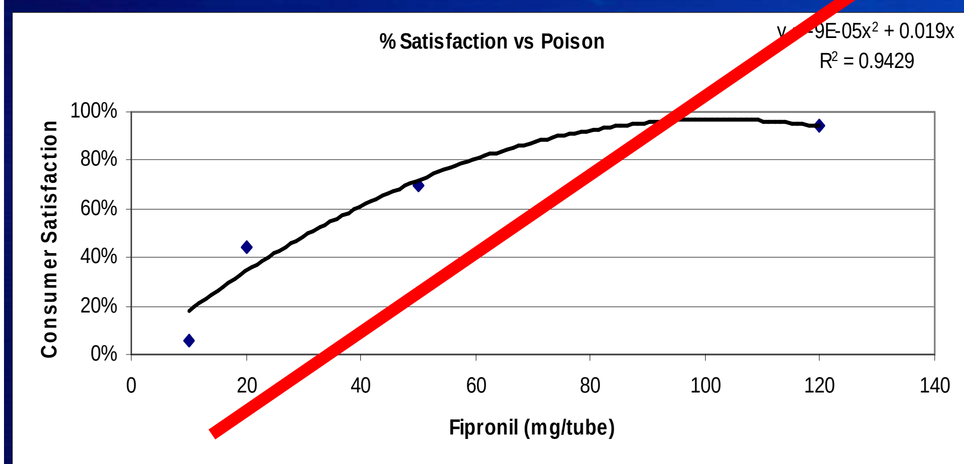
Population Dynamics: Vary Total Bait Amounts, Constant Pheromone, Maltose, and Fipronil, Add Poison on Day 100
Total Roaches
25000.000
20000.000
15000.000
10000.000
5000.000
0.000
0
50
100
150
200
250
300
350
400
Time (days)
105g
85g
65g
No Bait

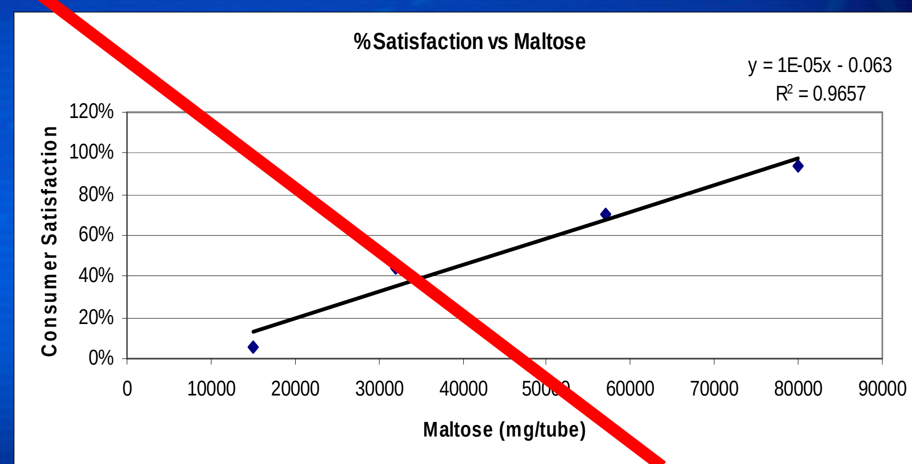
Population Model – Future Work

- More accurate death, attraction rates
  - Experiments in lab
    - Test attraction rates for varying concentrations of maltose, pheromone
    - Test death rates and secondary with varying concentrations of fipronil
    - Test consumption of gel bait

Speed Results







Speed and Durability??

- Trial and error approach using the population model
- Choose values over a wide range for each parameter
- The population model will give the result for each set of values, which can be related to consumer happiness
- Create a table from the data

Speed and Durability

Fipronil (mg)	Maltose (g)	Pheromone (µg)		Durability	Speed	Toxicity	Odor	S1 (Ours)	S2 (Maxforce)	β
			w_i	19%	33%	31%	17%			
10	5	0		0.0%	0.0%	54.2%	84.4%	31.1%	45.0%	1.45
		5		100.0%	14.3%	54.2%	84.4%	54.8%	45.0%	0.82
		10		100.0%	21.4%	54.2%	84.4%	57.2%	45.0%	0.79
		15		100.0%	21.4%	54.2%	84.4%	57.2%	45.0%	0.79
		20		100.0%	21.4%	54.2%	84.4%	57.2%	45.0%	0.79
	15	0		0.0%	0.0%	54.2%	84.4%	31.1%	45.0%	1.45
		5		54.4%	35.7%	54.2%	84.4%	53.3%	45.0%	0.84
		10		70.6%	35.7%	54.2%	84.4%	56.3%	45.0%	0.80
		15		80.6%	35.7%	54.2%	84.4%	58.2%	45.0%	0.77
		20		87.8%	35.7%	54.2%	84.4%	59.6%	45.0%	0.76
	25	0		0.0%	0.0%	54.2%	84.4%	31.1%	45.0%	1.45
		5		17.2%	42.9%	54.2%	84.4%	48.5%	45.0%	0.93
		10		24.4%	42.9%	54.2%	84.4%	49.9%	45.0%	0.90
		15		28.3%	42.9%	54.2%	84.4%	50.7%	45.0%	0.89
		20		30.0%	42.9%	54.2%	84.4%	51.0%	45.0%	0.88
	35	0		0.0%	0.0%	54.2%	84.4%	31.1%	45.0%	1.45
		5		0.0%	42.9%	54.2%	84.4%	45.3%	45.0%	0.99
		10		9.4%	50.0%	54.2%	84.4%	49.4%	45.0%	0.91
		15		11.7%	50.0%	54.2%	84.4%	49.8%	45.0%	0.90
		20		12.8%	50.0%	54.2%	84.4%	50.1%	45.0%	0.90
	45	0		0.0%	0.0%	54.2%	84.4%	31.1%	45.0%	1.45
		5		0.0%	50.0%	54.2%	84.4%	47.6%	45.0%	0.94
		10		0.0%	50.0%	54.2%	84.4%	47.6%	45.0%	0.94
		15		0.0%	50.0%	54.2%	84.4%	47.6%	45.0%	0.94
		20		0.0%	50.0%	54.2%	84.4%	47.6%	45.0%	0.94
	55	0		0.0%	0.0%	54.2%	84.4%	31.1%	45.0%	1.45
		5		0.0%	50.0%	54.2%	84.4%	47.6%	45.0%	0.94
		10		0.0%	50.0%	54.2%	84.4%	47.6%	45.0%	0.94
		15		0.0%	50.0%	54.2%	84.4%	47.6%	45.0%	0.94
		20		0.0%	50.0%	54.2%	84.4%	47.6%	45.0%	0.94

20	5	0	[redacted]	0.0%	0.0%	31.1%	82.5%	23.7%	45.0%	1.90
		5	[redacted]	100.0%	35.7%	31.1%	82.5%	54.5%	45.0%	0.83
		10	[redacted]	100.0%	42.9%	31.1%	82.5%	56.8%	45.0%	0.79
		15	[redacted]	100.0%	42.9%	31.1%	82.5%	56.8%	45.0%	0.79
		20	[redacted]	100.0%	42.9%	31.1%	82.5%	56.8%	45.0%	0.79
	15	0	[redacted]	0.0%	0.0%	31.1%	82.5%	23.7%	45.0%	1.90
		5	[redacted]	50.6%	57.1%	31.1%	82.5%	52.1%	45.0%	0.86
		10	[redacted]	64.4%	57.1%	31.1%	82.5%	54.8%	45.0%	0.82
		15	[redacted]	72.2%	57.1%	31.1%	82.5%	56.3%	45.0%	0.80
		20	[redacted]	78.3%	57.1%	31.1%	82.5%	57.4%	45.0%	0.78
	25	0	[redacted]	0.0%	0.0%	31.1%	82.5%	23.7%	45.0%	1.90
		5	[redacted]	17.8%	57.1%	31.1%	82.5%	45.9%	45.0%	0.98
		10	[redacted]	23.9%	64.3%	31.1%	82.5%	49.4%	45.0%	0.91
		15	[redacted]	26.7%	64.3%	31.1%	82.5%	50.0%	45.0%	0.90
		20	[redacted]	28.3%	64.3%	31.1%	82.5%	50.3%	45.0%	0.90
	35	0	[redacted]	0.0%	0.0%	31.1%	82.5%	23.7%	45.0%	1.90
		5	[redacted]	0.0%	64.3%	31.1%	82.5%	44.9%	45.0%	1.00
		10	[redacted]	11.1%	64.3%	31.1%	82.5%	47.0%	45.0%	0.96
		15	[redacted]	13.3%	64.3%	31.1%	82.5%	47.4%	45.0%	0.95
		20	[redacted]	13.9%	64.3%	31.1%	82.5%	47.5%	45.0%	0.95
	45	0	[redacted]	0.0%	0.0%	31.1%	82.5%	23.7%	45.0%	1.90
		5	[redacted]	0.0%	64.3%	31.1%	82.5%	44.9%	45.0%	1.00
		10	[redacted]	0.0%	64.3%	31.1%	82.5%	44.9%	45.0%	1.00
		15	[redacted]	5.6%	64.3%	31.1%	82.5%	45.9%	45.0%	0.98
		20	[redacted]	6.1%	64.3%	31.1%	82.5%	46.1%	45.0%	0.98
	55	0	[redacted]	0.0%	0.0%	31.1%	82.5%	23.7%	45.0%	1.90
		5	[redacted]	0.0%	64.3%	31.1%	82.5%	44.9%	45.0%	1.00
		10	[redacted]	0.0%	64.3%	31.1%	82.5%	44.9%	45.0%	1.00
		15	[redacted]	0.0%	64.3%	31.1%	82.5%	44.9%	45.0%	1.00
		20	[redacted]	0.0%	64.3%	31.1%	82.5%	44.9%	45.0%	1.00

30	5	0	[redacted]	0.0%	0.0%	17.9%	80.7%	19.3%	45.0%	2.34
		5	[redacted]	100.0%	42.9%	17.9%	80.7%	52.4%	45.0%	0.86
		10	[redacted]	100.0%	42.9%	17.9%	80.7%	52.4%	45.0%	0.86
		15	[redacted]	100.0%	50.0%	17.9%	80.7%	54.8%	45.0%	0.82
		20	[redacted]	100.0%	50.0%	17.9%	80.7%	54.8%	45.0%	0.82
	15	0	[redacted]	0.0%	0.0%	17.9%	80.7%	19.3%	45.0%	2.34
		5	[redacted]	48.9%	64.3%	17.9%	80.7%	49.8%	45.0%	0.90
		10	[redacted]	62.2%	64.3%	17.9%	80.7%	52.3%	45.0%	0.86
		15	[redacted]	69.4%	64.3%	17.9%	80.7%	53.7%	45.0%	0.84
		20	[redacted]	74.4%	64.3%	17.9%	80.7%	54.6%	45.0%	0.82
	25	0	[redacted]	0.0%	0.0%	17.9%	80.7%	19.3%	45.0%	2.34
		5	[redacted]	17.2%	64.3%	17.9%	80.7%	43.8%	45.0%	1.03
		10	[redacted]	22.2%	64.3%	17.9%	80.7%	44.7%	45.0%	1.01
		15	[redacted]	25.6%	64.3%	17.9%	80.7%	45.3%	45.0%	0.99
		20	[redacted]	26.7%	64.3%	17.9%	80.7%	45.5%	45.0%	0.99
	35	0	[redacted]	0.0%	0.0%	17.9%	80.7%	19.3%	45.0%	2.34
		5	[redacted]	0.0%	71.4%	17.9%	80.7%	42.8%	45.0%	1.05
		10	[redacted]	10.6%	71.4%	17.9%	80.7%	44.8%	45.0%	1.00
		15	[redacted]	12.2%	71.4%	17.9%	80.7%	45.2%	45.0%	1.00
		20	[redacted]	12.8%	71.4%	17.9%	80.7%	45.3%	45.0%	0.99
	45	0	[redacted]	0.0%	0.0%	17.9%	80.7%	19.3%	45.0%	2.34
		5	[redacted]	0.0%	71.4%	17.9%	80.7%	42.8%	45.0%	1.05
		10	[redacted]	0.0%	71.4%	17.9%	80.7%	42.8%	45.0%	1.05
		15	[redacted]	5.6%	71.4%	17.9%	80.7%	43.9%	45.0%	1.03
		20	[redacted]	6.1%	71.4%	17.9%	80.7%	44.0%	45.0%	1.02
	55	0	[redacted]	0.0%	0.0%	17.9%	80.7%	19.3%	45.0%	2.34
		5	[redacted]	0.0%	71.4%	17.9%	80.7%	42.8%	45.0%	1.05
		10	[redacted]	0.0%	71.4%	17.9%	80.7%	42.8%	45.0%	1.05
		15	[redacted]	0.0%	71.4%	17.9%	80.7%	42.8%	45.0%	1.05
		20	[redacted]	0.0%	71.4%	17.9%	80.7%	42.8%	45.0%	1.05

Minimum Beta

- Found the minimum value of Beta to find the best ideal product for the consumer
- This will not necessarily be the best economically for us

MINIMIZED BETA FUNCTION	
Amount of Fipronil (mg/tube)	10
Amount of Blattellaquinone (mg/tube)	0.02
Amount of Maltose (mg/tube)	15000
S1 (our product)	59.6%
S2 (Maxforce Gel)	45.0%
BETA FUNCTION (β)	0.76

Pricing Model

$$\Phi(d_1) = p_1 d_1 - \left(\frac{\alpha}{\beta}\right)^{\rho} p_2 \left[\frac{Y - p_1 d_1}{p_2}\right]^{1-\rho} d_1^{\rho} = 0$$

- p1, d1 is the price and demand for our product
- p2 is the price of Maxforce's product
- Y is an estimated amount of revenue for this market (20 million)
- α represents how knowledgeable the consumer is about our product (assumed to be 1).

Finding the Optimal Composition

$$\Phi(d_1) = p_1 d_1 - \left(\frac{\alpha}{\beta}\right)^{\rho} p_2 \left[\frac{Y - p_1 d_1}{p_2}\right]^{1-\rho} d_1^{\rho} = 0$$

Output Demand (d1)

From price, demand, and product composition calculate NPV

Choose new price for the same β or choose a different β value.

Input β and p_1

**Choose combination of β and product price that maximizes NPV*

Pricing Model

P_1D_1	P_1 ($/unit)	D_1 (# of units)	α	β	ρ	P_2 ($/unit)	Y	Φ	NPV (millions)
16451747.57	5	3290349.513	1	0.80	0.75	6.67	20000000	0.000	88.0
14569945.96	6	2428324.327	1	0.80	0.75	6.67	20000000	0.000	89.7
12564267.55	7	1794895.364	1	0.80	0.75	6.67	20000000	0.000	75.2
10619035.5	8	1327379.437	1	0.80	0.75	6.67	20000000	0.000	59.9
8858085.114	9	984231.6794	1	0.80	0.75	6.67	20000000	0.000	45.3
7338343.835	10	733834.3835	1	0.80	0.75	6.67	20000000	0.000	32.3
6067001.241	11	551545.5673	1	0.80	0.75	6.67	20000000	0.000	21.1
5023220.465	12	418601.7055	1	0.80	0.75	6.67	20000000	0.000	11.9
4174731.669	13	321133.2053	1	0.80	0.75	6.67	20000000	0.000	4.2
3487646.181	14	249117.5844	1	0.80	0.75	6.67	20000000	0.000	-2.0
2931149.894	15	195409.993	1	0.80	0.75	6.67	20000000	0.000	-7.1
2479149.8	16	154946.8625	1	0.80	0.75	6.67	20000000	0.000	-11.2
2110385.346	17	124140.3145	1	0.80	0.75	6.67	20000000	0.000	-14.7
1807894.151	18	100438.5639	1	0.80	0.75	6.67	20000000	0.000	-17.5
1558288.818	19	82015.20092	1	0.80	0.75	6.67	20000000	0.000	-19.8
1351051.498	20	67552.57492	1	0.80	0.75	6.67	20000000	0.000	-21.8
1177923.767	21	56091.60795	1	0.80	0.75	6.67	20000000	0.000	-23.4
1032408.758	22	46927.67083	1	0.80	0.75	6.67	20000000	0.000	-24.8
909377.3362	23	39538.14505	1	0.80	0.75	6.67	20000000	0.000	-25.9
804761.7432	24	33531.7393	1	0.80	0.75	6.67	20000000	0.000	-26.9
715319.3388	25	28612.77355	1	0.80	0.75	6.67	20000000	0.000	-27.8
638451.0355	26	24555.80906	1	0.80	0.75	6.67	20000000	0.000	-28.5
572061.8171	27	21187.47471	1	0.80	0.75	6.67	20000000	0.000	-29.1
0	28	0	1	0.80	0.75	6.67	20000000	0.000	-34.7
0	29	0	1	0.80	0.75	6.67	20000000	0.000	-34.7
0	30	0	1	0.80	0.75	6.67	20000000	0.000	-34.7

Multiple Compositions for β

- Choose the composition that gives the smallest reactant cost

β	Fipronil (mg)	Maltose (g)	Pheromone (µg)	Reactant Cost
0.86	20	15	5	93,369
0.86	30	5	5	95,169
0.86	30	5	10	95,185
0.86	30	15	10	95,185
0.86	40	5	10	96,986
0.86	40	5	15	97,002
0.86	40	5	20	97,018
0.9	10	25	10	88531
0.9	10	35	15	88547
0.9	10	35	20	88562
0.9	20	25	15	90287
0.9	20	25	20	90293
0.9	30	15	5	91995
0.9	40	5	5	93735
0.9	50	15	20	95522

Most Profitable Composition

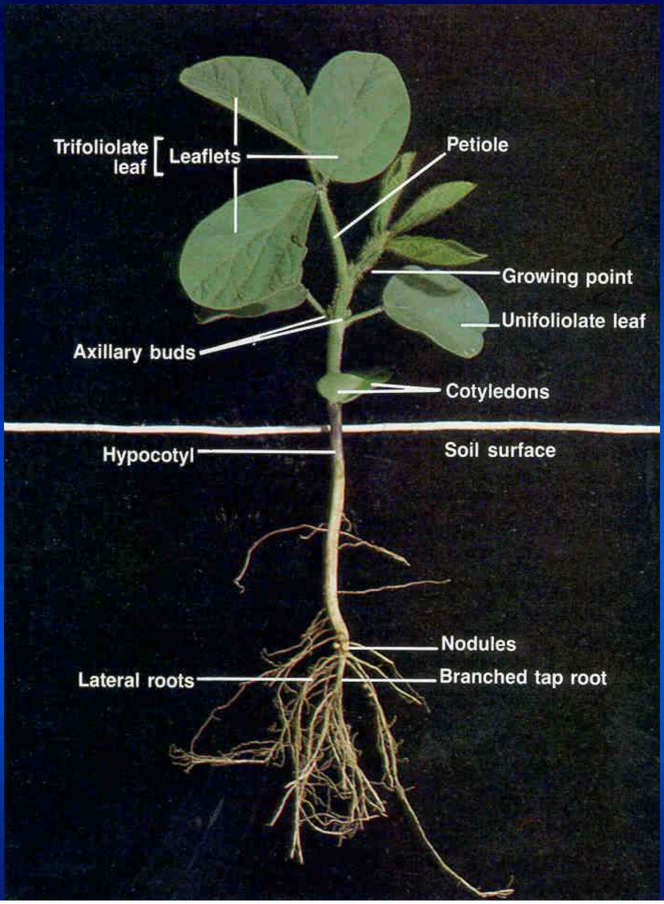
The most profitable composition is the minimum beta found earlier.

Product Composition

MINIMIZED BETA FUNCTION	
Amount of Fipronil (mg/tube)	10
Amount of Blattellaquinone (mg/tube)	0.02
Amount of Maltose (mg/tube)	15000
S1 (our product)	59.6%
S2 (Maxforce Gel)	45.0%
BETA FUNCTION (β)	0.76

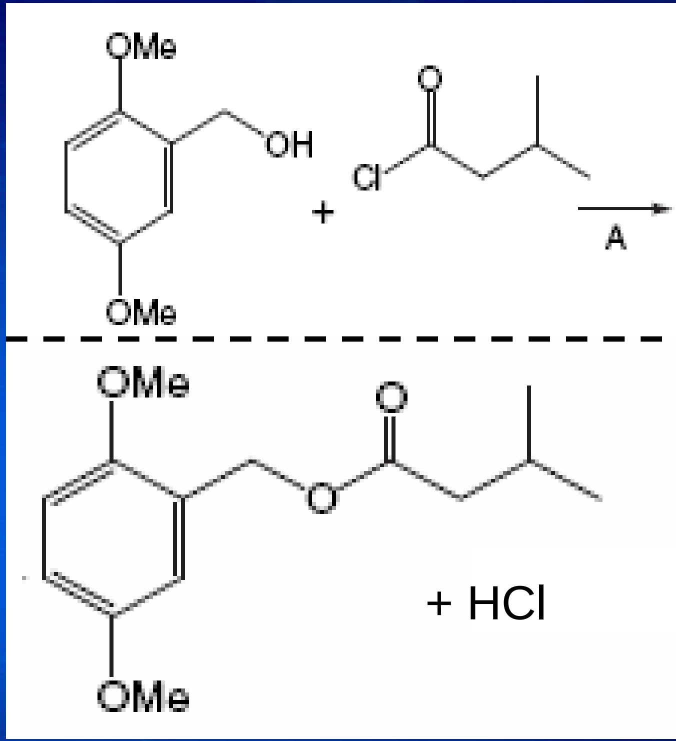
- At an optimum selling price $6 per unit
- Sell 2.5MM units a year

Plant Design



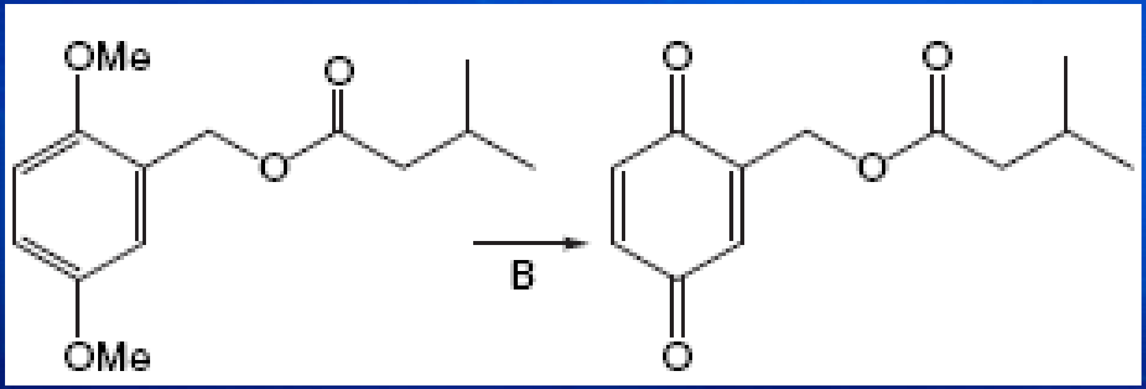
Overall Process

- Acylation
  - – Isovaleryl chloride
  - – 2,5 dimethoxybenzyl alcohol
  - – Pyridine
  - – DMAP (dimethylaminopyridine)
  - – Dichloromethane
  - – Diethyl ether (extraction)



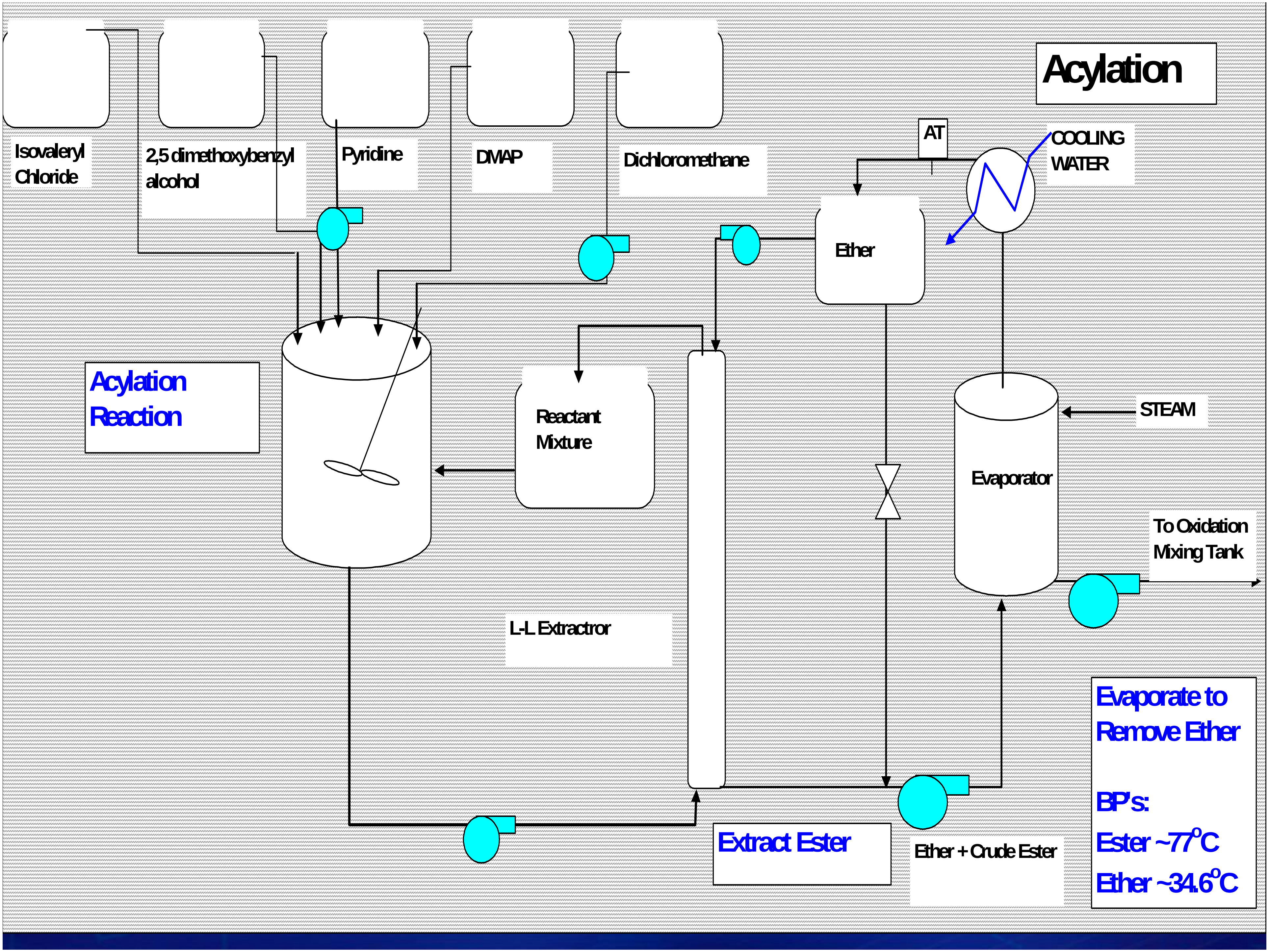
Overall Process

- Oxidation
  - Crude ester (from acylation)
  - Cerium ammonium nitrate (catalyst)
  - Acetonitrile
  - Dichloromethane (extraction)



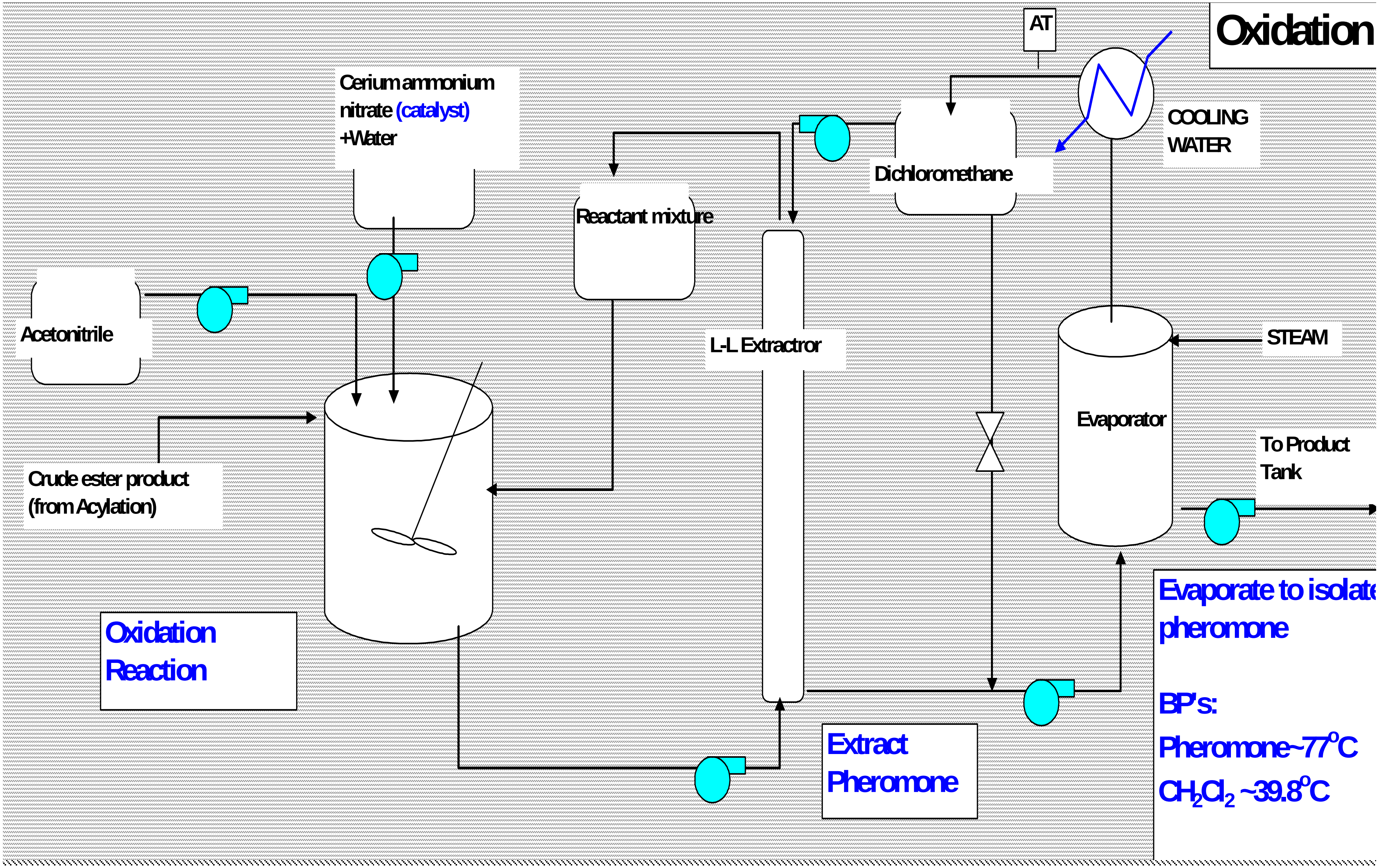
Overall Process

- Acylation → Extraction → Evaporation
- Oxidation → Extraction → Evaporation
- Gel Mixing → Packaging



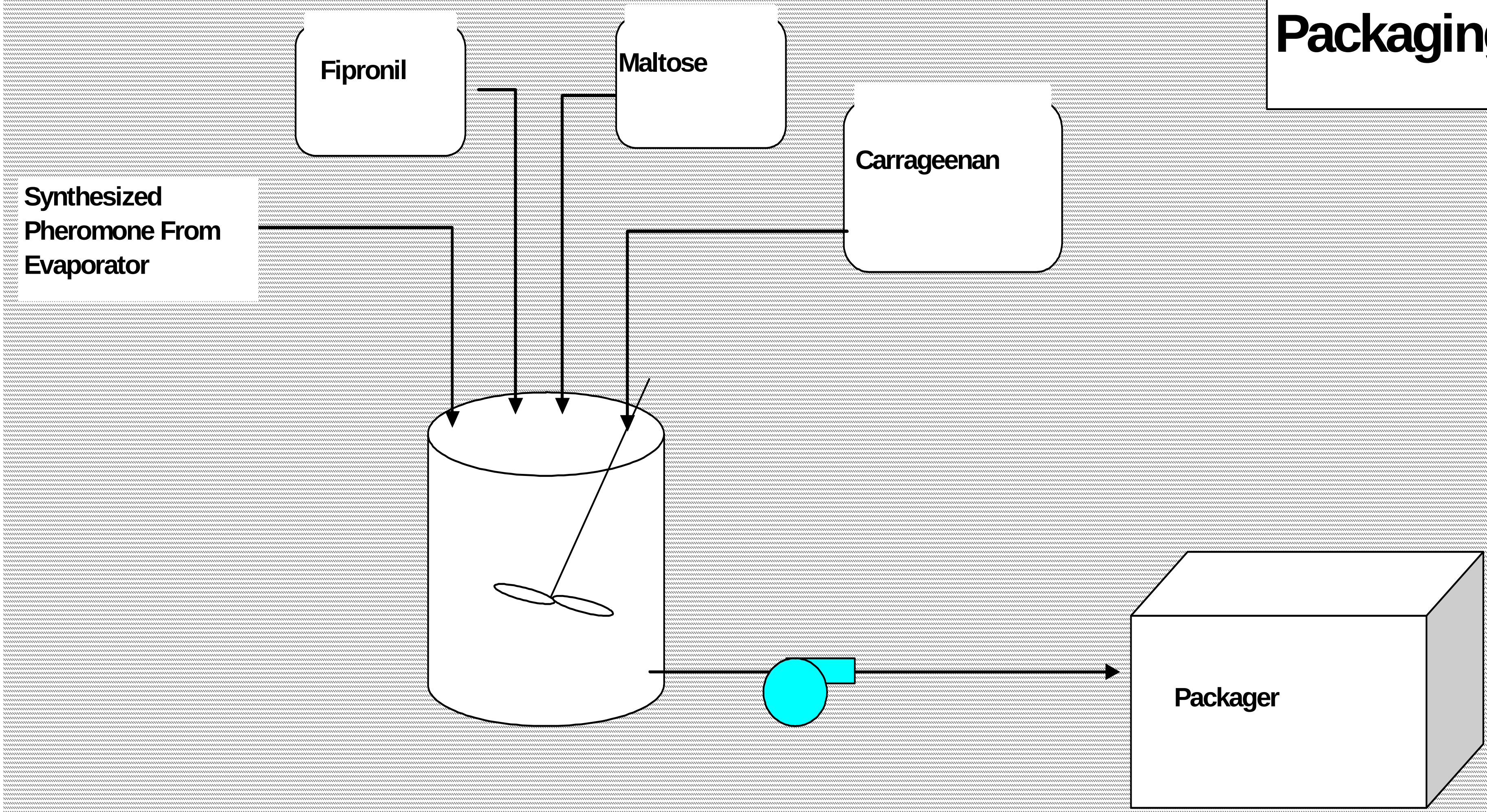
Acylation
Isovaleryl Chloride
2,5 dimethoxybenzyl alcohol
Pyridine
DMAP
Dichloromethane
AT
COOLING WATER
Ether
Acylation Reaction
Reactant Mixture
STEAM
Evaporator
To Oxidation Mixing Tank
L-L Extractror
Evaporate to Remove Ether
BP's:
Ester ~77°C
Ether ~34.6°C
Extract Ester
Ether + Crude Ester

Oxidation



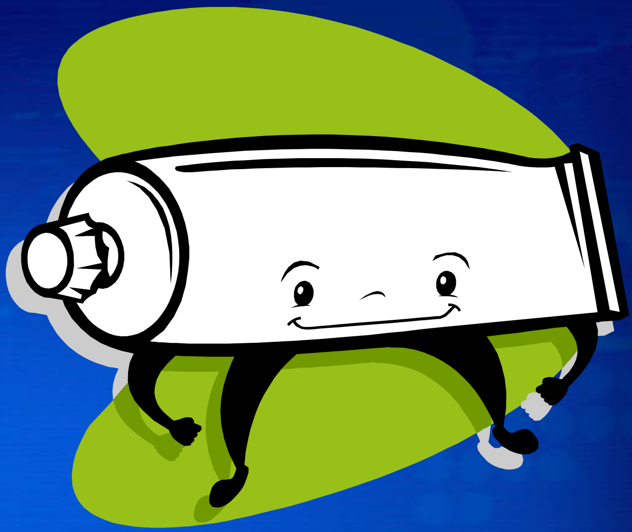
AT
Cerium ammonium nitrate (catalyst) +Water
COOLING WATER
Dichloromethane
Reactant mixture
Acetonitrile
L-L Extractror
STEAM
Evaporator
To Product Tank
Crude ester product (from Acylation)
Oxidation Reaction
Extract Pheromone
Evaporate to isolate pheromone
BP's:
Pheromone~77°C
CH2Cl2 ~39.8°C

Gelling & Packaging



Plant Design

- Process depends on three criteria
  - Composition of gel matrix
    - Blatellaquinone
    - Fipronil
    - Maltose
    - Carrageenan
  - # Tubes produced per year
  - # Batches per day



Plant Design

- Storage Tanks
  - 304 Stainless Steel
  - One month supply of reactant
- Liquid-Liquid Extractors
  - Use cost of column
- Evaporators
  - For heat sensitive components
- Mixing Tanks
  - Ribbon Blenders
- Pumps
- Packager

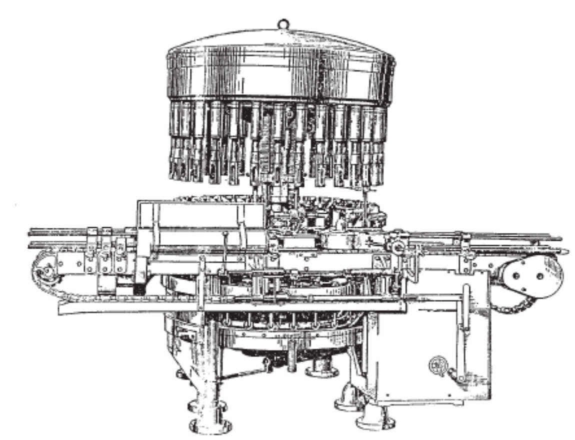
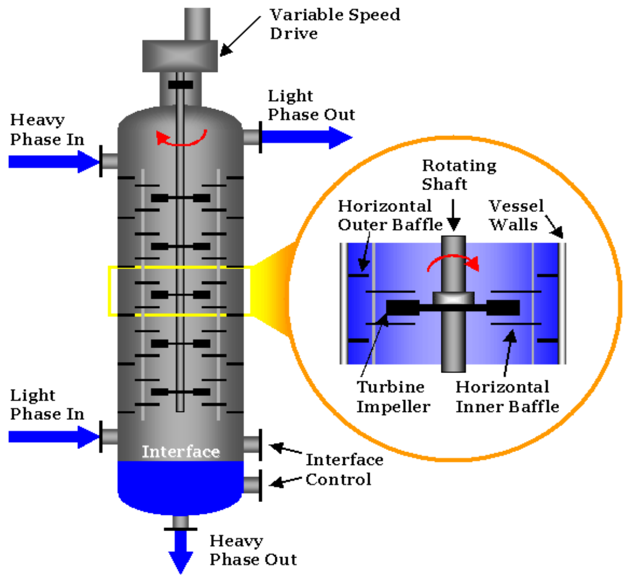


FIG. 21-45 HORIX 32 station carousel-type liquid filler for glass and plastic bottles and metal cans.



Economic Results

Equipment Costs

- Tanks: $84,000
- Extractors: $51,000
- Evaporators: $53,000
- Mixers: $110,000
- Pumps: $14,300

TOTAL COST = $262,000

Fixed & Total Capital Investment

- Based on percentage of equipment costs
  - Table 6-17, PT&W, pg. 273
  - Not completely accurate

Estimation of Capital Investment Cost (showing individual components) for a Solid/Fluid Processing Plant

I. Direct Costs	**Percent of delivered equipment cost**	**$**
Purchased equipment delivered	100	$262,227
Purchased equipment installation	39	$102,268
Instrumentation and controls (installed)	26	$68,179
Piping	31	$81,290
Electrical systems (installed)	10	$26,223
Buildings	29	$76,046
Yard improvements	12	$31,467
Service facilities (installed)	55	$144,225
Total direct plant cost	302	**$791,925**
Indirect costs		
Engineering and supervision	32	$83,913
Construction expenses	34	$89,157
Legal expenses	4	$10,489
Contractor's fee	19	$49,823
Contingency	37	$97,024
Total indirect plant cost	126	**$330,406**
Fixed Capital Investment	428	$1,122,331
Working Capital	75	$196,670
Total Capital Investment	503	$1,319,001

Fixed & Total Capital Investment

- FCI = $1.12 MM
- TCI = $1.32 MM

Production Costs

- Annual cost of reactants
- Annual cost of utilities

			Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Component		Basis for Estimate	1	2	3	4	5	6	7	8
I. Manufacturing cost										
A. Direct production costs										
1. Raw materials										
	Isovaleryl Chloride		$4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000
	2,5-Dimethoxybenzyl Alcohol		$1,141	$ 1,141	$ 1,141	$ 1,141	$ 1,141	$ 1,141	$ 1,141	$ 1,141
	Pyridine		$3,500	$ 3,500	$ 3,500	$ 3,500	$ 3,500	$ 3,500	$ 3,500	$ 3,500
	4-Dimethylaminopyridine		$5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000	$ 5,000
	Dichloromethane		$1,250	$ 1,250	$ 1,250	$ 1,250	$ 1,250	$ 1,250	$ 1,250	$ 1,250
	Cerium Ammonium Nitrate		$3,954	$ 3,954	$ 3,954	$ 3,954	$ 3,954	$ 3,954	$ 3,954	$ 3,954
	Acetonitrile		$1,500	$ 1,500	$ 1,500	$ 1,500	$ 1,500	$ 1,500	$ 1,500	$ 1,500
	Diethyl Ether		$2,100	$ 2,100	$ 2,100	$ 2,100	$ 2,100	$ 2,100	$ 2,100	$ 2,100
	Fipronil		$36,629	$ 36,629	$ 36,629	$ 36,629	$ 36,629	$ 36,629	$ 36,629	$ 36,629
	Maltose		$568,382	$ 568,382	$ 568,382	$ 568,382	$ 568,382	$ 568,382	$ 568,382	$ 568,382
	Carrageenan		$1,258,020	$ 1,258,020	$ 1,258,020	$ 1,258,020	$ 1,258,020	$ 1,258,020	$ 1,258,020	$ 1,258,020
	Sub-Total		$1,885,476	$ 1,885,476	$ 1,885,476	$ 1,885,476	$ 1,885,476	$ 1,885,476	$ 1,885,476	$ 1,885,476
2. Operating labor		(www.bls.gov) 40 emp.hrs per proc step, 350 days a year, 7 steps, $22.03/hr	$2,158,940	$ 2,158,940	$ 2,158,940	$ 2,158,940	$ 2,158,940	$ 2,158,940	$ 2,158,940	$ 2,158,940
3. Direct supervisory/clerical chair		20% of operating labor	$432,000	$ 432,000	$ 432,000	$ 432,000	$ 432,000	$ 432,000	$ 432,000	$ 432,000
4. Utilities										
	Steam		$500	$ 500	$ 500	$ 500	$ 500	$ 500	$ 500	$ 500
	Electricity		$1,200.00000	$ 1,200	$ 1,200	$ 1,200	$ 1,200	$ 1,200	$ 1,200	$ 1,200
	Total Utilities		$1,700	$ 1,700	$ 1,700	$ 1,700	$ 1,700	$ 1,700	$ 1,700	$ 1,700
5. Maintenance and Repairs		10% of FCI	$112,233	$ 112,233	$ 112,233	$ 112,233	$ 112,233	$ 112,233	$ 112,233	$ 112,233
6. Operating Supplies		1% of FCI	$2,622	$ 2,622	$ 2,622	$ 2,622	$ 2,622	$ 2,622	$ 2,622	$ 2,622
7. Laboratory Charges		20% of operating labor	$86,400	$ 86,400	$ 86,400	$ 86,400	$ 86,400	$ 86,400	$ 86,400	$ 86,400
Sub-Total			$4,679,371	$ 4,679,371	$ 4,679,371	$ 4,679,371	$ 4,679,371	$ 4,679,371	$ 4,679,371	$ 4,679,371
B. Fixed charges										
Local Taxes		1-4% of FCI	$44,893	$ 44,893	$ 44,893	$ 44,893	$ 44,893	$ 44,893	$ 44,893	$ 44,893
Insurance		1% of FCI	$11,223	$ 11,223	$ 11,223	$ 11,223	$ 11,223	$ 11,223	$ 11,223	$ 11,223
Financing		10% of TCI	$131,900	$ 131,900	$ 131,900	$ 131,900	$ 131,900	$ 131,900	$ 131,900	$ 131,900
Sub-Total			$188,017	$ 188,017	$ 188,017	$ 188,017	$ 188,017	$ 188,017	$ 188,017	$ 188,017
C. Plant Overhead Costs		70% of total costs for operating labor, supervision, and maintenance.	$1,892,221	$ 1,892,221	$ 1,892,221	$ 1,892,221	$ 1,892,221	$ 1,892,221	$ 1,892,221	$ 1,892,221
II. General Expenses										
A. Administrative Costs		25% of operating labor	$539,735	$ 539,735	$ 539,735	$ 539,735	$ 539,735	$ 539,735	$ 539,735	$ 539,735
B. Distribution/Selling Costs		2-20% of TPC	$235,684	$ 235,684	$ 235,684	$ 235,684	$ 235,684	$ 235,684	$ 235,684	$ 235,684
C. Research and Development Costs		5% of TPC	$117,842	$ 117,842	$ 117,842	$ 117,842	$ 117,842	$ 117,842	$ 117,842	$ 117,842
Sub-Total			$893,262	$ 893,262	$ 893,262	$ 893,262	$ 893,262	$ 893,262	$ 893,262	$ 893,262
III. Total Annual Cost		Manufacturing cost + general expenses	$5,760,649	$5,760,649	$5,760,649	$5,760,649	$5,760,649	$5,760,649	$5,760,649	$5,760,649
VI. Product Profit		#units sold per year * Price of Product	$ 15,156,864	$ 15,156,864	$15,156,864	$ 15,156,864	$ 15,156,864	$ 15,156,864	$ 15,156,864	$ 15,156,864
VII. Revenue		Profit - Total annual cost	$9,396,215	$9,396,215	$9,396,215	$9,396,215	$9,396,215	$9,396,215	$9,396,215	$9,396,215
		Units made per year	2,526,144							
		Batches per day	4							
		Price of Product	6							
		Units Sold	2,020,915							

Production Costs

- Total Annual Cost (year 1) = $5.6 MM
- Revenue (year 1) = $9.5 MM
  - Recover initial investment after first year
- Net Present Worth = $96.7 MM
  - Based on 10 year plant life
  - Process is profitable

Environmental Concerns

- Terrestrial damage
  - Acetonitrile weakly adsorbs to soil
  - Pyridine adsorbs to clay
- Aquatic damage
  - Fipronil, CH_2Cl_2 , acetonitrile, & pyridine deadly to fish
- Atmospheric pollution
  - Pyridine can last over 30 days in air
  - CH_2Cl_2 can last several months in air

Questions?

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