CULTIVATION STRATEGIES FOR MICROALGAE TO PRODUCE BIOFUELS

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Outline

- Introduction & Background
- Batch Reactor Modeling
- Larger Scale Cultivation

Energy Demand

- U.S. gasoline usage: 140 billion gallons/year
- U.S. petroleum diesel: 66 billion gallons/year
- U.S. jet fuel: 25 billion gallons/year

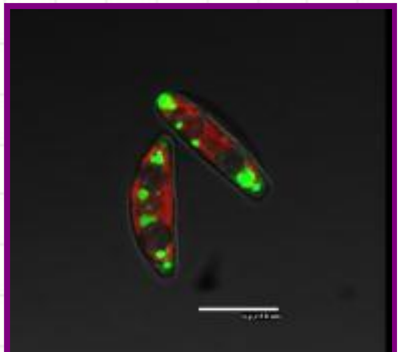


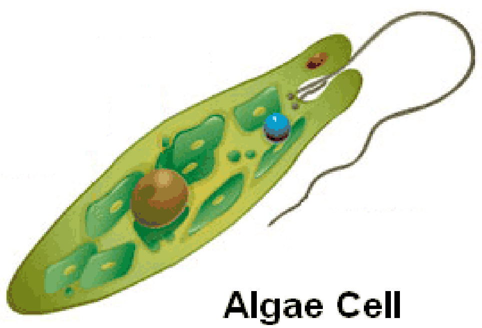
Triglycerides (TAGs) from oilseed crops can not meet U.S. diesel demand!

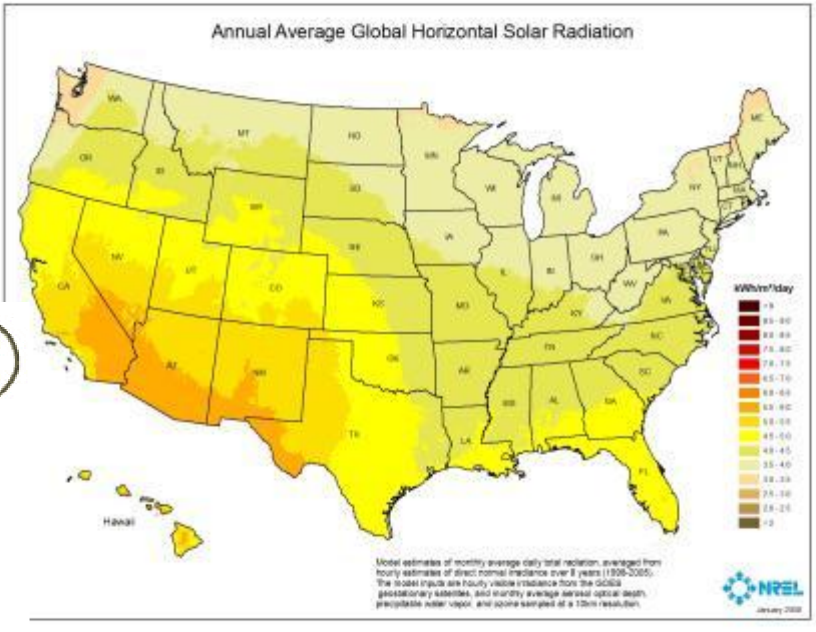
Alternative sources of TAGs are needed!

Advantages of Microalgae

- High oil content
- Short growth period and high growth rate
- Low cost of maintenance
- Grow in arid land and wastewater
- Carbon neutral
- Secondary products







Challenges

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Cultivation → **Oil Recovery** → **Fuel Production**

Cultivation	Oil Recovery	Fuel Production
Strain selection: high growth rate, oil content and fatty acids profile; Cultivation optimization; Water recycle & waste water; Open system design and scale up; Photobioreactor design; Temperature control; Invasion control; Environmental influence.	Harvesting biomass: Sedimentation, flocculation, floatation, filtration and centrifugation; Oil recovery: mechanical cell disruption followed by solvent extraction; Residual biomass.	Process optimization; Costs and life cycle analysis; Fuel characteristics; Additives required; Engine testing; ASTM standard.

Modeling

- A mathematical model was developed to describe growth curve, nitrate consumption and final lipid yield under nitrogen limited conditions;
- Will apply for other strains or similar batch system in the aim of predicting biomass yield and lipid accumulation;
- A useful tool to optimize fermentation process and design bioreactor in biofuel industry.

Modeling Assumption

1. Microalgae grow in a homogeneous and well mixed batch reactor.
2. Light intensity and temperature is constant under cultivation conditions.
3. Lipid accumulation depends on microalgae growth and nitrogen concentration.

Modeling Equations

Microalgae growth

Nitrogen limited growth for microalgae follows the well established cell-quota model, which shows that growth rate is more closely related to the intracellular nutrient concentration than to the external one.

$$\frac{dA(t)}{dt} = \mu(A,N)A(t)$$

$$\mu(A,N) = \mu_m(1 - \frac{q_0}{Q(t)})$$

$$Q(t) = \frac{A(0)Q(0) + N(0) - N(t)}{A(t)}$$

A(t) is microalgae biomass density (g/L dw); μ(A,N) is algae growth rate (hr^{-1}); Q(t) is the cell quota or internal nitrate concentration per biomass density.

Modeling Equations

Nitrate consumption

Inorganic nitrogen assimilation is modeled using the Michaelis-Menten expression and the maximum nitrogen assimilation rate is regulated by the cell N quota.

$$\frac{dN(t)}{dt} = -v(A, N)A(t)$$

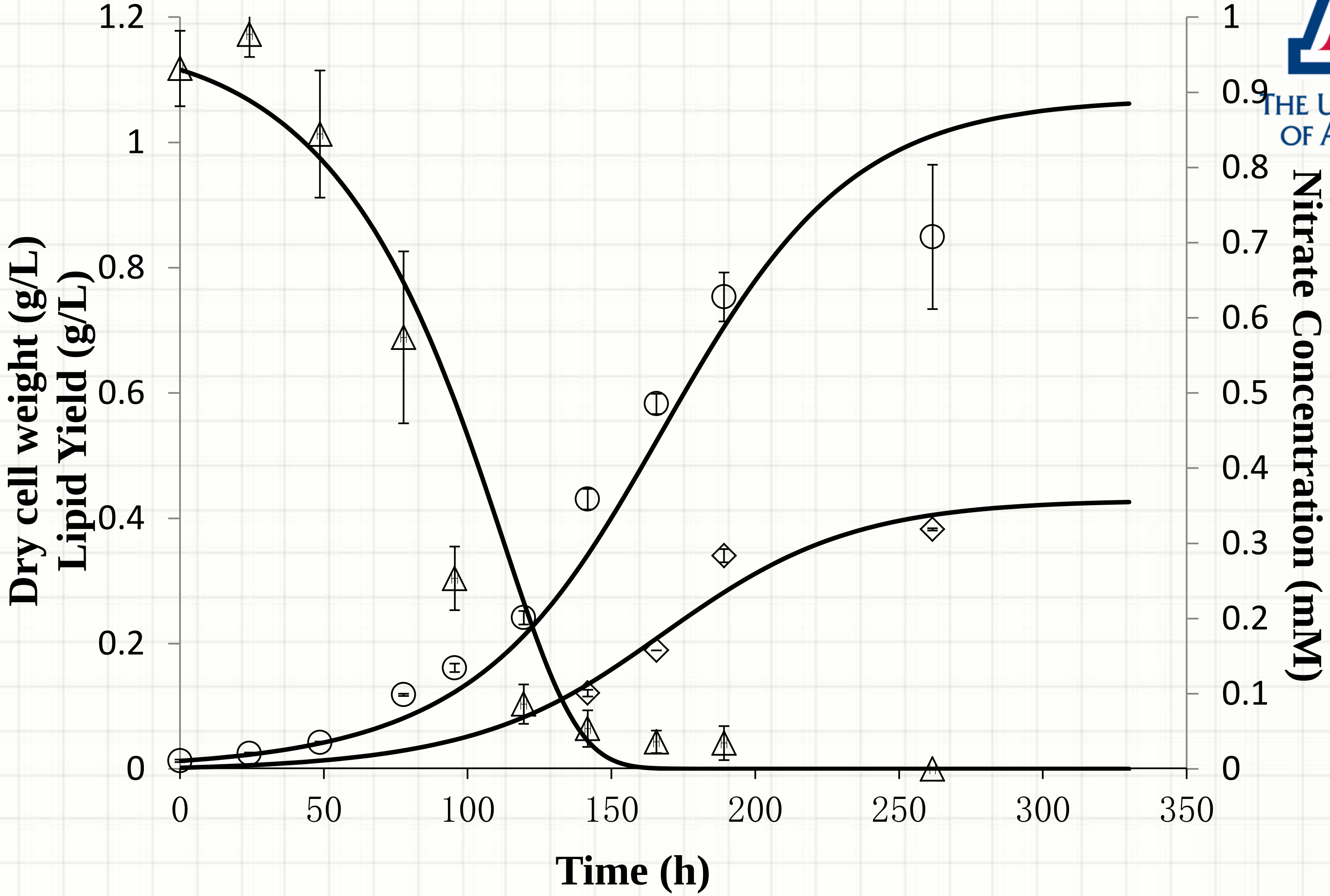
$$v(A, N) = \frac{Q_{\max} - Q(t)}{Q_{\max} - q_0}\left(\frac{v_m N(t)}{N(t) + K_{nit}}\right)$$

Lipid production

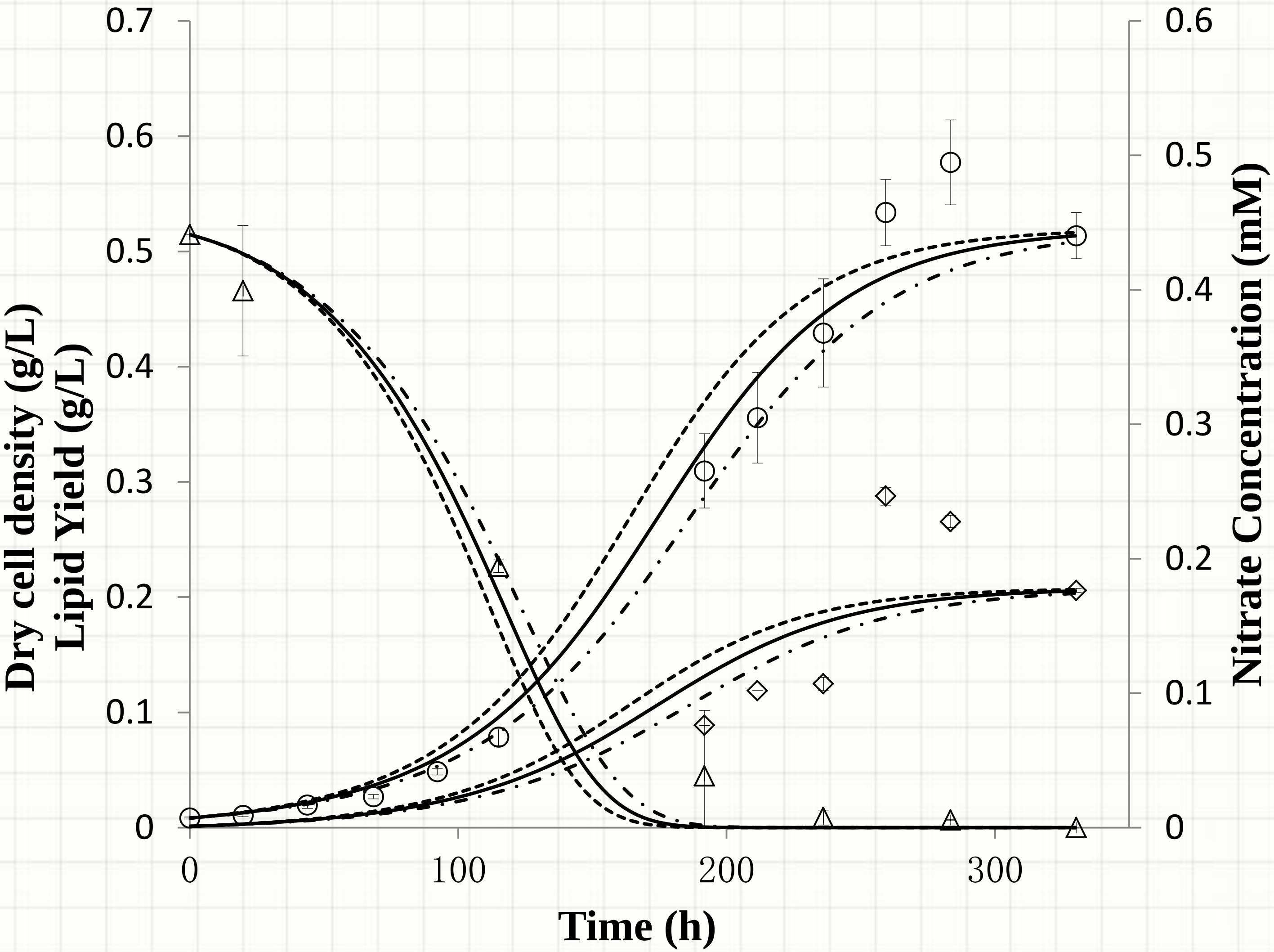
The equation used to model lipid production is derived from the Luedeking-Piret equation.

$$\frac{dL(t)}{dt} = \alpha\frac{dA(t)}{dt} + \beta A(t)$$

N(t) is nitrogen concentration in the solution(g/L); L(t) is lipid yield(g/L).



Simulation results of microalgae growth, nitrate consumption and lipid yield (solid line) at 100% N versus time. Experimental data are shown as dry cell density (o), nitrate concentration (Δ) and lipid yield (◊).



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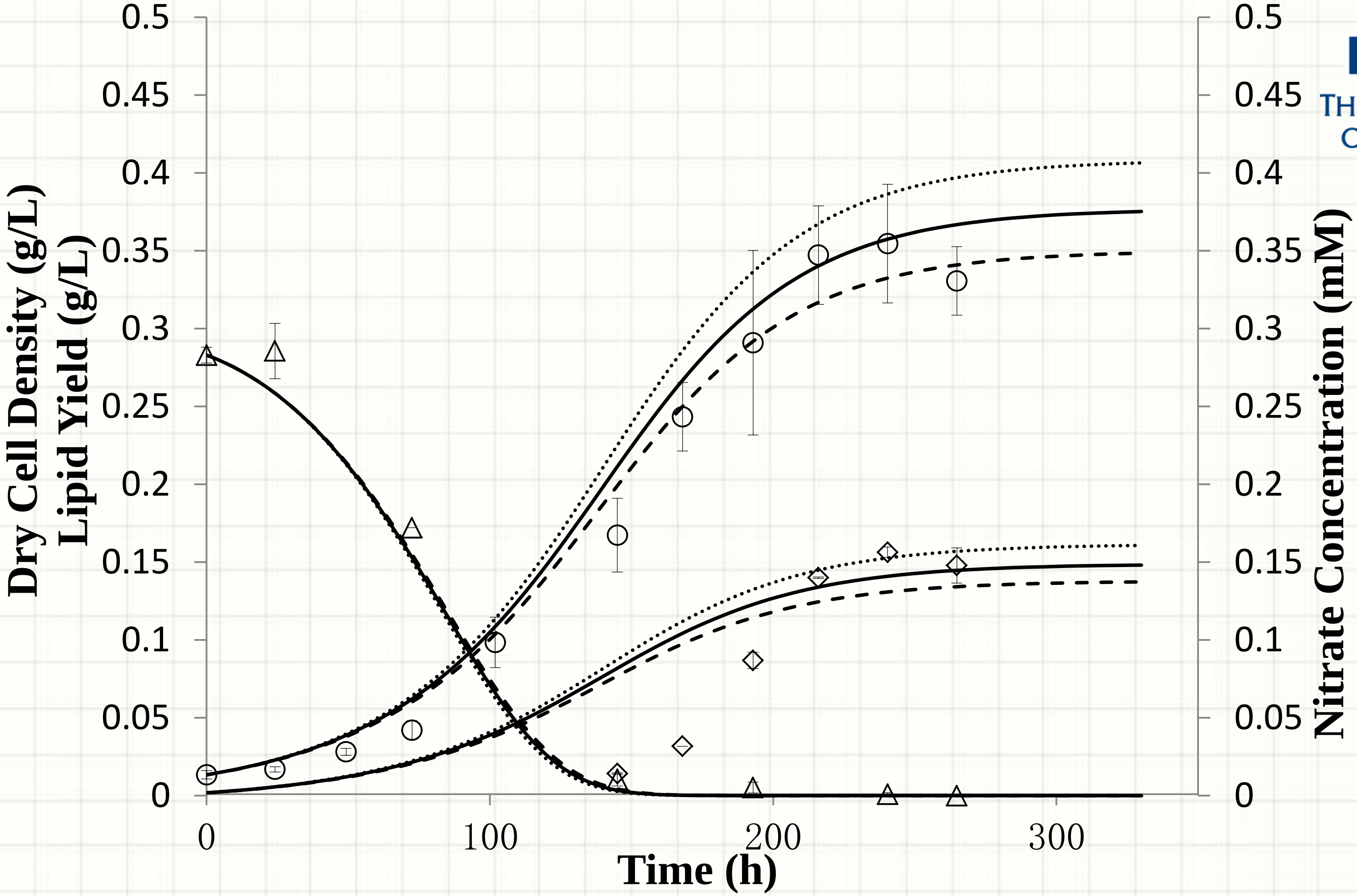
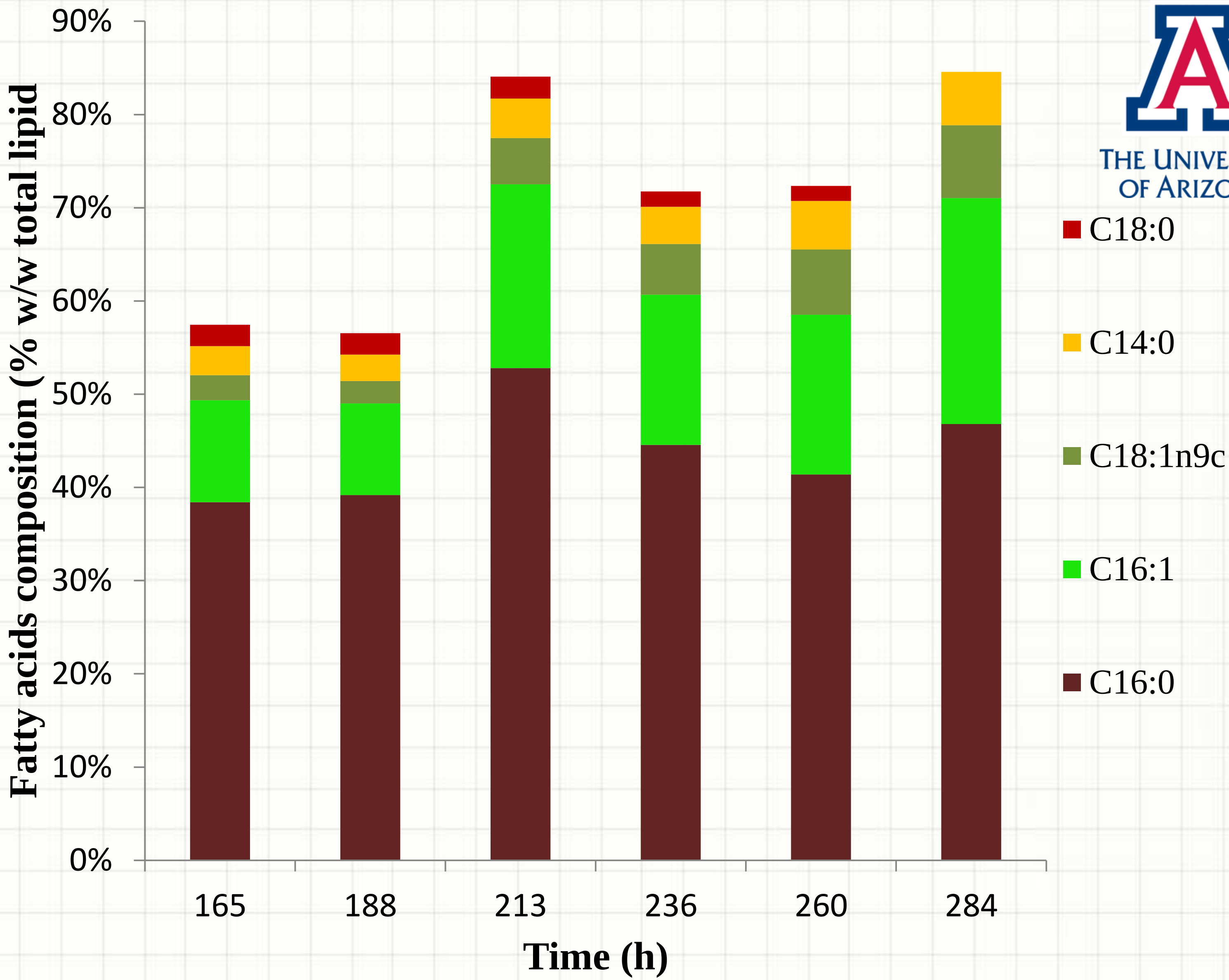
Simulation results of microalgae growth, nitrate consumption and lipid yield (solid line) at 50% N versus time when μ_m=0.028±0.002hr^{-1}. Experimental data are shown as dry cell density (o), nitrate concentration (Δ) and lipid yield (◊).



Simulation results of microalgae growth, nitrate consumption and lipid yield (solid line) at 25% N versus time when q_0=0.0013±0.0001g N g^{-1} dw. *Experimental data* are shown as dry cell density (o), nitrate concentration (Δ) and lipid yield (◊).



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Percentage of individual fatty acid methyl ester (FAME) composition profile with time course (25% NaNO3). Values shown are averages of four replicated

Conclusions-Modeling

- Model successfully described microalgae growth curve, nitrate consumption and lipid yield under nitrogen limitations.
- This is a simple mathematical model requiring less parameters and experiments, easy to understand and apply.
- Lipid composition is a weak function of cultivation time at stationary phase.

Outdoor Cultivation

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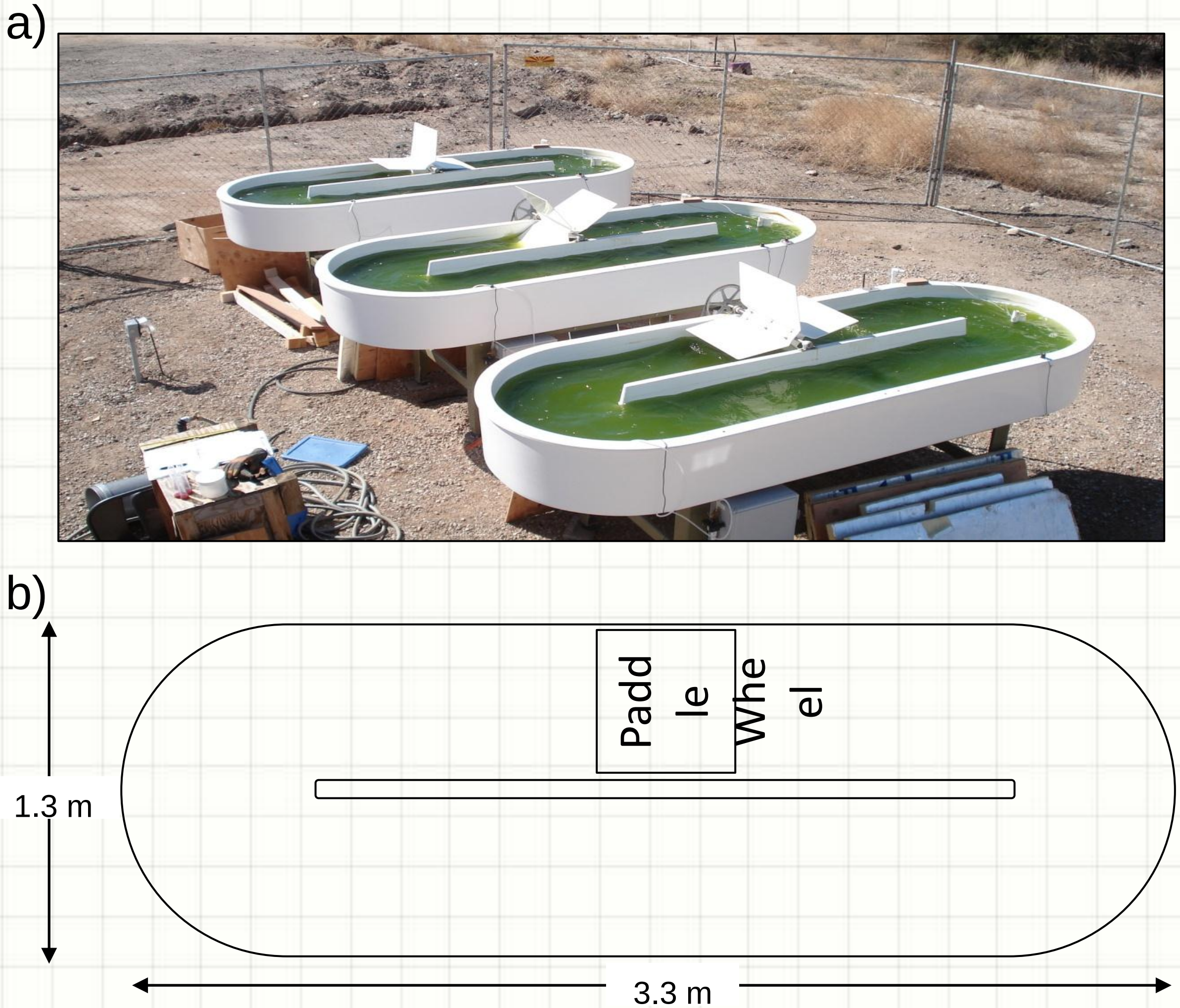
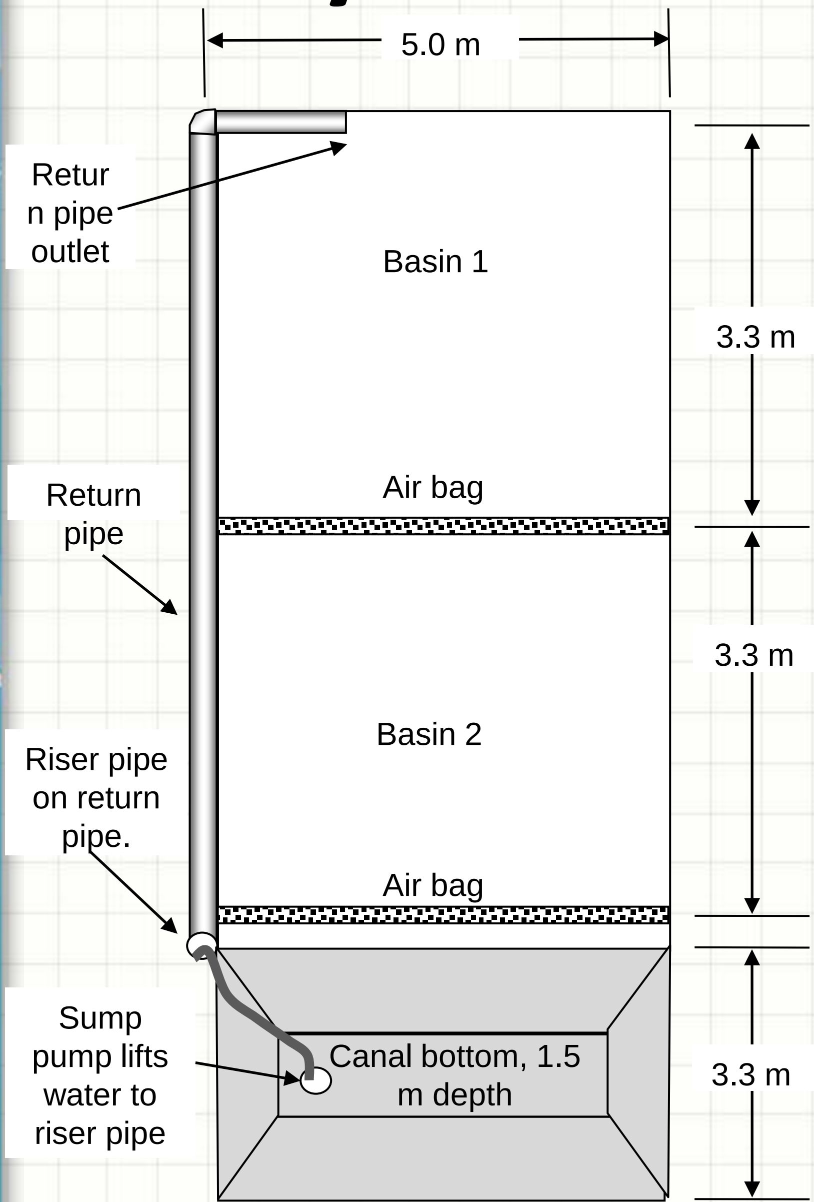
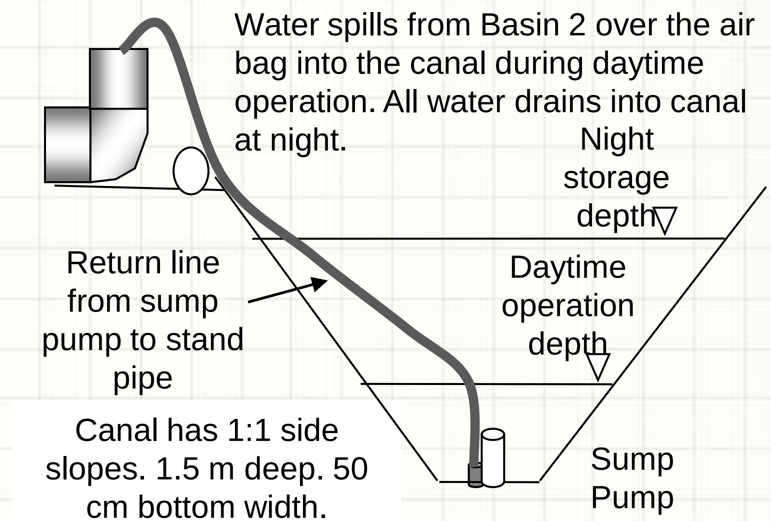


a) Conventional raceways on day 26, 2/21/2011. b) Raceway schematic and dimensions.

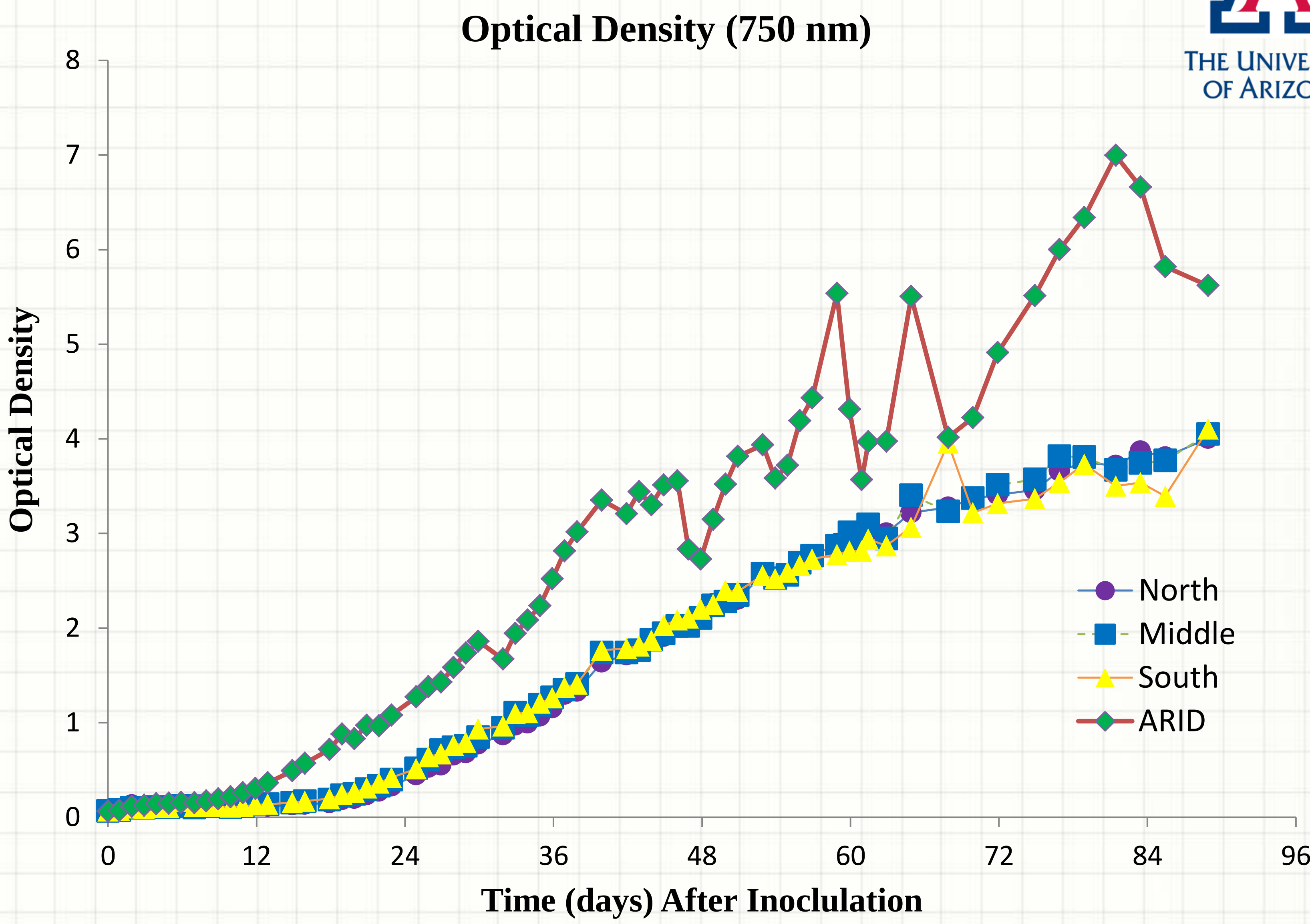
Arid System



5.0 m
Return pipe outlet
Basin 1
3.3 m
Air bag
Return pipe
Basin 2
3.3 m
Riser pipe on return pipe.
Air bag
Sump pump lifts water to riser pipe
Canal bottom, 1.5 m depth
3.3 m



Water spills from Basin 2 over the air bag into the canal during daytime operation. All water drains into canal at night.
Night storage depth
Return line from sump pump to stand pipe
Daytime operation depth
Canal has 1:1 side slopes. 1.5 m deep. 50 cm bottom width.
Sump Pump



Optical Density (750 nm)
Optical Density
Time (days) After Inoclulation
0
1
2
3
4
5
6
7
8
0
12
24
36
48
60
72
84
96
North
Middle
South
ARID
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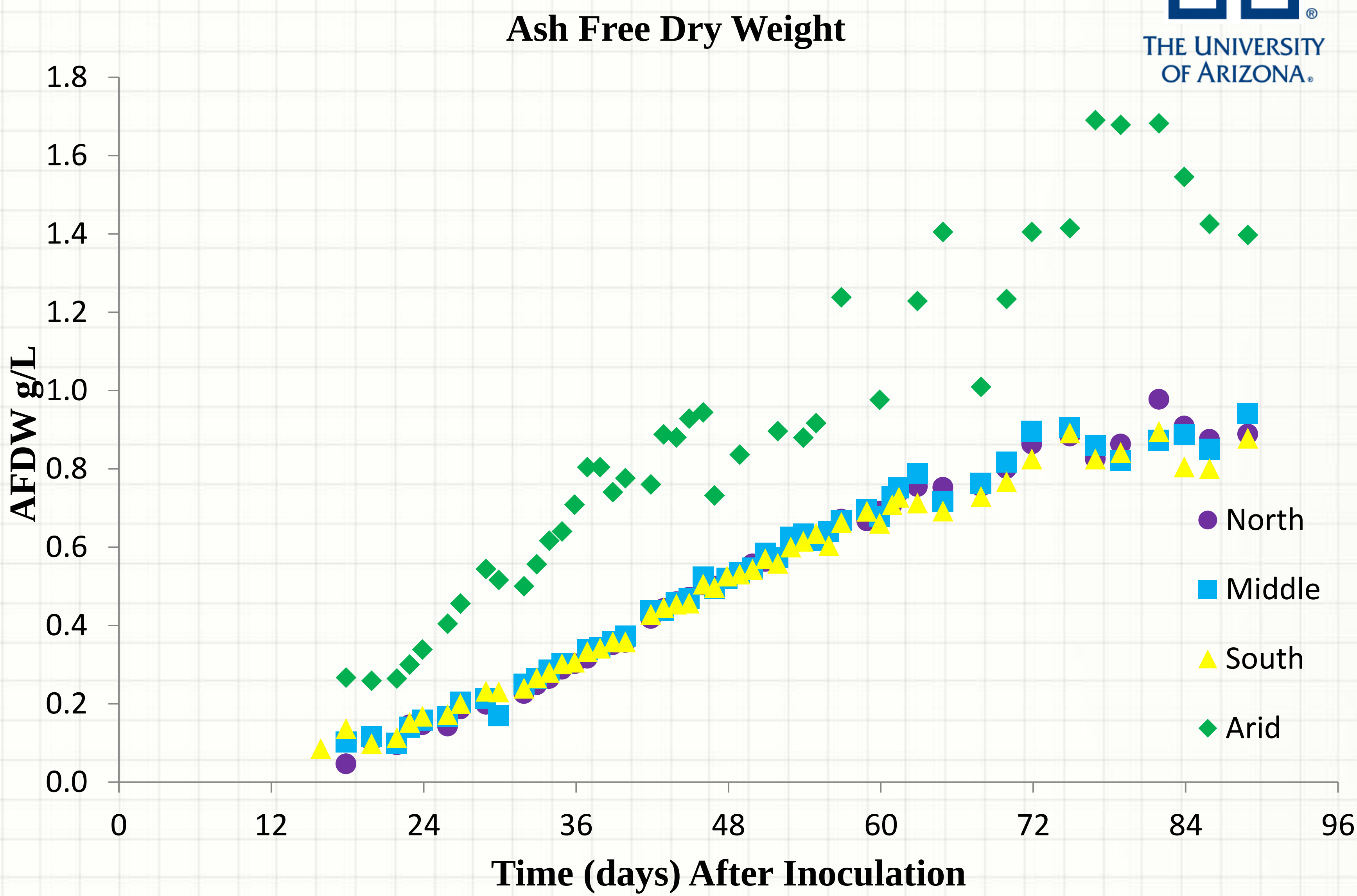

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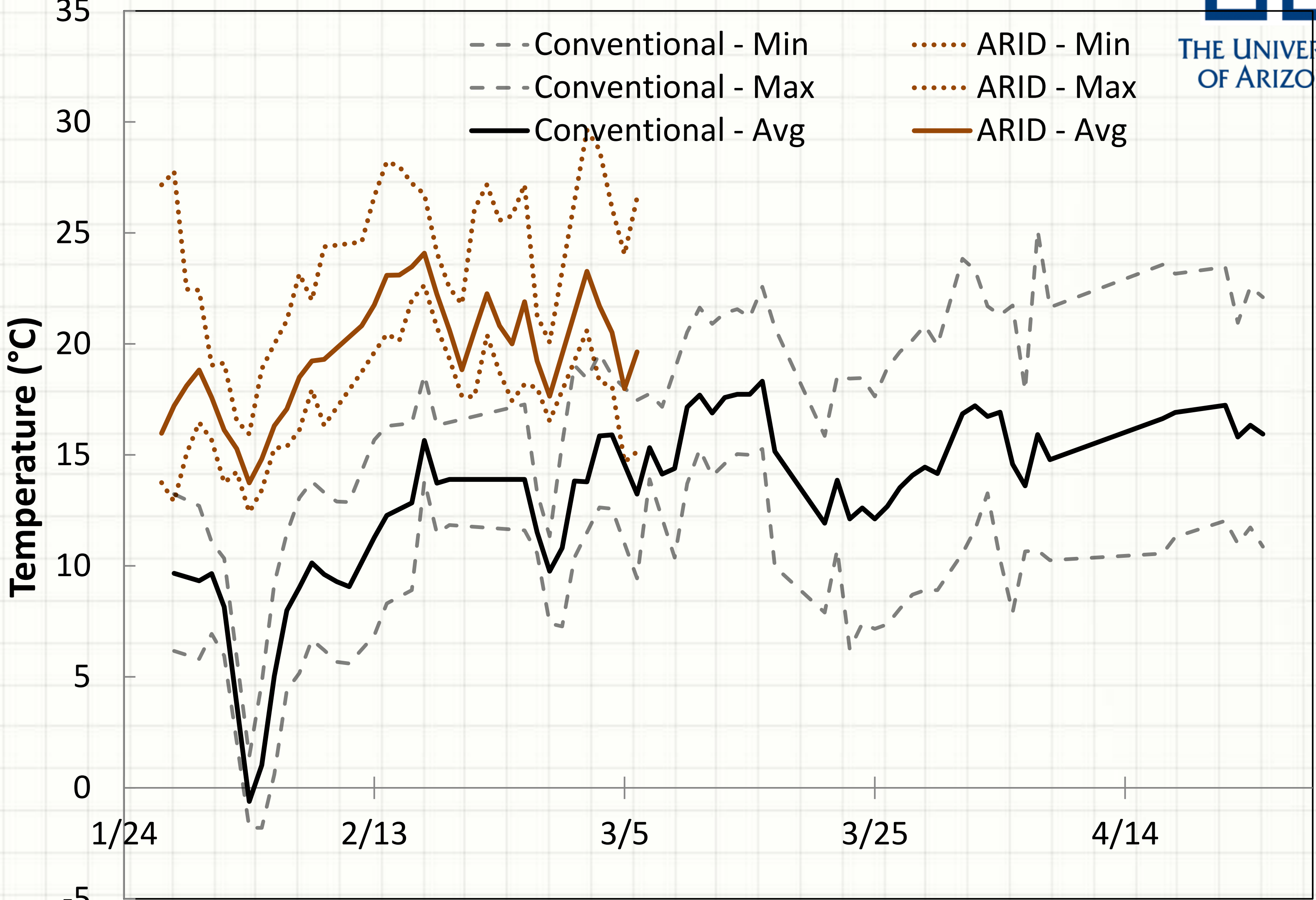

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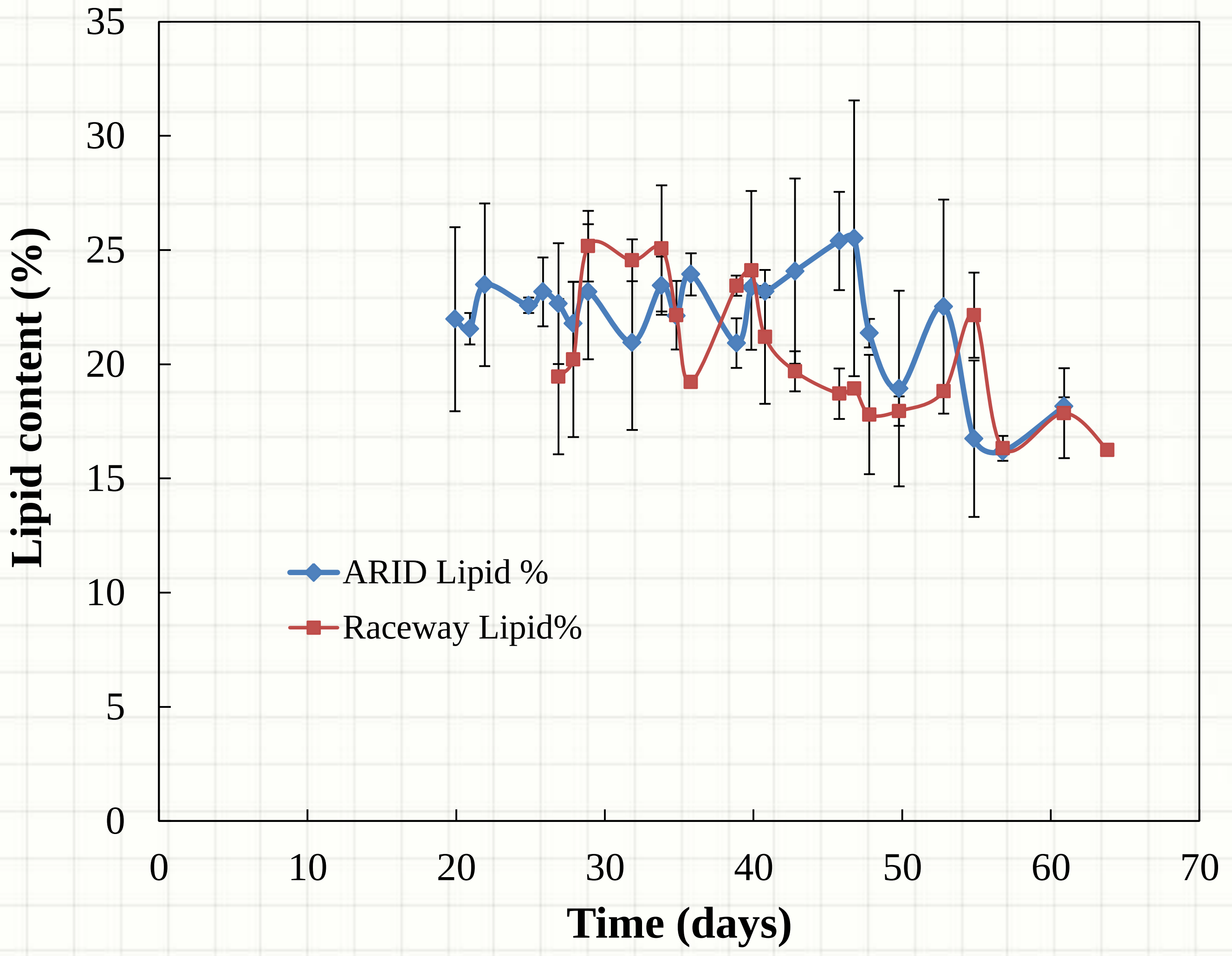
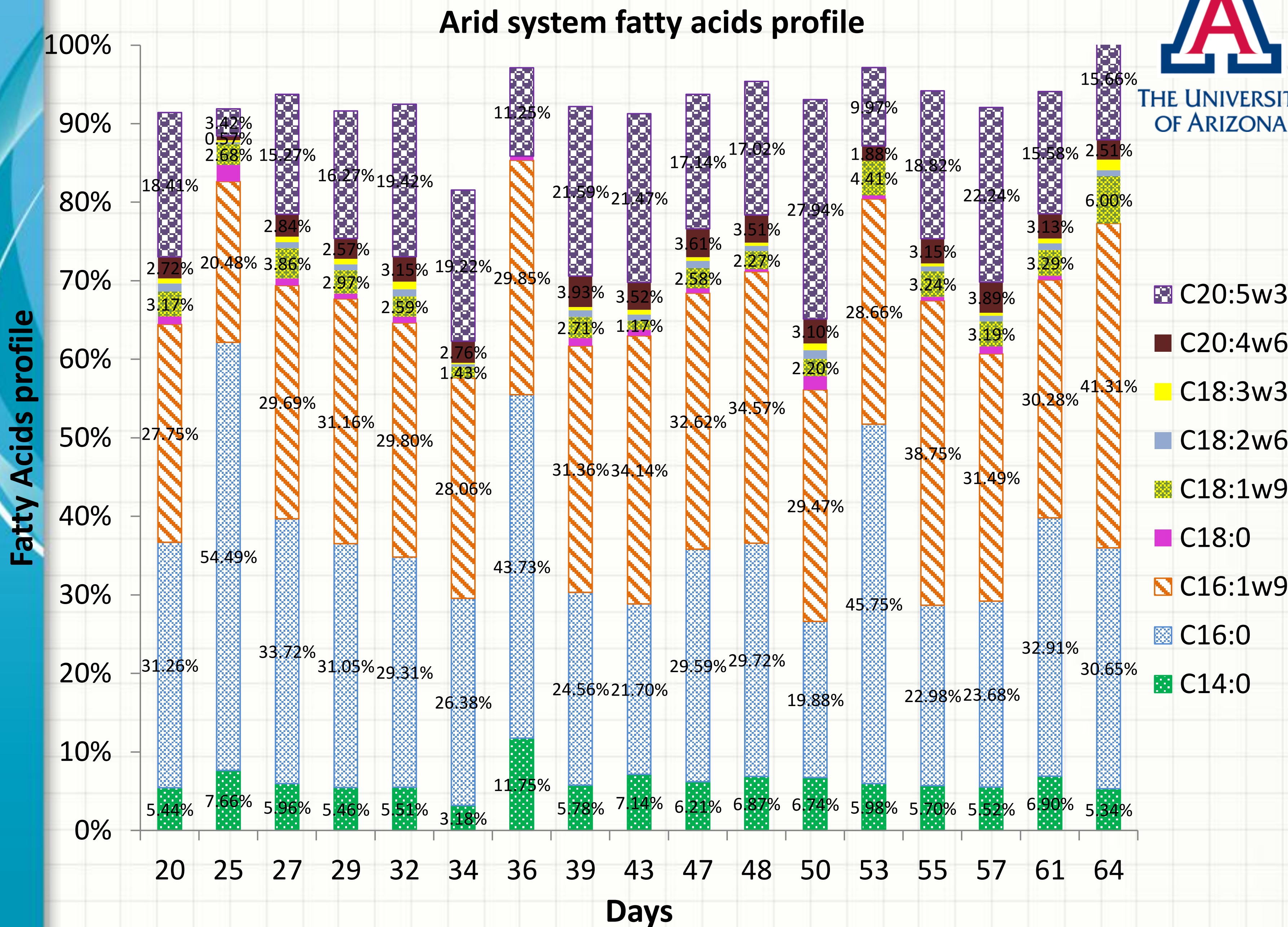
Lipid content vs time





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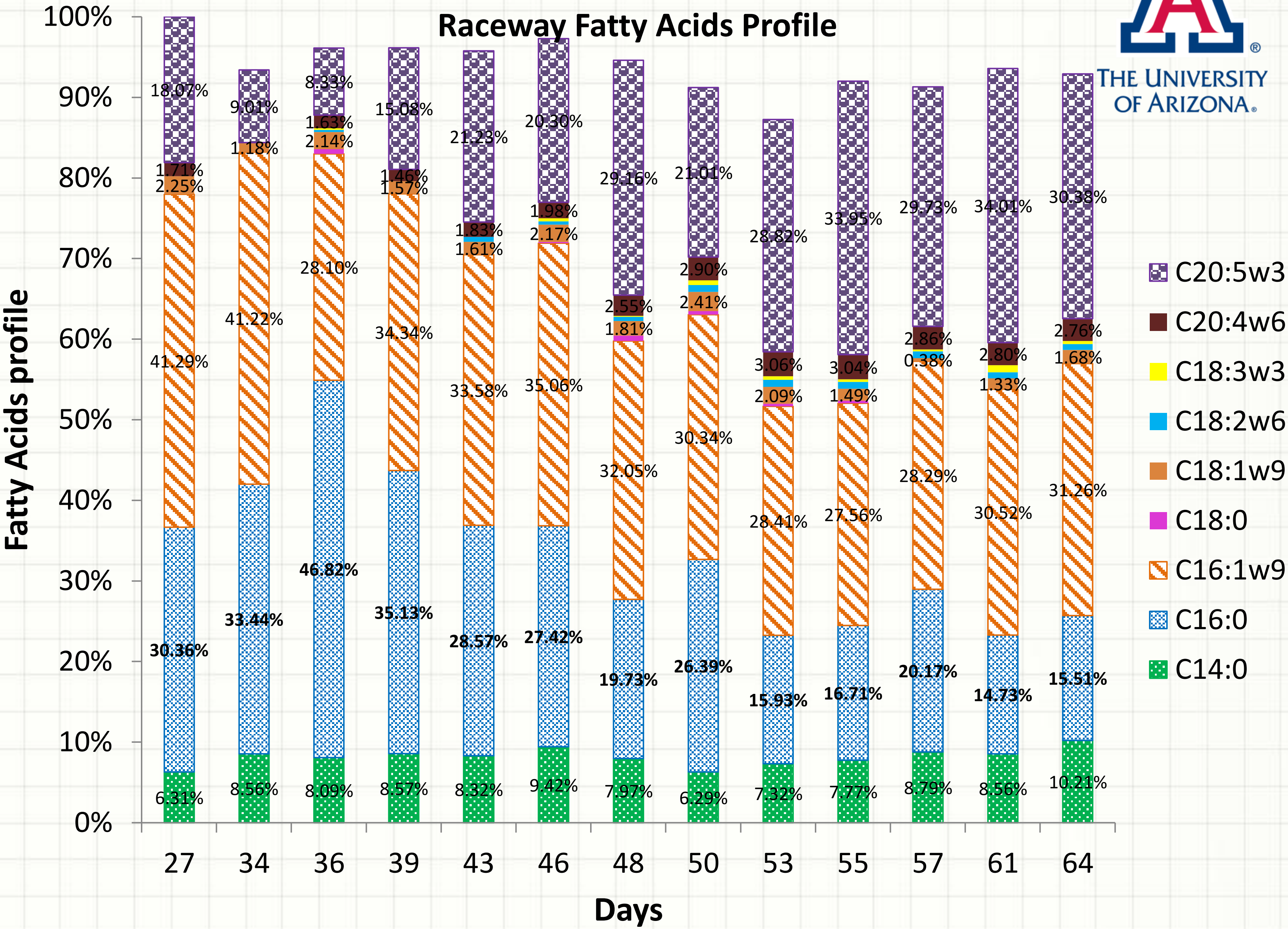
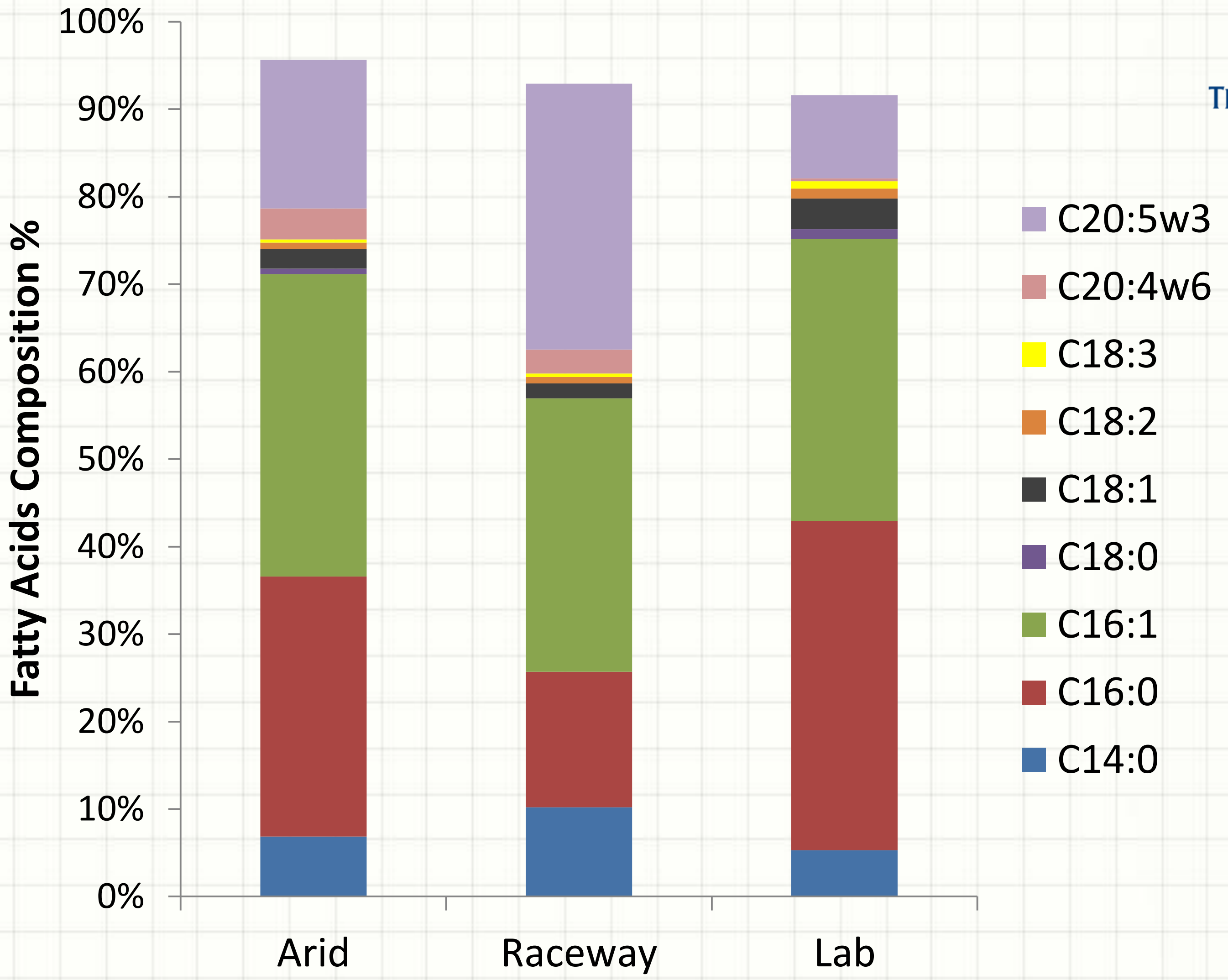


Raceway Fatty Acids Profile
Fatty Acids profile
Days
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
27
34
36
39
43
46
48
50
53
55
57
61
64
C20:5w3
C20:4w6
C18:3w3
C18:2w6
C18:1w9
C18:0
C16:1w9
C16:0
C14:0
18.07%
1.71%
2.25%
41.29%
30.36%
6.31%
9.01%
1.18%
41.22%
33.44%
8.56%
8.33%
1.63%
2.14%
28.10%
46.82%
8.09%
15.08%
1.46%
1.57%
34.34%
35.13%
8.57%
21.23%
1.83%
1.61%
33.58%
28.57%
8.32%
20.30%
1.98%
2.17%
35.06%
27.42%
9.42%
29.16%
2.55%
1.81%
32.05%
19.73%
7.97%
21.01%
2.90%
2.41%
30.34%
26.39%
6.29%
28.82%
3.06%
2.09%
28.41%
15.93%
7.32%
33.95%
3.04%
1.49%
27.56%
16.71%
7.77%
29.73%
2.86%
0.38%
28.29%
20.17%
8.79%
34.01%
2.80%
1.33%
30.52%
14.73%
8.56%
30.38%
2.76%
1.68%
31.26%
15.51%
10.21%



Fatty acids profile comparison at stationary phase in three different culture systems

Conclusions-outdoor cultivation

- Lipid content achieved maximum in the middle and end of first exponential growth period.
- Cells aging and no nitrogen starvation might be reasons of lower lipid content with longer cultivation.
- Cell growth rate was highly depended on environmental temperature.
- Low levels of predators present throughout experiment.
- Fatty acid composition was affected by environmental factors.
- Demonstrate the potential of culturing large scale algae in desert area

QUESTIONS?