PHOTOSYNTHESIS IN ENHANCED CATFISH PRODUCTION SYSTEMS

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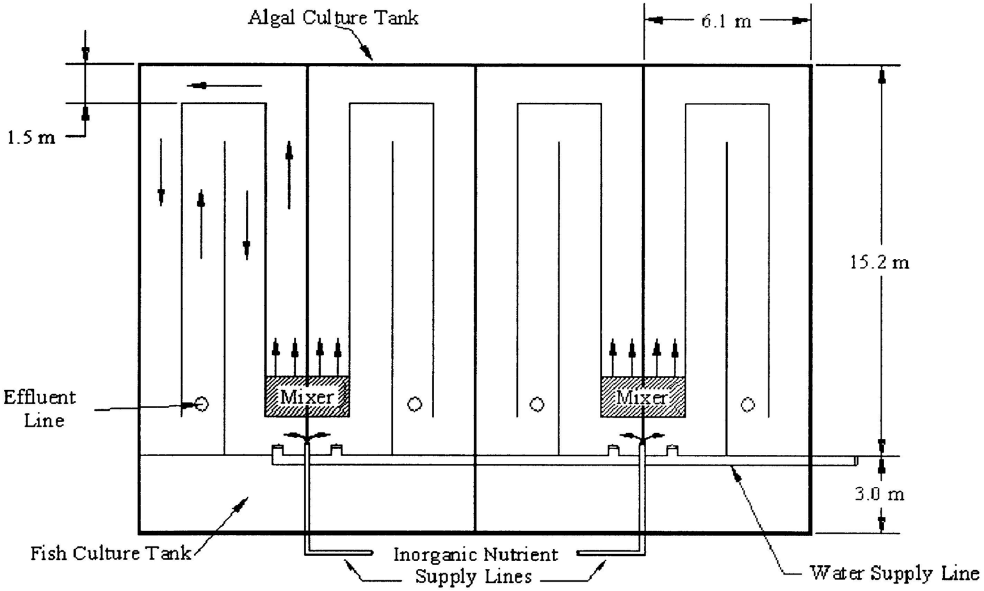
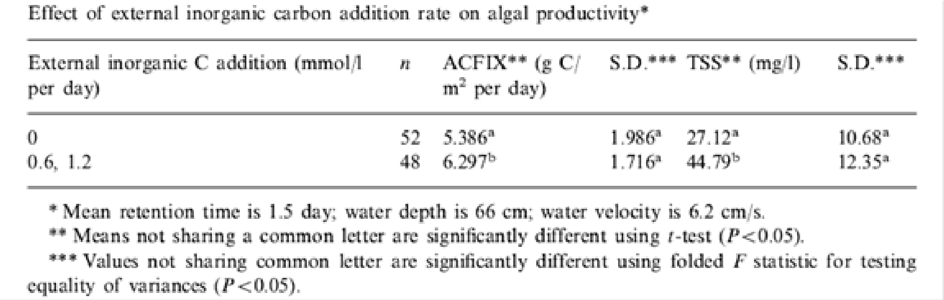
Enhanced Photosynthetic Aquaculture Production Systems

1) Partitioned Aquaculture System; 1/40, 1/3 and 2 acre systems at Clemson University
2) Split-Pond Prototypes at Stoneville MS; 5-7 acres
3) Intensively Aerated Ponds at Stoneville MS 1.0-4.0 acres
4) In-Pond Raceways at Auburn University; 4-6 acres



Prototype 1/40 acre Partitioned Aquaculture System;

Cycle time = 10 - 30 min,
Water depth =2.2 ft
Water velocity = 0.2-0.4 ft/sec.
Alkalinity 60 -120 mg/l
Algal cell age = 1.2-2.5 days (hydraulic detention)



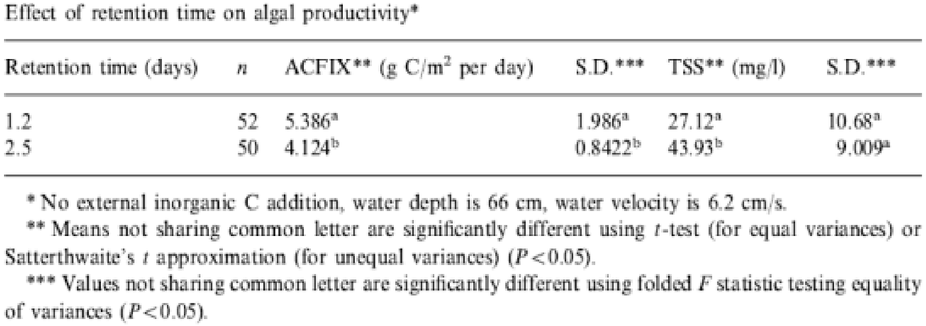
Effect of external inorganic carbon addition rate on algal productivity*

External inorganic C addition (mmol/l per day)	*n*	ACFIX** (g C/m^2 per day)	S.D.***	TSS** (mg/l)	S.D.***
0	52	5.386^{a}	1.986^{a}	27.12^{a}	10.68^{a}
0.6, 1.2	48	6.297^{b}	1.716^{a}	44.79^{b}	12.35^{a}

* Mean retention time is 1.5 day; water depth is 66 cm; water velocity is 6.2 cm/s.

** Means not sharing a common letter are significantly different using *t*-test ($P<0.05$).

*** Values not sharing common letter are significantly different using folded *F* statistic for testing equality of variances ($P<0.05$).



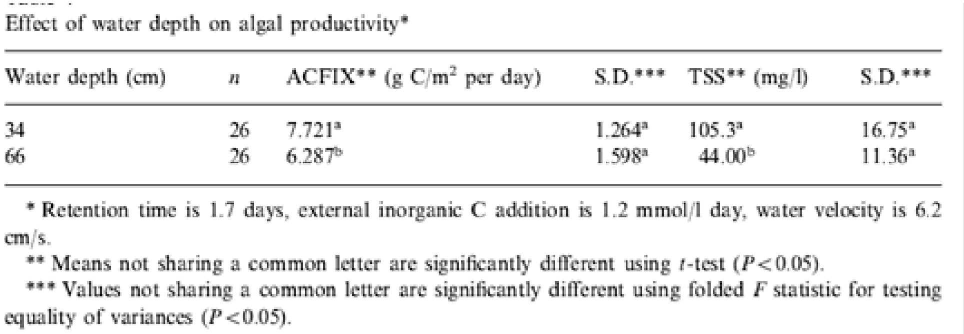
Effect of retention time on algal productivity*

Retention time (days)	*n*	ACFIX** (g C/m^2 per day)	S.D.***	TSS** (mg/l)	S.D.***
1.2	52	5.386^{a}	1.986^{a}	27.12^{a}	10.68^{a}
2.5	50	4.124^{b}	0.8422^{b}	43.93^{b}	9.009^{a}

* No external inorganic C addition, water depth is 66 cm, water velocity is 6.2 cm/s.

** Means not sharing common letter are significantly different using *t*-test (for equal variances) or Satterthwaite's *t* approximation (for unequal variances) ($P<0.05$).

*** Values not sharing common letter are significantly different using folded *F* statistic testing equality of variances ($P<0.05$).



Effect of water depth on algal productivity*

Water depth (cm)	*n*	ACFIX** (g C/m^2 per day)	S.D.***	TSS** (mg/l)	S.D.***
34	26	7.721^{a}	1.264^{a}	105.3^{a}	16.75^{a}
66	26	6.287^{b}	1.598^{a}	44.00^{b}	11.36^{a}

* Retention time is 1.7 days, external inorganic C addition is 1.2 mmol/l day, water velocity is 6.2 cm/s.

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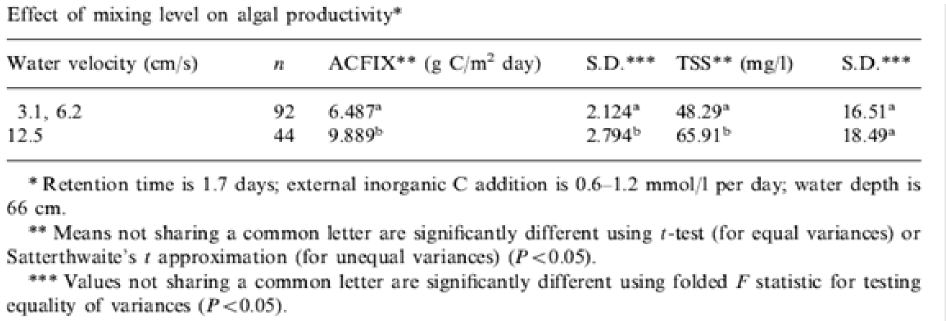


Effect of mixing level on algal productivity*

Water velocity (cm/s)	*n*	ACFIX** (g C/m^2 day)	S.D.***	TSS** (mg/l)	S.D.***
3.1, 6.2	92	6.487^{a}	2.124^{a}	48.29^{a}	16.51^{a}
12.5	44	9.889^{b}	2.794^{b}	65.91^{b}	18.49^{a}

* Retention time is 1.7 days; external inorganic C addition is 0.6–1.2 mmol/l per day; water depth is 66 cm.

** Means not sharing a common letter are significantly different using *t*-test (for equal variances) or Satterthwaite's *t* approximation (for unequal variances) ($P<0.05$).

*** Values not sharing a common letter are significantly different using folded *F* statistic for testing equality of variances ($P<0.05$).

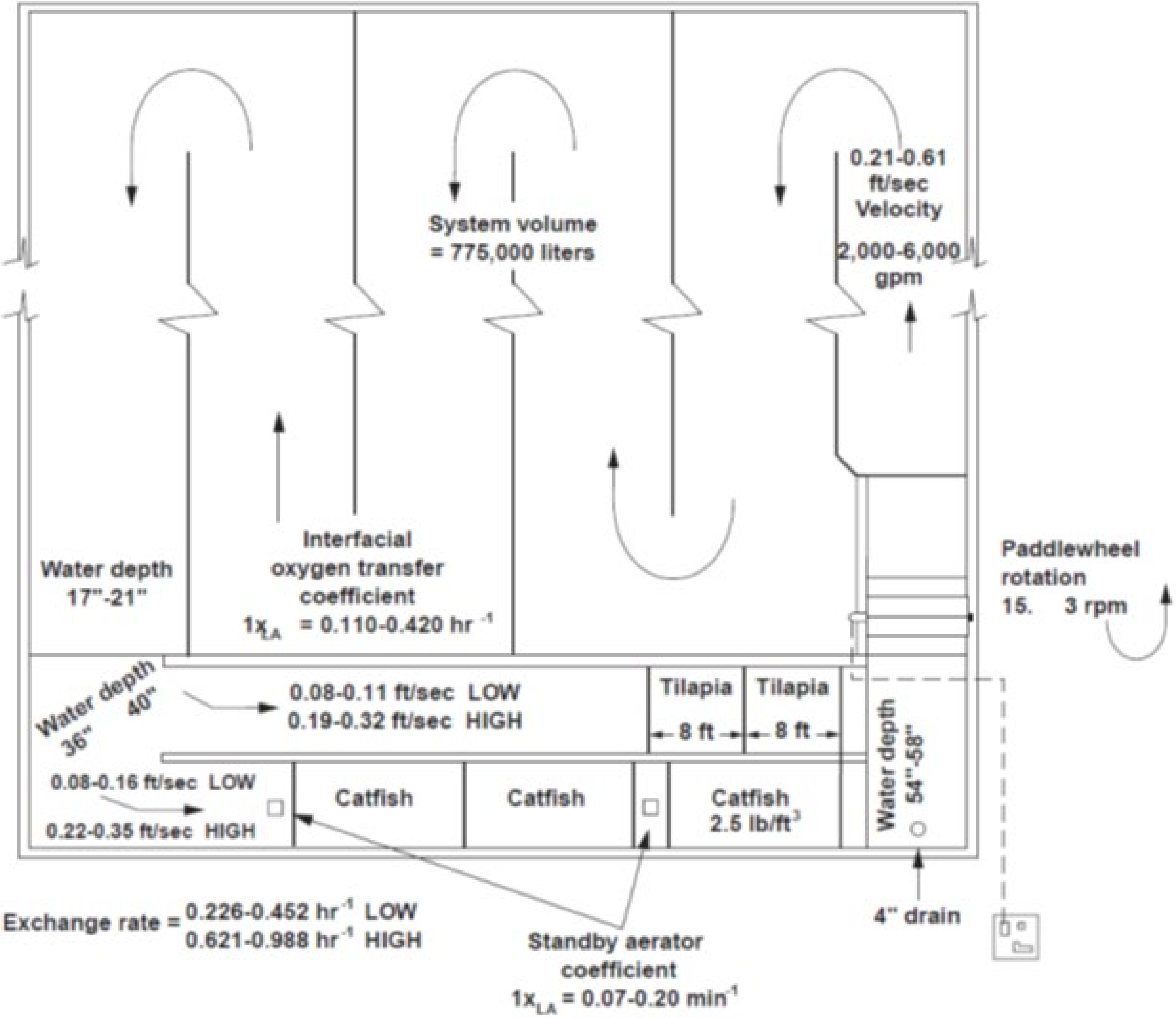
*Variables examined = alkalinity, cell age, water depth, and water velocity

Most significant controllable variable (on photosynthesis) is water velocity

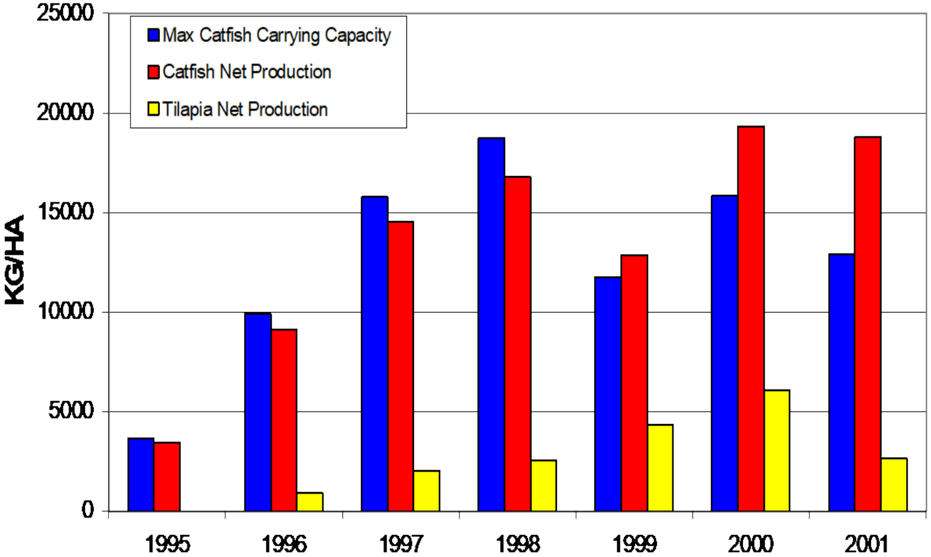
Increasing velocity from 0.2 to 0.4 fps increased algal production from 6.5 to 9.9 g-C/m^2-day

*Drapcho, C. M., and D. E Brune, The Partitioned Aquaculture System; Impact of Design and Environmental Parameters on Algal Productivity and Photosynthetic Oxygen Production, Aquacultural Engineering, 21 (2000) 151-168

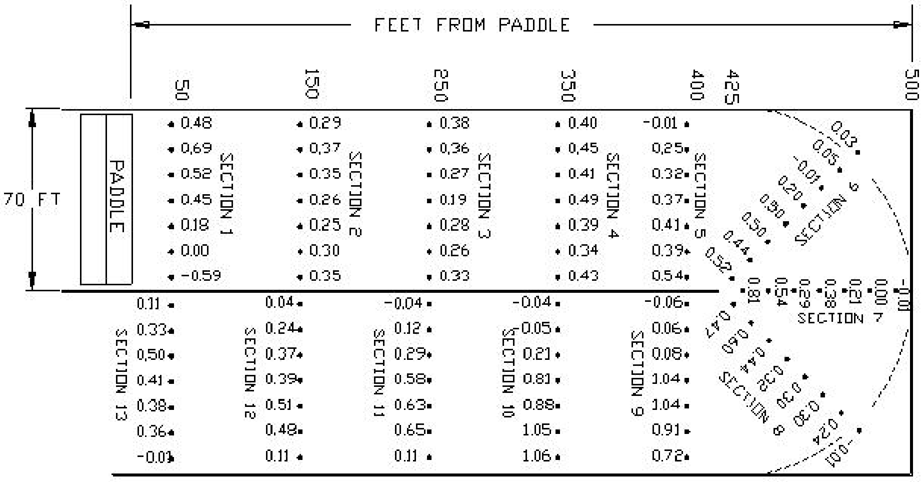
Representation of 1/3 acre PAS ;Typical water velocity = 0.4 ft/sec, Cycle time ~ 1 hr



Two-acre Partitioned Aquaculture System (PAS); Paddlewheels providing uniform water mixing/increased photosynthesis (in treatment zone) with cultured fish in high-density raceways.



Clemson University Two-Acre PAS averaging 2.3 hrs cycle-time in waste treatment zone (~ 0.38 fps velocity); Increased fish production ~ 18,000 lb/acre



AVERAGE VELOCITY
2 PADDLE 3.4 rpm

To take advantage of enhanced algal treatment in PAS, a lower cost version of the PAS, entitled the Split-Pond (SP), was installed at the Warm Water Aquaculture Center in Stoneville Mississippi in 2001.

Seven-Acre Split-Pond with Levee in Five-Acre Waste Treatment Zone using Culvert Pumps Delivering 8,000 gpm (11.8 hrs cycle time, ~ 0.0 – 0.048 fps)

Seven-Acre Split-Pond without Levee in Five-Acre Waste Treatment Zone using Paddlewheel Delivering 10,000 to 15,000 gpm Water Flow (9.4-6.3 hrs cycle time, ~ 0.0- 0.06 fps)

Paddlewheel Used to Move Water in Split-Pond at NWAC.

Enhanced Photosynthetic Catfish Production Systems; Intensively Aerated Ponds

Intensively aerated ponds (IP) at NWAC/MS (2014-2018) demonstrated 9,000–15,000 lb/acre-yr catfish production in 1.0-4.0 acre ponds with fish confined to 100% of pond area(9)

Enhanced Photosynthetic Catfish Production Systems; In-Pond Raceways

In-Pond Raceways (IPR) at Auburn University (2006-2017) demonstrated 18,300 lb/acre catfish production in 6.0 acre pond with fish confined to 2.0% of pond area(10,11)

Comparison of Oxygen Dynamics in PAS, Conventional Catfish Ponds, Split Ponds, and Intensively Aerated Ponds.

	Oxygen (lb/acre-day)				
System	Surface	Fish	Photosynthesis	Sediment	Photo % of Fish
Clemson PAS	+72	-150	+180	-102	120 %
Conventional Pond	+40	-50	+32	-22	64 %
MS Split-Pond	+40	-180	+140	-76	78 %
MS IP	+80	-237	+157	-78	66 %

Catfish Production and Feed Application in PAS, Conventional Ponds, (CP), Intensively Aerated Ponds, (IP), and Split-Ponds (SP) with/without Dividing Levee within Treatment Zone (250 lbs-feed/acre-day ~ 4-6 gm-C/m^2-day algal photosynthesis)

Type	Max capacity lbs-fish/acre	Feed loading (lbs/acre-day)	FCR feed/fish
		1995-2008 (2 acre)	
PAS	15,000-18,000	160/250	1.4-1.6
CP	5,000-7,500	100/150	~2.0
		2014 -2015 (2 acre)	
SP	12,800 -14,032	110/280	1.7- 1.9
IP	9,200- 18,245	84/270	1.8 -1.9
		2015- 2020 (7 acre)	
SP open	12,330-19,872	190/210	1.8-2.6
SP channel	9,830-15,600	105/164	1.9-2.6

Representative Culture Footprint, Aeration Energy, and Yield of Enhanced Catfish Production

System	Fish Culture	Typical Acres	Aeration energy hp/ac	Yield Range lb/ac
PAS	5%	2.0	6.0	17,000-18,000
SP	20%	5-7	6-10	13,000-17,000
IP	100%	1-4	6-10	7,000-17,000
IPR*	2%	6	3.0	13,400
CP	100%	5-10	1-2	5,000-8,000

Average PAS production is highest, followed by SP, IP, IPR and CP. Observed fish production in IP is more variable than in SP(12,13)

* IPR highly variable

Algal Removal Mechanism, Density/ Cell Age and Dominant Algal Species in Enhanced Catfish Production Systems

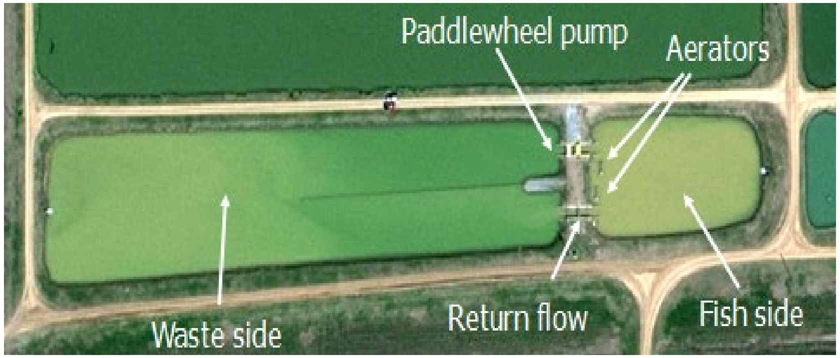
Type	Algal Density Seechi Disk/TSS (cm / mg/l)	Algal removal mechanism (apparent)	Algal genera	Algal cell age (days)
PAS	18 / 80	tilapia/sedimentation	green	3.3
SP	13 /110	zooplankton/sedimentation	bluegreen[1]	4.6
IP	12 / 115	zooplankton/sedimentation	bluegreen[1]	3.8
CP	13 / 110	zooplankton/sedimentation	bluegreen[2]	9.0

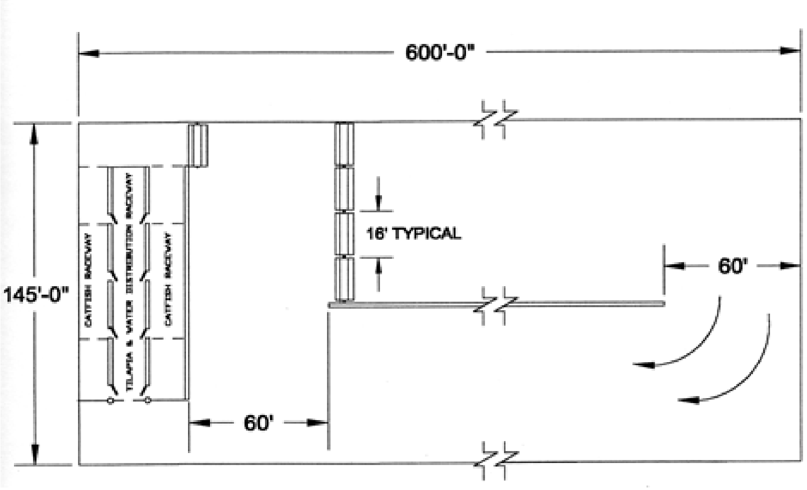
[1] Oscillatoria

[2] Oscillatoria, Microcystsis Anabaena

PAS algal density 70% of SP, IP and CP and dominated by green algae (because of tilapia feeding).
BG algae dominate SP, IP and CP(20)

Comparison of Functionality of Enhanced Catfish Production Systems: SP vs PAS





Water Treatment 4.3 ft,
(72% of total volume)
Photosynthesis; Top 30%
Aerobic Treatment; Top 65%

Anoxic Treatment; Variable15%

Anaerobic Treatment; bottom 35%

Fish Culture 6.0 ft,
(28% of total volume)

12,000 gpm
5 fish-zone exchanges/day

	Photo	N-Recycle	Nitrification	Sludge Retention
PAS	H	H	L	L
SP	H	H	M	H
IP	H	M	L	H
CP	L	M	L	H

PAS operates with shallow water column/high velocity, and high rate of photosynthesis, N recycle and storage in tilapia biomass

SP stores bulk of excreted nitrogen as settled algal biomass in anaerobic waste treatment zone providing increased nitrogen treatment (including nitrification), with improved operator control of ammonia levels within fish culture zone.

IP and CP store settled algal biomass in fish culture sediments, more prone to ammonia release within fish culture zone, driven by changing wind/temperature.

Detailed determination of risk benefit of SP vs IP will required more data on sedimentation and mineralization rates in IP.

(21,22)

Enhanced Catfish Production Systems;
Projected Investment, Yield, Break-Even Cost, and (2019) Industry Adoption

	Capital $/acre	Yield lb/ac	BE Cost $/lb	Industry Fraction
PAS	32,000	17,000	1.46	< 1.0%
SP*	7,262	21,258	0.92	7.8%
IP*	5,894	14,989	0.93	39.5%
IPR	22,630	9,463	1.32	<1.0%
CP	4,870	4,800	1.05	52.7%

PAS and IPR highest capital and break-even costs.
SP and IP significantly less capital cost, with similar BE.
CP lowest investment cost with BE similar to SP/IP depending on level of productivity.

*2019 industry average at 9,766 lb/acre using enhanced systems (SP+IP) vs 7,672 lb/acre using non-enhanced ponds(13,14,15,16,17,18)

Summary

1) Two-acre PAS prototypes with paddlewheels (water velocity of 0.38 fps) with fish yield of 15,000 to 18,000 lbs/acre
2) Culvert pumps at 8,000 gpm in split-ponds with levee (water velocity of ~ 0.048 fps mixes 33-50% of treatment zone, with fish yield of 9,800 to 15,600 lbs/acre.
3) Paddlewheel at 10,000 gpm in split-pond without levee (water velocity ~ 0.06 fps) mixes 50% of treatment zone.
4) Paddlewheel at 15,000 gpm in five-acre split-pond without internal levees provides fish yield of 12,330 to 19,872 lbs/acre
5) IP wider variation in yield (8,000-19,000 lb/acre) compared to SP (12,000-18,000 lb/ac)
6) PAS provide high rate of photosynthesis, N-recycle and N-storage in tilapia biomass yielding consistent control of TAN (< 4 mg/l), SP provides more consistent control of TAN as opposed to IP
7) IP requires minimal modification of existing ponds, major cost being addition and maintenance of aerators
8) SP requires substantial modification of existing ponds, but provides more predictable increase in fish production and treatment of ammonia nitrogen

Summary continued

9) SP accumulates algal sludge in waste treatment zone separated from fish culture zone; bulk of settled algal biomass is retained in anaerobic zone providing increased nitrogen treatment (including nitrification)
10) IP and CP store settled algal biomass in sediment which is prone to ammonia release within fish culture zone, driven by changing wind/temperature
11) IP (42% of industry) and SP (7.8% of industry) are most cost effective at break-even production cost of ~ $0.92/lb
12) Detailed determination of risk/benefit of SP vs IP will required more data on solids sedimentation and mineralization rates IP and SP.

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Presentations/Additional Resources

MU Extension Aquaculture Website

https://extension.missouri.edu/programs/aquaculture-extension

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