The production of poultry in integrated aquaculture-agriculture systems

Part II: The integration of laying hens with fish and vegetables in integrated aquaculture-agriculture food production systems

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Abstract

The incorporation of laying hens in an integrated aquaculture-agriculture family-based food production unit, was investigated. The Hyline-silver laying hen hybrid was found to be extremely suitable with an exceptionally high egg production as well as a 100% survival rate over more than 200 d. Fish used included the sharptooth catfish *Clarias gariepinus* and the three-spot barb *Barbus trimaculatus*, both stocked at a relatively low density. Fish yields were satisfactory without any supplementary diet. Water quality conditions were generally good with no signs of oxygen depletion. Problems were encountered with fungal diseases amongst some of the vegetable crops during the wet season of the summer-autumn cycle. Recommendations are made to remedy the problems encountered and to improve fish yields.

Introduction

Attempts to establish warm-water pond-fish farming in Southern Africa did not always succeed, largely due to the high costs of pelleted fish feeds which contained fish meal from marine fish resources. Another reason for the general lack of success of this kind of venture can be ascribed to the volatility of the market for pond fish products (Cross, 1991; Lightfoot et al., 1993).

In South Africa, aquaculture as such, is not a concept with which our rural populations are familiar even though it has been shown that it can provide the vital animal protein necessary to relieve much of the prevailing problems of malnutrition (Steyn et al., 1995).

In contrast to stand-alone pond-fish culture, the success of which is subject to the already mentioned factors, integrated aquaculture-agriculture farming systems are less risky because of the efficiency derived from synergisms amongst the different components of such food production ecosystems (Lightfoot et al., 1993). Integrated aquaculture-agriculture farming systems also provide a more acceptable and familiar form of agriculture to the rural population, of which the production of fish now becomes only a subcomponent. New (1991) supported by Lightfoot et al., (1993), are of the opinion that the integration of aquaculture with agriculture can contribute substantially towards the actual reduction in costs and the eventual success of the fish culture component. New (1991) is of the opinion that the future bulk of fish produced world-wide, may well be generated by fish-farming ventures of an integrated aquaculture-agriculture nature.

In recent years water has been provided widely to the rural communities in South Africa. It remains, however, a scarce resource and must be utilised optimally by the various communities. With the necessary scientific and technical extension services which are now available, small family- or community-scale integrated, sustainable aquaculture-agriculture systems can be practically implemented. Components of these systems such as poultry and vegetables, which as stated, are already familiar food and farming practices, can now be integrated with fish farming. If, during this process, the amount of fish feed normally required can be reduced substantially, total food production costs of such an integrated system can then be minimised.

The present paper is the second in a series of investigations on the integration of aquaculture-agriculture food-production systems largely aimed at rural community development in South Africa. Specific attention is given to the egg production of Hyline-silver laying hens, which is a hardy commercial hybrid bird developed at the Department of Animal Health, Medunsa, and which is particularly suitable for egg production under rural conditions.

Materials and methods

Fish ponds

A total of five 30 m^2 earthen ponds sealed with a 400 μ plastic lining, were used in the investigation. The fish ponds were stocked with two species of fish, grown at relatively low densities during a summer-autumn (*Clarias gariepinus* (Burchell)), and a winter-spring cycle (*Barbus trimaculatus* (Peters)), respectively. The nutrient-rich water from the fish ponds was then used to irrigate a variety of vegetable crops. Yields of eggs, fish as well as the various vegetable crops, are evaluated.

Chickens

Five chicken sheds of a simple inexpensive construction were suspended over the ponds and were insulated with plastic material. Each shed contained nine 18 week-old laying hens housed in specially constructed welded mesh batteries supplied with feeding troughs and water. All hens were inoculated against the

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common chicken viral diseases. Wasted food and chicken manure was allowed to be discharged into the pond water.

To determine the possible effect of day length on egg production, two of the five sheds were illuminated by 65 W glow lamps during the winter-spring cycle. A specially formulated 15% protein egg-laying mash was provided at a ratio of 150 g/hen·d for both the summer-autumn and winter-spring cycles.

Egg laying commenced when the chickens were 20 weeks old. Eggs were removed daily and counted. The warmer summer-autumn egg-laying cycle was evaluated from 8 January and lasted until 28 April, whilst the winter-spring cycle followed from 29 April until 27 August.

Fish

The two fish species used to stock the ponds, were the sharptooth catfish *C. gariepinus* (summer-autumn cycle) and the three-spot barb *B. trimaculatus* (winter-spring cycle). Both species were bred and reared in the hatchery of the Aquaculture Research Unit. It is known that *C. gariepinus* has a decline in growth rate during the colder winter months because of inactive feeding. This fish was therefore not considered for stocking in the ponds during winter. The three-spot barb, although small and not yet investigated for its commercial potential, is known for its hardiness and cold-water resistance. It is also an omnivore utilising mainly the aquatic macro-invertebrate fauna as well as algae in its diets - both of which developed optimally in the manured nutrient-rich ponds.

With fish densities so low, no supplemented feed was provided to the fish in the ponds. Stocking densities for *C. gariepinus* was 275 fish/150 m^2 (18 000/ha) and for *B. trimaculatus* 480 fish/150 m^2 (32 000/ha). At the end of each cycle, the fish ponds were drained and all fish removed, counted and weighed.

Water chemistry

The chemical analyses of the pond water during the summer-autumn and winter-spring production cycles were done according to standard international procedures (*Standard Methods*, 1995). Water temperatures (°C) were measured using a Thies hydrothermograph. Dissolved oxygen concentrations ($mg \cdot \ell^{-1}$) of the pond water were determined using an Oxy 92 oxygen meter. pH values were determined with a portable Hanna 8424 pH meter and the electrical conductivity ($\mu \cdot Scm^{-1}$) recorded with a Hanna HI 8633 conductivity. Turbidity values (FTU) were determined using a Hach spectrophotometer. Mean values, as well as ranges for each parameter, were determined and tabulated.

Results

The findings on the various aspects of the integrated poultry-fish-vegetable production for both the summer-autumn and winter-spring cycles are summarised in Tables 1 to 6.

Egg production

Egg production during both the summer-autumn and winter-spring cycles was grouped into fortnightly periods (Tables 1 and 2). Except for the first period when the young hens commenced egg-laying, the number of eggs produced/hen·d, exceeded, in all cases, 0.90 with a peak of 0.95 during the 5th period. A total number of 4 620 eggs were produced by 45 hens over the summer-autumn cycle of 110 d.

As indicated in Table 2, the egg production results during the winter-spring cycle, were unfortunately seriously affected by rats which infested the chicken houses and resulted in data for the period 10 June to 3 July being omitted. Despite this interference, some valid deductions can still be made. The mean daily egg production per hen over the winter-spring cycle, was slightly lower in both the illuminated and non-illuminated sheds compared to that of the summer-autumn egg production cycle (Tables 1 and 2). It is predicted that, where illumination is provided, slightly higher egg production can be expected during the winter cycle. The decline in egg production during Period 3 of the winter-spring cycle, was probably also affected by the egg predation by rats.

A general observation on the egg production suggests an extremely high rate of egg-laying during both the summer-autumn and winter-spring cycles, particularly during summer and autumn. Of importance was the fact that 100% survival of laying hens occurred during both cycles.

TABLE 1
TOTAL AND MEAN EGG PRODUCTION FOR 45 LAYING HENS HOUSED OVER 150 m^2 FISH PONDS DURING THE SUMMER-AUTUMN CYCLE, (JANUARY - APRIL 1997)

Date	Fortnightly periods	No of hens	Total no of eggs produced	Mean no of eggs/hen/day	Laying mash in kg
08/01-21/01	1	45	511	0.81	95
22/01-04/02	2	45	574	0.90	95
05/02-18/02	3	45	598	0.94	95
19/02-04/03	4	45	595	0.94	95
05/03-18/03	5	45	600	0.95	95
19/03-01/04	6	45	584	0.92	95
02/04-15/04	7	45	581	0.92	95
16/04-28/04	8	45	577	0.91	95
Total			**Total: 4620**	**Mean: 0.91**	**Total: 760**

TABLE 2
TOTAL AND MEAN EGG PRODUCTION FOR 45 LAYING HENS HOUSED OVER 150 m² FISH PONDS DURING THE WINTER-SPRING CYCLE (MAY - AUGUST 1997)

With illumination to extend day length						Without illumination					
Date	Fort-nightly periods	Number of hens	Total no of eggs produced	Mean no of eggs/ hen·d	Laying mash in kg	Date	Fort-nightly periods	Number of hens	Total no of eggs produced	Mean no of eggs/ hen/day	Laying mash in kg
29/04-12/05	1	45	567	0.90	95	29/04-12/05	1	45	567	0.90	95
13/05-26/05	2	45	592	0.94	95	13/05-26/05	2	45	567	0.90	95
27/05-09/06	3	45	599	0.85	95	27/05-09/06	3	45	554	0.88	95
10/06-03/07	4-6	This period omitted because of rat infestation and consequent destruction of eggs									
04/07-16/07	7	45	573	0.91	95	04/07-16/07	7	45	486	0.77	95
17/07-30/07	8	45	561	0.89	95	17/07-30/07	8	45	517	0.82	95
31/07-13/08	9	45	542	0.86	95	31/07-13/08	9	45	523	0.83	95
14/08-27/08	10	45	561	0.89	95	14/08-27/08	10	45	517	0.82	95
			Total:3995	Mean:0.89	Total:665				Total:3734	Mean:0.85	Total:665

Fish production

As mentioned, the stocking density of both fish species was comparatively low. The survival rate for *C. gariepinus* (93.1%) and *B. trimaculatus* (86.7%) was, in both cases, satisfactory (Table 3). There was a significantly higher percentage increase in total biomass of *B. trimaculatus* (212.2%) compared to that of *C. gariepinus* (67.3%). Yields for both species per 150 m² pond space amounted to 18.132 kg (*C. gariepinus*) and 1.780 kg (*B. trimaculatus*), respectively. This translates to 1 207.5 kg·ha^{-1} for *C. gariepinus* and 111.9 kg/ha for *B. trimaculatus*.

Water chemistry

Water chemistry results of the fish ponds during the summer-autumn and winter-spring periods are summarised in Tables 4 and 5. A comparison of the summer-autumn and winter-spring water temperatures showed the temperature to be significantly lower during the period May to September with a lowest mean of 11.3°C in June. The highest mean temperature (23.9°C) during the summer-autumn period was recorded in February.

Dissolved oxygen conditions for the two cycles fluctuated during July, September and October of the winter-spring cycle when values as low as 2.1 mg·ℓ$^{-1}$ (October) and 2.6 mg·ℓ$^{-1}$ (July) were recorded (Table 5) but remained relatively normal otherwise.

Alkaline conditions prevailed in the pond water during both cycles with highest values for pH not exceeding 10.

Conductivity did not build up to exceptionally high values during any of the two cycles and fluctuated between a mean of 138.8 µS·cm^{-1} (September) and 178.8 µS·cm^{-1} (October) (Table 5). Conductivities of the summer-autumn cycle (Table 4) varied between 131.3 µS·cm^{-1} (February) and 180.6 µS·cm^{-1} (January).

The effects of the discharge of chicken manure into the ponds is clearly reflected by the concentrations of ammonia, nitrite and nitrate during both cycles. The average concentrations of ammonia were lower during the summer-autumn cycle with mean values fluctuating between 0.40 mg·ℓ$^{-1}$ (February) and 2.83 mg·ℓ$^{-1}$ (March). During the winter-spring cycle, a highest ammonia value of 4.17 mg·ℓ$^{-1}$ was recorded in October, which was also preceded by comparatively high values for this parameter during July, August and September (Table 5). Values for nitrite generally tended to be the highest during the winter-spring cycle. In contrast, nitrate concentrations were, with one exception (December), significantly higher during the summer-autumn cycle.

Highest values for soluble reactive phosphates were recorded during January to March of the summer-autumn cycle. None of the monthly mean values for phosphate exceeded 10 mg·ℓ$^{-1}$ during the winter-spring cycle.

TABLE 3
PRODUCTION OF *CLARIAS GARIEPINUS* (SUMMER-AUTUMN) AND *BARBUS TRIMACULATUS* (WINTER-SPRING) IN 150 m^2 FISH PONDS RECEIVING WASTE FEED AND DROPPINGS FROM OVERHANGING LAYING HEN BATTERIES

Parameters	Summer cycle (December 1996 - April 1997)	Winter cycle (May - October 1997)
Fish species	*Clarias gariepinus*	*Barbus trimaculatus*
Total pond surface area (m^2)	150	150
Stocking density (no)	275	480
Initial individual biomass (g)	117.9	2.05
Initial total biomass (g)	32 412.6	983.3
Total no of fish harvested (no)	256	416
% Survival	93.1 %	86.7 %
Final individual biomass (g)	197.2	6.4
% Mass increase	67.3 %	212.2 %
Final total biomass (g)	50 545	2 663.3
Yield/150 m^2	18.132 kg	1.680 kg
Yield/ha	1 207.5 kg	111.9 kg

Values for turbidity were found to be relatively similar during the two cycles, being in both cases comparatively low.

Vegetable production

During the summer-autumn cycle, green mealies were produced in addition to the vegetable crops (Table 6). The summer-autumn period was affected by blight on the green beans and spinach and to a lesser extent also on the pumpkin. This clearly affected the yields of these specific crops. A comparison of the obtained mean yields with recorded yields in commercial agriculture, showed that all crops, with the exception of green beans and spinach, exceeded the production figures quoted by Oosthuizen (1995) and Coertze (1996). The blight-affected crops, however, provided lower mean yields than those given by Coertze (1996). During the winter-spring cycle, all crops with the exception of spinach exceeded commercial yields (Coertze, 1996).

Discussion

Distribution of water supplies to the rural communities of South Africa has paved the way for establishing integrated aquaculture-agriculture food production systems. With water always being a scarce resource in South Africa, the incorporation of fish and poultry production (Prinsloo and Schoonbee, 1987; Prinsloo et al., 1999 a, b and c), and the consequent reuse of nutrient-rich fish pond water for vegetable crop production, contribute to an efficient use of this scarce commodity. At the same time, the rural farming communities can acquaint themselves, with a simplified, manageable form of fish production to provide in the necessary animal protein source as food to combat the problem of malnutrition (Steyn et al., 1995; Tichelaar et al., 1995).

The use of Hyline-silver hybrid laying hens in the integrated aquaculture-agriculture system provided extremely good results of more than 9 eggs per hen per 10 d period. This means that a battery of 45 laying hens produced 675 dozen eggs over a 200 d period, without any bird mortalities. With an optimal egg production for a period of at least 12 months before replacement, the Hyline-silver laying hens were found to be a sound investment.

The water quality conditions of the nutrient-rich fish ponds remained satisfactory during both the summer-autumn and winter-spring production cycles. The build-up of nitrogenous wastes and phosphates was not unduly high and did not result in oxygen depletion during any part of the food production trials. Lowest values in the oxygen concentration of 2.1 to 2.6 $mg \cdot \ell^{-1}$ of the pond water suggest a higher replacement rate of irrigation water with fresh water when contemplating higher densities of fish in these ponds and/or chickens over them.

Should higher yields of fish be required, it may be necessary to provide supplementary feed to increase the fish yields significantly. This may, however, require technical assistance from extension specialists. Aeration of pond water to avoid oxygen depletion may then become necessary.

During the present investigation only the monoculture of two species of fish, namely the sharptooth catfish and the three-spot barb, was employed. Other fish species such as the European common carp *Cyprinus carpio* L, tilapia species such as the Mozambique tilapia *Oreochromis mossambicus* (Peters) and the red breast tilapia *Tilapia rendalli* (Boulenger), which feeds mainly on higher plants, should also be considered in polyculture with some of the other fish species. Depending on the climate and the locality of the venture, higher yields and fish growth than recorded during the present investigations can then be achieved.

Compared to the vegetable production achieved by Prinsloo et al. (1999c) some disappointing results were obtained during the present project. Blight amongst green beans and spinach during the wet summer-autumn cycle, resulted in much lower yields than expected for these specific vegetables (Table 6). The potential build-up of nutrients such as phosphates in the soils for consecutive periods of vegetable production, using the nutrient -ich water from the fish ponds over numerous seasons, may well become a limiting factor in vegetable production in the medium to long term (Rozanov et al., 1999).

TABLE 4
WATER QUALITY CONDITIONS IN THE PONDS DURING THE SUMMER-AUTUMN CYCLE HOUSING THE LAYING HENS OVER A PERIOD OF FIVE MONTHS (DECEMBER 1996 - APRIL 1997)

Analysis		Consecutive months (December 1996 - April 1997)				
		December N = 5	January N = 25	February N = 20	March N = 10	April N = 5
Temperature °C	$\bar{x}$ range	22.0 (21.8-22.1)	23.0 (21.3-24.7)	23.9 (21.4-25.9)	18.9 (18.7-19.2)	18.8 (18.1-19.0)
Dissolved oxygen, $mg \cdot \ell^{-1}$	$\bar{x}$ range	11.6 (11.1-11.8)	7.8 (4.2-11.8)	10.1 (7.5-13.5)	7.1 (4.1-8.5)	6.7 (4.8-9.2)
pH	$\bar{x}$ range	8.89-9.79	7.11-9.20	8.15-9.30	6.98-7.80	7.77-8.65
Conductivity, $\mu S \cdot cm^{-1}$	$\bar{x}$ range	169.8 (150.0-209.0)	180.6 (131.0-269.0)	131.3 (113.0-138.0)	165.0 (142.0-183.0)	158.6 (142.0-180.0)
Ammonia (NH_3), $mg \cdot \ell^{-1}$	$\bar{x}$ range	0.83 (0.37-1.46)	0.75 (0.37-4.33)	0.40 (tr-1.34)	2.83 (0.43-5.74)	0.49 (0.40-0.59)
Nitrite (NO_2), $mg \cdot \ell^{-1}$	$\bar{x}$ range	tr (tr-tr)	0.127 (0.007-0.574)	0.043 (tr-0.330)	0.354 (tr-0.891)	0.022 (0.010-0.046)
Nitrate (NO_3), $mg \cdot \ell^{-1}$	$\bar{x}$ range	0.1 (tr-0.5)	6.5 (4.8-8.8)	6.1 (tr-17.6)	6.3 (4.4-8.8)	7.2 (6.2-9.2)
Orthophosphate (PO_4), $mg \cdot \ell^{-1}$	$\bar{x}$ range	6.688 (4.985-9.010)	16.627 (3.480-54.750)	17.963 (11.613-31.175)	11.273 (7.775-21.225)	0.905 (0.525-1.250)
Turbidity (FTU)	$\bar{x}$ range	-	79.2 (36.0-114.0)	69.1 (31.0-139.0)	65.3 (56.0-79.0)	63.0 (42.0-82.0)

Recommendations

Poultry

- Based on the practical experience gained from the present investigation, the Hyline-silver laying hen hybrids were found to be ideally suitable for their egg-laying ability and also for their survival in an integrated aquaculture-agriculture venture.
- The present density of poultry can be increased provided that fish-pond water is replenished accordingly to avoid an unnecessary build-up of nitrogenous and phosphorus wastes.

Fish

- To increase fish yields, a fish polyculture system is advocated. This will allow the different fish species to exploit all the various niches in the pond ecosystem.
- Depending on the locality of the venture, climate will determine the selection and combinations of fish species to be used.

Available on website **http://www.wrc.org.za**

TABLE 5
WATER QUALITY CONDITIONS IN THE PONDS DURING THE WINTER-SPRING CYCLE HOUSING THE LAYING HENS OVER A PERIOD OF SIX MONTHS (MAY - OCTOBER 1997)

Analysis		Consecutive months (May - October 1997)					
		May N = 20	June N = 15	July N = 30	August N = 10	September N = 10	October N = 5
Temperature °C	$\bar{x}$ range	14.0 (10.4-18.9)	11.3 (9.9-12.8)	12.2 (9.8-15.4)	12.0 (9.7-14.4)	16.7 (13.7-20.1)	18.5 (18.3-18.6)
Dissolved oxygen mg·ℓ^{-1}	$\bar{x}$ range	10.0 (6.7-13.3)	8.0 (6.3-9.3)	10.0 (2.6-14.4)	9.5 (5.1-12.9)	6.5 (3.1-10.0)	5.2 (2.1-7.8)
pH	$\bar{x}$ range	7.78-9.75	7.07-8.96	6.88-9.32	7.02-8.90	7.07-8.94	7.28-9.31
Conductivity µS·cm^{-1}	$\bar{x}$ range	146.2 (137.0-165.0)	149.9 (130.0-175.0)	147.5 (120.0-183.0)	149.9 (124.0-204.0)	138.8 (110.0-166.0)	178.8 (118.0-245.0)
Ammonia (NH_3), mg·ℓ^{-1}	$\bar{x}$ range	0.79 (0.08-1.20)	0.99 (0.73-1.35)	2.13 (0.16-6.20)	2.11 (1.12-5.40)	1.77 (0.98-3.22)	4.17 (1.06-7.98)
Nitrite (NO_2), mg·ℓ^{-1}	$\bar{x}$ range	0.218 (0.007-0.343)	0.106 (0.009-0.201)	0.104 (0.013-0.231)	0.070 (tr-4.000)	0.369 (tr-3.301)	0.006 (tr-0.017)
Nitrate (NO_3), mg·ℓ^{-1}	$\bar{x}$ range	2.28 (0.90-7.50)	1.51 (tr-6.60)	1.09 (tr-7.00)	3.57 (tr-10.60)	5.29 (1.80-8.00)	5.36 (3.10-8.80)
Orthophosphate (PO_4), mg·ℓ^{-1}	$\bar{x}$ range	4.737 (0.098-10.910)	8.217 (5.935-10.390)	7.280 (3.253-10.085)	3.463 (2.208-3.988)	5.069 (2.738-8.815)	6.801 (3.625-10.360)
Turbidity (FTU)	$\bar{x}$ range	30.6 (18.0-45.0)	39.5 (27.0-62.0)	56.6 (12.0-102.0)	62.9 (16.0-94.0)	44.9 (12.0-63.0)	64.4 (24.0-112.0)

TABLE 6
SUMMER-AUTUMN AND WINTER-SPRING VEGETABLE PRODUCTION USING NUTRIENT RICH WATER FROM FISH PONDS IN FLOOD IRRIGATION OF CROPS

Vegetables	Number of plots	Vegetable production in kg/1 000 m²		
		Mean	Range	Average production in agriculture (Coertze, 1996)
Summer-autumn cycle (November - March 1997)				
Green mealies	10	5 100 (cobs)	4 940 - 5 280 (cobs)	2 500 (cobs) **
Cabbage (Conquistador)	10	6 947	5 568 - 7 482	5 000
Cabbage (Star 3301)	10	11 779	11 056 - 12 768	5 000
* Green beans	5	206	-	1 000
* Spinach	5	1 065	-	1 200
* Pumpkin (Boer)	5	4 973	-	2 000
Winter-spring cycle (May - October 1997)				
Cabbage (Star 3306)	50	7 950	5 958 - 9 720	5 000
Spinach	10	1 020	958 - 1 084	1 200
Lettuce	5	4 294	-	1 500
Beetroot	5	4 260	-	3 000
Onions	5	4 006	-	3 500

* Crops seriously affected by blight due to excessive rainfall.
** According to Oosthuizen (1995)

Vegetables

- Routine treatment against fungal and other vegetable diseases will become necessary, especially during the wet seasons of the year.
- A rotation of the vegetable plots will be necessary to avoid the undue build-up of nutrients and other chemical substances in the soils.
- Specific investigations will be necessary to determine medium- to long-term effects of first pond water on soil quality.

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