June 1995

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Edited by
Kenneth T. MacKay

International Development Research Centre

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Ottawa • Cairo • Dakar • Johannesburg • Montevideo
Nairobi • New Delhi • Singapore

Published by the International Development Research Centre
PO Box 8500, Ottawa, ON, Canada K1G 3H9

June 1995

MacKay, K.T.
Chinese Academy of Agricultural Sciences, Beijing CN
Chinese Academy of Fisheries Sciences, Wuxi CN

Rice–fish culture in China. Ottawa, ON, IDRC, 1995. 276 p. : ill.

/Rice/, /plant production/, /fish production/, /mixed farming/, /cultivation systems/, /China/ — /appropriate technology/, /ecology/, /economic aspects/, /on-farm research/, /case studies/, /conference reports/, references.

UDC: 633.18:639.2(510) ISBN: 0-88936-776-0

A microfiche edition is available.

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Rice-Azolla-Fish Cropping System

Liu Chung Chu[54]

China has a long history of raising fish in ricefields. However, fish yields are low because of difficulties in applying feed to the large areas of fish-raising fields. Azolla is a small aquatic plant that contains abundant nutrients because it can fix atmospheric nitrogen, carry out photosynthesis, and uptake nutrients from its surrounding environment through its root system. It is also an excellent feed for fish. Azolla is rich in the amino acid arginine, which may play an important role in fish growth (Tables 1 and 2). Azolla grow quickly, produce high yields, are a suitable size for fish grazing, do not require harvesting or chopping, and can grow in the ricefield. To increase its ecological and economic benefits, a rice-azolla-fish cropping system was established in 1981. These experiments have indicated the potential of this cropping system.

The Role of Azolla

Fish Feed

Both grass-feeding and omnivorous fish eat azolla. Grass carp (*Ctenopharyngodon idella)* and nile tilapia (*Oreochromis niloticus*) consume the equivalent to more than 50-60% of their body weight in azolla each day. The amount of azolla consumed by the common carp (*Cyprinus carpio*) increases with increased size.

Feeding experiments with four fish species were conducted by the Soil and Fertilizer Institute, Hunan Academy of Agricultural Sciences. The feed conversion coefficient of azolla was 49.0 for grass carp, 52.1 for tilapia, 31.2 for Hunan crucian carp, and almost zero for lotus carp. The weight gain for these species was 174 g, 134 g, 36 g, and 5 g, respectively. There were high levels of ^{15}N-labelled azolla in the internal organs of nile tilapia and low ^{15}N-labelled azolla levels in the external organs at the start of the experiments. However, the level of ^{15}N-labelled azolla in the internal organs gradually decreased, whereas the level of ^{15}N-labelled azolla in the muscles greatly increased (Table 3). After uptake of ^{15}N-labelled azolla for 96 h, ^{15}N recovery in the intestine, stomach, and liver decreased from 10.3% to 1.0%, 1.6% to 0.2%, and 2.4% to 0.7%, respectively. A similar trend was found in other internal organs. In contrast, ^{15}N recovery in muscles was 6.3% at 18 h and increased to 10.1% at 96 h. Metabolism balance estimates were obtained from a 4-day nile tilapia experiment. The amount of nitrogen accumulated

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Table 1. Nutrient contents (% dry weight) of various green feeds.

Green Feed	Dry Matter	Crude Protein	Crude Fat	Crude Cellulose	N-free Extract	Ash	Ca	P
Azolla filliculoides	6.93	25.0	3.1	11.5	34.9	17.3	1.52	0.96
Eichhorinia sp.	5.04	20.3	1.8	13.8	32.8	22.6	1.19	2.90
Trifolium sp.	11.57	16.6	4.0	26.1	34.4	11.3	1.24	0.82
Sweet-potato vine	12.27	17.7	3.1	13.9	41.5	9.8	1.81	0.43
Astragalus sp.	11.43	20.8	5.7	23.2	34.9	7.5	0.79	0.62
Grass	23.60	14.1	1.4	20.3	44.1	14.0	0.72	0.29
Pennisetum purpuremu	16.10	9.7	1.3	29.3	37.8	14.5	0.48	0.52

Source: Guangdong Academy of Agricultural Sciences.

Table 2. Amounts of 10 essential amino acids contained in various green feeds for fish (dry matter, mg amino-acid/100 g protein).

	Azolla filiculoides	*Eichhornia*	*Pistia shatiotes*	Sweet-Potato Vine	*Astragalus* sp.	*Trifolium* sp.
Arg	6.84	6.45	6.86	2.00	6.54	5.60
His	2.28	2.36	2.68	1.37	3.13	2.65
Ile	4.56	3.79	3.87	1.36	4.62	4.28
Lea	8.64	6.89	8.45	4.04	8.32	7.65
Lys	5.48	6.75	7.99	0.28	6.59	6.27
Met	1.40	1.87	1.56	0.72	1.29	1.33
Phe	4.68	4.58	4.89	2.36	5.00	5.12
Thr	5.00	3.84	5.05	2.37	3.85	4.39
Trp	7.44	11.92	7.53	8.55	8.75	8.19
Val	4.88	4.04	5.00	1.88	5.91	5.48

Source: Guangdong Academy of Agricultural Sciences.

Table 3. Recovery of ^{15}N-labelled azolla from various organs of nile tilapia.

	^{15}N Abundance (%)	
Organ	18-h Sampling	96-h Sampling
Head	–	3.22±1.10
Skeleton	–	3.73±0.08
Muscle	6.34±1.17	10.05±1.17
Scales	–	0.65
Brain	–	0.05±0.031
Ovary	–	1.31±1.08
Intestine	10.30±3.45	0.97±0.51
Stomach	1.64±0.80	0.24±0.21
Liver	2.36±0.80	0.68±0.11
Heart	0.064±0.0017	0.035±0.007
Blood	0.455±0.329	0.60±0.14
Spleen	0.28±0.22	0.06
Gall	0.219±0.010	0.24±0.23
Gill	2.96±0.50	1.35

Source: National Azolla Research Centre, Fujian Academy of Agricultural Sciences.

by the tilapia represented 30% of total azolla N. Tracer techniques (using ^{15}N) were used to obtain a better understanding of nutrient abundance in fish faeces. During the 96-h excretion period, the highest determined ^{15}N level was 3.8%, the lowest was 2.1%. This was much lower than the level of ^{15}N in the azolla fed to the fish. This reduction was probably due to the dilution of ^{15}N from the azolla by the other nitrogenous matter excreted from the alimentary canal of the fish (which includes digestive juice, sloughed cells from the stomach, and azolla). These results demonstrate that azolla-N accounts for 30% of N in fish faeces. Because another 30% of total azolla-N accumulates in the fish body, it can be estimated that azolla-N is about 60% digested by the fish (N may also be excreted into the water in the form of urine, as excretions from the body surface, as falling scales, or as matter exchanged by the gills). The utilization of ^{15}N from azolla in the rice–azolla–fish system is increased to 67.8% (Table 4); whereas, the rice–azolla treatment using ^{15}N-labelled azolla as a top dressing at the maximum tillering stage had a utilization rate of 46.1%.

Table 4. Utilization ratio of ^{15}N-labelled azolla.

Treatment	Utilization Ratio of ^{15}N-Labelled Azolla (%)		
	By Fish	By Rice	Total
Rice-azolla-fish (as fish feed)	38.24	29.52	67.76
Rice-azolla (^{15}N-labelled azolla, basal)	—	46.06	56.06
Rice-azolla (^{15}N-labelled azolla, top dressed)	—	51.60	51.60

Source: National Azolla Research Centre, Fujian Academy of Agricultural Sciences.

Table 5. Effects of azolla on fish yields.

Species	Fish Yield (t/ha)		Weight of Fish (g)	
	With Azolla	Without Azolla	With Azolla	Without Azolla
Silver carp	0.35	0.15	600	450
Grass carp	0.15	0.15	150	130
Nile tilapia	0.54	0.40	125	100

Source: National Azolla Research Centre, Fujian Academy of Agricultural Sciences.

Fish Yields

In the traditional rice-fish system, fish grow slowly because there is insufficient feed. This problem can be solved by introducing azolla. Experiments over 3 years demonstrated that the rice-azolla-fish system will produce fish yields of 1 000 kg/ha. As well, yields can be further increased by using some other techniques (e.g., the polyculture of grass carp and nile tilapia). Fish yields were almost doubled compared with the traditional system for silver carp (Table 5). The yield of edible fish is also raised. The rice-azolla-fish system increased farm income by about CNY1 954/ha.

Effect on Rice Yield

The rice-azolla-fish system provides an excellent growing environment for rice, fish, and azolla. Because of the high amount of organic fertilizer provided by fish, the rice grows well (Table 6), and because the fish eat azolla, rice pests, and weeds, the use of chemical pesticides can be reduced. However, the environment

Table 6. Agronomic characteristics of rice grown under different cropping systems.

Season	Treatment	No. of Seedlings per Hill	No. of Effective Panicles per Hill	No. of Filled Grains per Panicle	Filled Grain Rate (%)	1 000-Grain Weight (%)	Theoretical Yield (kg)
Early rice	Single rice	11.38	10.13	47.0	65.9	22.4	4288.5
	Rice-azolla	12.25	11.38	33.5	65.2	21.7	4255.5
	Rice-fish	13.25	12.00	44.8	65.6	23.2	4969.5
	Rice-azolla-fish	11.75	10.63	50.0	69.7	23.5	5589.0
Late rice	Single rice	7.25	7.25	112.1	76.9	28.8	6930.0
	Rice-azolla	7.67	7.67	119.4	76.5	29.6	8085.0
	Rice-fish	8.08	7.92	113.2	76.5	29.0	7656.0
	Rice-azolla-fish	9.33	7.32	116.8	75.7	29.7	9324.0

Source: Fujian Academy of Agricultural Sciences.

Table 7. Growth of weeds in the rice-azolla-fish system.

Cropping System	Weeds per m^2	Weeds (g)	Average Weight (g/m^2)	Weed Weight (kg/ha)	Remarks
Rice (compared)	48	446	454	4 500	Floating azolla species 80% Waterweed species 20%
Rice-azolla	9	62	64	630	Floating azolla species 50% Waterweed species 25%
Rice-fish	—	—	—	—	Others 25%
Rice-azolla-fish	—	9	9	112	Weeds

created by the rice-azolla-fish system is also conducive to the survival of the natural enemies of rice pests (e.g., spiders and black ants). This further decreases pesticide requirements. For example, during a plant leafhopper outbreak in Fuqing Country, Fujian Province, in 1984, four applications of pesticides were required in traditional rice-growing systems and provided incomplete control. In contrast, only one application was required under the rice-azolla-fish system. Observations from 1983 to 1986 indicate that the rice-azolla-fish system effectively suppresses weeds and rice pests (Table 7).

Soil Fertility

In the rice-azolla-fish system, plant nutrients are provided by decomposition of azolla and by excretion of fish faeces. Improvements in fertility were greater in the ditches than on the field surfaces (Table 8). This can be attributed to the effect of the fish in the system, especially the role played by fish faeces in improving soil fertility. The rapid increase of available potassium is also apparent, which demonstrates the capability of azolla to enrich potassium levels. Although the rice yields from this system are similar to traditional systems, an extra 375-600 kg/ha of fish are harvested. The fish decrease the amount of mineral fertilizer required by the rice plants, maintain or improve soil fertility, and create an excellent ecological environment.

Implementation of the Rice-Azolla-Fish System

Field Design

Two forms of field design can be considered for the introduction of the rice-azolla-fish system. The first method involves digging pits and ditches in a traditional ricefield and transplanting rice seedlings in accordance with normal spacing practices. In the second method, rice seedlings are transplanted on ridges and fish are raised in the ditches between the ridges. The selection of fields is particularly important for both designs. In both cases, the field must have sufficient water and have good controlled of irrigation and drainage. In most cases, a rectangular pit(s) that occupies 5% of the total ricefield area will suffice. In all cases, pit depth should be between 1 and 1.5 m. Ditches are 30-50 cm deep, 40-50 cm wide, and occupy 3-5% of the total ricefield area. The field is designed according to the desired yields of rice and fish. In another words, to harvest more fish, pits and ditches should occupy more area, field ridges should be wide and thick to prevent fish escape, and drainage openings should provide for good irrigation.

Combinations of Fish Species

Fish species should be chosen in accordance with their feeding efficiency. For example, grass carp are unable to fully digest cell walls of plants because their alimentary canal lacks cellulase. Consequently, they excrete feed residues into the water along with fish faeces. Nile tilapia excretions stimulate the propagation of plankton. Under these conditions, pure cultures of either species do not use azolla efficiently. However, this problem can be solved if a mixed culture (polyculture) of silver carp and common carp with grass carp, nile tilapia, and common carp (ratio of 100:300:100:7500 fingerlings/ha) is introduced after the rice seedlings are transplanted.

Growing Season for Azolla

The key technological problem in the rice-azolla-fish system is a healthy and sufficient azolla biomass. Two methods are recommended to increase the azolla

Table 8. Characteristics of soil fertility under various rice-cropping systems.

Season	Site	Treatment	O.M. (%)	Total N (%)	Total P P_2O_5 (%)	Alkali N	K (ppm)	P_2O_5 (ppm)
Early rice	Field surface	Single rice	3.748	0.219	1.20	200	91	6.9
		Rice-azolla	3.917	0.223	1.20	205	244	6.9
		Rice-fish	3.896	0.226	1.19	218	86	8.5
		Rice-azolla-fish	3.972	0.239	1.35	216	172	8.8
Early rice	Ditch	Single rice	3.928	0.228	1.29	202	172	5.2
		Rice-azolla	3.977	0.239	1.36	219	253	6.0
		Rice-fish	4.272	0.272	1.53	198	334	5.6
		Rice-azolla-fish	4.548	0.283	1.59	219	494	5.3
Late rice	Field surface	Single rice	3.677	0.205	0.12	158	88	7.3
		Rice-azolla	3.784	0.203	0.12	157	120	7.5
		Rice-fish	3.849	0.198	0.14	172	172	8.2
		Rice-azolla-fish	3.948	0.247	0.14	182	165	10.3
Late rice	Ditch	Single rice	4.107	0.239	0.13	200	157	6.9
		Rice-azolla	4.108	0.206	0.14	209	197	7.4
		Rice-fish	4.825	0.289	0.15	298	192	8.4
		Rice-azolla-fish	4.954	0.296	0.16	264	259	9.1

Source: Central Laboratory, Fujian Academy of Agricultural Sciences.

biomass: increase the space between rice rows to give the azolla sufficient room to grow, and prolong the propagation period to ensure the fish have sufficient food to eat. Polyculture of different azolla species and other waterweeds can also be introduced. Various kinds of waterweeds (e.g., *Lemna minor* and *Wolffia arrhiza)* can be cultivated in the ricefield to supply fish feed in June and July (this method is called rotational cultivation of azolla).

Field Management

Water management is the most important factor in the rice-azolla-fish system. During the early stage of rice growth, fingerlings can swim freely in the shallow water, which is good for tillering of early rice. Later, the larger fish need deeper water. At this time, the water temperature can sometimes reaches 40°C, and it is necessary to keep the irrigation water at the depth of 8–10 cm.

Fertilizer should be applied principally as green manure supplemented with chemical fertilizers. Basal application is stressed and should account for 70% of the total amount of fertilizer used. Deep placement of granules of N fertilizer decreases the loss of N, which benefits both fish and rice. To prevent disease and pests, it may be necessary to apply some insecticides, but the type, application rate, and application methods must be suitable for fish. Biological control methods are preferred.