# Investigations into the feasibility of a duck-fish-vegetable integrated agriculture-aquaculture system for developing areas in South Africa

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**Abstract**

The production potential of a duck-fish-vegetable integrated aquaculture-agriculture farming system was investigated. Pekin ducks were used which were first grown indoors for a period of 28 days before being released into enclosed fish-ponds with shelters over the pond water. Manure and waste feed was dropped directly into the water containing fish in polyculture which included the European common carp, *C. carpio*, the bighead carp *A. nobilis*, silver carp, *H. molitrix* and the grass carp, *C. idella*. Only the common carp received predetermined quantities of supplementary feed based on growth, by means of demand feeders, as other species largely utilised the nutrients discharged into the ponds with the faeces of the ducks as well as plankton growths which developed as a result. The nutrient-rich water in the ponds was used to irrigate vegetable crops.

Ducks grew to an average of 2,65 kg in a period of 55-56 d. Fish yields obtained exceeded 8 t $ha^{-1}$ over a period of 149 d. Substantial yields of vegetable crops were obtained with vegetables such as tomatoes, spinach and lettuce clearly benefitting from the nutrient-rich water.

## Introduction

Transkei has a relatively high rainfall with a precipitation estimated to be about 25% of South Africa's total rainfall. This country is traditionally dependent on its agriculture with its major resources being the land, the climate and its people (Hawkins Associates, 1980). Even so, agriculture only contributes approximately 30% towards its present day Gross Domestic Product.

A combination of factors negatively affect livestock production in Transkei. These include land pressure as a result of population growth and the continuously expanding cultivated land which encroaches on the available grazing areas. As a result, overstocking and overgrazing occur. At the same time the existing natural resources such as fruit, game and even fish are diminishing rapidly (Hawkins Associates, 1980).

The shortage of protein amongst the rural population is manifested by the increasing incidence of malnutrition (Rose, 1972; Kirsten, 1974; Frankish, 1978). In view of the anticipated population growth, there is therefore a considerable need to improve agricultural production in Transkei by maximising the available land and water resources.

Because of the generally good quality of the water in the major river systems in Transkei (Du Preez, 1985 a, b), and because of its suitability for aquaculture, an initial investigation into the production of fish using, amongst others, agricultural wastes was undertaken at Tsolo (Scoonbee, Nakani and Prinsloo, 1979). Based on the promising results obtained during this investigation, a Five Year Plan for the development of an aquaculture industry in Transkei was initiated (Schoonbee and Prinsloo, 1980).

The first phase comprised the establishment of hatchery and fish pond facilities at the Umtata Dam. Fish species were selected on the basis of their proven aquacultural potential as well as their ability to survive the prevailing winter temperatures of less than 10°C. Fish were raised to maturity and spawned there, using techniques specifically developed for local environmental conditions (Prinsloo and Schoonbee, 1983; 1984; 1986 a, b). In the process, attention was also given to the mass rearing of larvae using live and artificial diets (Prinsloo and Schoonbee, 1986b) as well as the large-scale transportation of juvenile fish (Prinsloo and Schoonbee, 1985).

A considerable amount of information exists on fish polyculture in other parts of the world including integrated aquaculture-agriculture systems as practiced for decades in Far Eastern countries and Europe (Pullen and Shedadeh, 1980; Hepher and Pruginin, 1981). However, it was found necessary to adapt and, where possible, to improve upon procedures followed elsewhere in the world to suit local environmental conditions.

The first fish production investigations in Transkei were conducted by Cronje (1981) using a fish polyculture system in cattle and poultry manured fish ponds which included a variety of carp species. In this experiment fish production was enhanced with high protein pelleted fish feed. This was followed by a series of three further investigations using pig, cattle and poultry manure with and without pelleted fish feed where the fish growth potential of particular fish species and densities was evaluated locally for this kind of system. (Prinsloo and Schoonbee, 1984 a, b, c, d).

In order to reduce the costs of fish production, but also to make fish culture more acceptable to the local population, fish polyculture was combined with vegetable production using effluent water from fish ponds receiving pig manure with and without formulated fish feed (Prinsloo and Schoonbee, 1986a). Results obtained during these investigations clearly revealed the acceptability of this system to the local population.

Recent information obtained on fish sales (Nakani, 1983; Personal observations) not only supported a previous survey conducted by Roode (1978), namely that freshwater fish is readily accepted by the local population, but also dispelled any misconceptions which still might have prevailed about the demand for freshwater fish.

In view of the response obtained during the latter investigations, incorporating animal manures, the integrated aquaculture-agriculture systems were further expanded to incorporate duck production which could be placed directly onto the fish-ponds. Ducklings were initially grown for a period indoors before they were released onto the ponds where they were confined and fed

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TABLE 1
SUMMARY OF RESULTS OBTAINED ON PHYSICAL AND CHEMICAL CONDITIONS OF FISH-CUM-DUCK POND WATER ANALYSED ON A REGULAR BASIS DURING THE PERIOD OCTOBER 1985 TO MARCH 1986

| Analyses | N | $\bar{x}$ | Min | Max | Sx | CV |
|---|---|---|---|---|---|---|
| Dissolved oxygen mg $\ell^{-1}$ | 18 | 3,5 | 2,5 | 7,6 | 1,51 | 43,14 |
| pH | 18 | | 6,33 | 7,32 | 0,33 | |
| Conductivity $\mu$S cm$^{-1}$ | 18 | 134 | 105 | 175 | 20,07 | 14,97 |
| Alkalinity as $CaCO_3$, mg $\ell^{-1}$ | 18 | 29,72 | 10,00 | 61,00 | 12,79 | 43,03 |
| Total Hardness as $CaCo_3$, mg $\ell^{-1}$ | 18 | 32,78 | 12,00 | 93,00 | 19,81 | 60,43 |
| Nitrate ($NO_3$) mg $\ell^{-1}$ | 16 | 0,349 | 0,031 | 2,935 | 0,682 | 195,41 |
| Ammonia ($NH_4$) mg $\ell^{-1}$ | 18 | 0,576 | 0,298 | 1,099 | 0,249 | 43,23 |
| Orthophosphate ($PO_4$) mg $\ell^{-1}$ | 17 | 0,131 | 0,074 | 0,269 | 0,045 | 34,35 |

Sx: Standard deviation
CV: Coefficient of variability

so that their manure was directly discharged into the ponds stocked with fish in polyculture. Excessive nutrient loads in these ponds caused by the duck manure were periodically reduced by using effluent water from such ponds to irrigate a number of vegetable crops. This was then replenished with freshwater. By following this procedure, a model of integrated aquaculture-agriculture systems was evolved and evaluated under local conditions which, because of the size of the experiment, could be translated into small-scale commercial units suitable for conditions in Transkei.

The present paper deals with the major findings of this investigation and comments on the practical and possible financial advantages of such systems in rural development programmes elsewhere in southern Africa.

## Materials and methods

### Preparation of ponds used for the experiments

Two 200 m² earthen fish ponds constructed at the Umtata Dam Fish Research Station and provided with monk overflows, were used in the experiment. Gravity-fed piped water for the ponds was obtained from the Umhlalane River approximately 50 km from the Research Station. Water used to compensate for evaporation in the ponds, as well as irrigation water drawn off for the watering of the vegetable crops was accurately determined using a Kent 50 mm Helix water flow meter. Evaporation and precipitation was determined at a nearby meteorological station. The mean depth of the ponds, when full, was 0,75 m. Chicken mesh wire fences were erected around each pond close to the edge of the water, thereby restricting the ducks as far as possible to the pond water. Duck houses of a relatively simple construction and insulated with plastic material were erected over the fish ponds. Floors were covered with chicken mesh wire so that the duck faeces and any food wasted could fall directly into the pond water. Trap doors opened out into the ponds, allowing the ducks kept in the duck houses overnight, to enter the ponds.

In contrast with the usual procedure followed during fish polyculture experiments conducted at the Umtata Dam Fish Research Station (Prinsloo and Schoonbee, 1984a, c; 1986a), fish ponds were not fertilised with inorganic fertilisers as it was feared that the considerable loads of manure discharged into the pond by the high density of ducks used, may induce excessive algal blooms.

In view of the anticipated problems with anoxic conditions which could have developed as a result of the heavy manuring of the fish ponds, aeration was provided in each pond by means of perforated plastic pipes in the ponds connected to a low pressure, high volume air blower (Roots D 90 L 2,2 kW air blower).

Demand feeders were installed in each pond for the application of formulated fish feed. For the purpose of irrigation, water was siphoned from the ponds using 50 mm diameter PVC piping provided with filters and stop valves.

### Physical and chemical analyses of pond water

Analysis of the pond water was initially done on a fortnightly basis on samples collected between 07h00 and 08h00. With the development of algal blooms during the second half of the experiment, analysis was done weekly.

Water temperatures in the ponds were recorded on an installed Thies hydro-thermograph supplied with a seven-day recorder. Dissolved oxygen values of the water in the ponds were determined with a Syland $0_2$ Meter model 400-R whilst pH values were measured with a portable Metrohm Meter Model E604, recording to the nearest 0,01 reading. Electrical conductivity was measured with a Metrohm Conductivity Meter Model E587. Chemical parameters were determined according to APHA (1980) (Table 1).

### Ducks used in the experiment

Five consecutive batches of day-old Pekin ducklings were obtained from the Animal and Dairy Science Research Institute of the Department of Agriculture and Water Supply, Irene, Pretoria. Each batch varied between 110 to 120 ducklings. On arrival, the ducklings were immediately transferred to a temperature controlled room for four weeks where they were kept at temperatures ranging from 35°C during the first week to 21°C, or room temperature, during the fourth week. Two feeding programmes were followed and three batches of ducklings were observed (Tables 2 and 3). Three batches of ducklings were fed only on Epol broiler starter mash with a protein content of 200 g kg$^{-1}$ for the entire four-week period before transfer to the ponds (Table 2). Another two batches of ducklings were fed for two weeks on Epol broiler starter mash followed by a further two weeks on 195 g kg$^{-1}$ protein Epol broiler finisher mash (Tables 3 and 7). A fixed feeding programme was followed for all batches of ducklings. Dry feed was weighed out on an electronic balance accurate to the nearest gram and then moistened with water after which the wet mass was also determined in the same manner. Any food left over at the next feeding-time was weighed again and accounted for.

TABLE 2
MEAN YIELD AND FEED CONVERSION RATIOS OF THREE BATCHES OF DUCKS FED ON CHICKEN BROILER STARTER MASH DURING THE FIRST 27 (INDOORS) DAYS OF FEEDING FOLLOWED BY CHICKEN BROILER FINISHER MASH (14 INDOOR DAYS) AND CHICKEN BROILER POST FINISHER MASH (14 DAYS) ON PONDS

Empirical values based on final numbers and biomass of ducks

| Period | Days | Pond stockings (s) and final (fl) densities of ducks $ha^{-1}$ pond water | Estimated (E) and actual (A) mean standing crop in kg $ha^{-1}$ | Mean yield increment in kg $ha^{-1}$ | Mean production in kg $ha^{-1}$ $d^{-1}$ | Formulated feed dosage quantities applied (kg $ha^{-1}$) | Mean FCR (Feed conversion ratio)* |
|---|---|---|---|---|---|---|---|
| 0 | 0 | | 170,0 (E) | | | | |
| 1 | 6 | Ducks in | 411,2 (E) | 241,2 | 40,2 | 397,5 | 1,6 |
| 2 | 13 | rearing | 1 151,3 (E) | 740,1 | 105,7 | 1 074,2 | 1,5 |
| 3 | 20 | house | 2 328,2 (E) | 1 176,9 | 168,1 | 1 710,2 | 1,5 |
| 4 | 27 | | 3 343,5 (E) | 1 105,3 | 145,0 | 2 479,7 | 2,4 |
| 5 | 35 | 2 500 (s) | 4 083,2 (A) | 739,7 | 92,5 | 2 832,0 | 3,8 |
| 6 | 42 | Ducks on | 5 211,0 (A) | 1 127,7 | 161,1 | 3 109,1 | 2,8 |
| 7 | 48 | fish ponds | 6 028,0 (A) | 817,0 | 136,2 | 3 587,5 | 4,4 |
| 8 | 55 | 2 451 (f) | 6 404,5 (A) | 376,5 | 53,8 | 4 179,0 | 11,1 |
| | | | Total | 6 324,4 | | 19 369,2 | x̄ = 3,1** |

*Calculations based on feed quantities used
**Mean FCR over entire period

TABLE 3
MEAN YIELD AND FEED CONVERSION RATIOS OF TWO BATCHES OF DUCKS FED ON CHICKEN BROILER STARTER MASH DURING THE FIRST 14 (INDOORS) DAYS OF FEEDING FOLLOWED BY CHICKEN BROILER FINISHER MASH (14 INDOOR DAYS) AND CHICKEN BROILER POST FINISHER MASH (28 DAYS) ON PONDS

Empirical values based on final numbers and biomass of ducks

| Period | Days | Pond stockings (s) and final (fl) densities of ducks $ha^{-1}$ pond water | Estimated (E) and actual (A) mean standing crop in kg $ha^{-1}$ | Mean yield increment in kg $ha^{-1}$ | Mean production in kg $ha^{-1}$ $d^{-1}$ | Formulated feed dosage quantities applied (kg $ha^{-1}$) | Mean FCR (Feed conversion ratio)* |
|---|---|---|---|---|---|---|---|
| 0 | 0 | | 159,5 (E) | | | | |
| 1 | 7 | Ducks in | 551,0 (E) | 391,5 | 55,9 | 430,2 | 1,1 |
| 2 | 14 | rearing | 1 329,2 (E) | 778,2 | 111,2 | 1 111,2 | 1,4 |
| 3 | 21 | house | 2 435,7 (E) | 1 106,5 | 158,1 | 1 981,2 | 1,8 |
| 4 | 28 | | 3 353,5 (E) | 917,8 | 131,1 | 2 525,0 | 2,7 |
| 5 | 35 | 2 500 (s) | 4 074,2 (A) | 720,7 | 102,9 | 3 022,7 | 4,2 |
| 6 | 42 | Ducks on | 5 285,0 (A) | 1 210,8 | 173,0 | 3 275,0 | 2,7 |
| 7 | 49 | fish ponds | 6 338,7 (A) | 1 053,7 | 150,5 | 3 825,0 | 3,6 |
| 8 | 56 | 2 475 (f) | 6 797,7 (A) | 459,0 | 65,6 | 3 850,0 | 8,4 |
| | | | Total | 6 638,2 | | 20 020,3 | x̄ = 3,0** |

*Calculations based on feed quantities used
**Mean FCR over entire period

During the first fortnight, 17 to 18% feed per duckling was applied daily in five applications over a period of twelve hours. This was reduced to approximately 12% during the third week and 10% during the fourth week. This feeding programme was based on results from a mean growth feeding curve of ducklings obtained over a one month period at the Umtata Dam Fish Research Station.

A sample selected at random of not less than 35% of the total number of ducklings was weighed weekly to establish the growth rate and to adjust the quantities of food required. Clean, freshwater was available at all times. Saw-dust covering the entire floor space was replaced once per day to remove faeces and spilled water.

**Transfer of ducks to ponds**

Young ducks were either transferred on day 27 (Table 2) or on day 28 (Table 3) to the duck houses on the fish ponds where the two ponds were each stocked with ducks at a density of 2 500 ducks $ha^{-1}$. The first three batches of ducks (Table 2) all received Epol broiler finisher mash for the first fortnight after which a 170 g $kg^{-1}$ protein Epol broiler post-finisher mash was supplied for the rest of the period. The other two batches of ducks (Table 3) received only Epol broiler post-finisher mash over the entire pond period of 28 days. Ducks on the ponds were fed at a rate of 8 to 10% of the mean body mass of the ducks, adjusted weekly after weighing 38% of the total number of ducks. This series of experiments was terminated on day 55.

The entire duration of the experiment was 149 days during which time the ponds were stocked with five successive batches of ducks. During that period the ponds were free of ducks for only 9 d when the ducks were marketed and the duck houses properly cleaned before the introduction of the next batch. This investigation was conducted during the summer period of October 1985 to

March 1986. At the end of each of the growth trials the ducks were weighed individually and then sold live on the local market.

### Fish species used in polyculture

The fish used in the present series of experiments included the Israeli Dor 70 variety of the common carp, *Cyprinus carpio L.*, the Chinese silver carp *Hypophthalmichthys molitrix* (Val) the Chinese grass carp *Ctenopharyngodon idella* (Val) and the Chinese bighead carp *Aristichthys nobilis* (Richardson).

Both the Chinese carp and the European common carp used in the present study were artificially spawned at the Umtata Dam Fish Research Station (Prinsloo and Schoonbee, 1983, Schoonbee and Prinsloo, 1984). The juveniles were overwintered and only used during the following summer growing period when they were large enough to grow to marketable sizes within one summer growing season.

Fish were stocked in both ponds at the onset of the experiment on the day when the first ducks were introduced on the ponds at a total stocking density of 12 500 fish ha$^{-1}$. The relative mean densities of each of the fish species stocked in polyculture are listed in Table 5.

### Fish feeding programme

In contrast with previous fish polyculture experiments conducted in Transkei (Prinsloo and Schoonbee, 1984 a to c) where manure and/or feed was used to grow fish, the fish feeding programme in the present series of experiments was based exclusively on the calculated biomass of the benthic feeding common carp alone. Instead of using the much more expensive 18% protein carp pellets, formulated 18% protein Epol poultry laying pellets were used with very good results. A dosage quantity of feed based on 4% of the calculated total biomass of the common carp only was applied daily by means of demand feeders. Feeding took place each morning at 09h00 for the duration of the experiment which lasted for 149 days. Adjustments were made fortnightly based on mass determinations of the common carp. A subsample of 30 to 40% of each fish species was weighed accurately to the nearest gram on an electronic balance on a monthly basis over the entire period of investigation.

Based on our previous experience (Prinsloo and Schoonbee, 1986a), supplementary feed was not provided in the feeding requirements of for instance the grass, silver and bighead carps. The grass carp was mainly introduced to clear the ponds of excessive weeds and grass whilst the silver and bighead carps were included to utilise the anticipated development of detritus as well as blooms of phyto and zooplankton respectively as a result of the discharge of manure by the ducks into the pond water.

### Calculation of manure quantities released into the ponds

From the available literature, it is clear that ducks may contribute considerable amounts of manure to ponds (Woynarovich, 1979). According to Hopkins and Cruz (1982), manure output of ducks is calculated at 11% of total live duck mass d$^{-1}$ on the ponds, with a moisture content of 69%. This figure was used in the present study to obtain estimates of the daily duck manure quantities released into the ponds.

### Vegetable production

Two plots of equal size, measuring 500 m$^2$ each, were used in the experiment. Vegetables planted included beetroot, lettuce, potatoes, spinach and tomatoes. Subportions allocated to each of these vegetables per replicate plot are indicated in Table 6. Conversions to express these proportions in m$^2$ and ha$^{-1}$ were also made. The first vegetables were planted in spring at the beginning of October 1985. The experiment was terminated at the end of March 1986 after five months. Because of a severe hailstorm, tomatoes had to be replanted during the first week of December. Despite this, one crop of each vegetable could be harvested.

Irrigation water for the one plot was obtained from the duck ponds as described earlier on, and the land was flood irrigated

**TABLE 4**
**RESULTS OBTAINED ON THE MEAN GROWTH AND PRODUCTION OF THE EUROPEAN COMMON CARP AND THE CHINESE BIGHEAD GRASS CARP AND SILVER CARP USED IN POLYCULTURE IN PONDS RECEIVING DUCK MANURE AND FORMULATED FEED DURING THE PERIOD OCTOBER 1985 TO MARCH 1986 (149 DAYS). MEAN AND EXTREME VALUES OF POND WATER TEMPERATURES DURING THE DIFFERENT PERIODS ARE ALSO INCLUDED**

| Period | Days | Date | Mean and extreme pond temperatures (°C) | Stocking (s) and final (f) densities (fish ha$^{-1}$) | Standing crop (kg ha$^{-1}$) | Yield increment (kg ha$^{-1}$) | Production in kg ha$^{-1}$.d$^{-1}$ | Esitmated manure dosage quantities in kg (as dry mass ha$^{-1}$) | Formulated feed dosage quantities in kg ha$^{-1}$ | FCR (Feed conversion ratio)* |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 15/10/85 | | 12 500 (s) | 1 085,30 | | | | | |
| 1 | 32 | 15/10-14/11 | 17,3<br>14,6-20,0 | | 2 802,30 | 1 717,00 | 53,6 | 6 454 | 118,7 | 0,7 |
| 2 | 57 | 15/11-9/12 | 22,5<br>21,6-23,4 | 12 400*** | 5 049,19 | 2 246,90 | 89,9 | 6 454 | 1 730,0 | 0,8 |
| 3 | 85 | 10/12-6/1 | 22,6<br>21,1-23,6 | 12 350*** | 7 409,59 | 2 360,40 | 84,3 | 6 454 | 3 545,0 | 1,5 |
| 4 | 120 | 7/1-11/2 | 21,2<br>20,6-21,6 | | 9 006,09 | 1 596,50 | 45,6 | 6 454 | 5 075,0 | 3,2 |
| 5 | 149 | 12/2-12/3 | 20,3<br>17,8-22,5 | 12 350 (f) | 10 028,20 | 1 022,11 | 35,2 | 6 454 | 6 380,0 | 6,2 |
| | | | | | | | Total: | 32 269 | 16 848 | x̄ = 1,9** |

*Calculations based on feed quantities used
**Mean FCR over entire period
***Estimates based on final empirical results obtained

TABLE 5
CONTRIBUTION OF THE INDIVIDUAL FISH SPECIES TO THE TOTAL PRODUCTION IN THE PONDS RECEIVING DUCK MANURE AND FORMULATED FEED DURING THE PERIOD OCTOBER 1985 TO MARCH (149 DAYS)

| | Stocking density and initial biomass $ha^{-1}$ | | | Final density and total fish biomass | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fish species | Mean stocking density $ha^{-1}$ | Mean initial biomass (kg $ha^{-1}$) | % | Final fish density $ha^{-1}$ | Mean final biomass (kg $ha^{-1}$) | % | Mean final individual mass of fish in g | Fish yield in kg $ha^{-1}$ | % |
| Common carp | 7 000 | 728,6 | 67,1 | 7 000 | 6 374,9 | 63,6 | 910,7 | 5 646,3 | 63,1 |
| Bighead carp | 1 000 | 74,8 | 6,9 | 1 000 | 640,1 | 6,4 | 640,0 | 565,3 | 6,3 |
| Grass carp | 750 | 219,4 | 20,2 | 750 | 1 103,7 | 11,0 | 1 471,6 | 884,3 | 9,9 |
| Silver carp | 3 750 | 62,5 | 5,8 | 3 600 | 1 909,5 | 19,0 | 530,4 | 1 847,0 | 20,7 |
| Total | 12 500 | 1 085,3 | 100,0 | 12 350 | 10 028,2 | 100,0 | | 8 942,9 | 100,0 |

twice weekly when required. Exceptionally high precipitation was recorded during this period so that the regular irrigation as planned was not necessary. The second plot was irrigated with clean, piped water from the Umhlahlane River.

Inorganic and organic fertilisers were applied in identical quantities before and during the period of vegetable production according to standard procedure for vegetable cultivation elsewhere in South Africa. (Joubert and Coertze, 1980; Van Niekerk, 1984; Nott, 1980; Jackson, 1974; Daiber, 1984; Joubert, 1974).

When required, insecticides and fungicides were sprayed on crops such as potatoes, tomatoes and spinach with a knapsack sprayer.

During cropping of each vegetable type, all edible material produced was accurately weighed to the nearest gram on an electronic balance. Vegetables were sold to the local community at a reduced but profitable rate.

## Results

### Pond water chemistry

A summary of results on the water quality conditions and prevailing water temperatures in both ponds are given in Tables 1 and 4. With the exception of one month (10 October to 14 November 1985) at the beginning of the summer period, mean pond water temperatures in the ponds exceeded 23 °C according to recordings made during November 1985, December 1985 and part of January 1986. Towards the end of the investigation, in March 1986, minimum water temperatures declined to below 18 °C. The generally low pond water temperatures recorded during the present investigation period as compared to other years (Prinsloo and Schoonbee, 1984 a to c) can be partially ascribed to the abnormally high rainfall during October and December 1985 and January to February 1986, when overcast conditions prevailed for prolonged periods.

Despite constant aeration of the ponds, values recorded for dissolved oxygen were generally low with a mean over the entire period of only 3,5 mg $\ell^{-1}$. A combination of two main factors may have been responsible for this condition, namely the long periods of overcast conditions, which inhibited photosynthetic activity of the phytoplankton and the high loads of organic material derived from the faeces of the ducks which promoted bacterial build-up and increased the biochemical oxygen demand in the ponds. These conditions also partially explain the relatively low pH and alkalinity values obtained.

The effects of the fresh duck manure on nitrate, ammonia and to a lesser extent phosphate concentrations in the water can be clearly seen in Table 1. These values would have been much higher but for the periodic discharge of pond water and its replacement with clean fresh water.

### Water consumption

Results obtained on the utilisation of water to compensate for evaporation and withdrawal for irrigation converted to $m^3$ $ha^{-1}$ for November 1985 to January 1986 showed an interesting parallel between water used and that lost through evaporation. Volumes of water used for irrigation fluctuated between 936 $m^3$ $ha^{-1}$ (December 1985) and 1 195 $m^3$ $ha^{-1}$ (January 1986). The highest evaporation (1 485 $m^3$ $ha^{-1}$) occurred in January 1986 with the lowest being in November (1 195 $m^3$ $ha^{-1}$). A substantial amount of water is also lost through seepage. The period October 1985 to March 1986 was characterised by periods of exceptionally high rainfall for this region. With the exception of two months, the monthly precipitation exceeded 130 mm during this period.

### Duck production

Results for each feeding programme are summarised in Tables 2 and 3 and Figures 1 and 2. An analysis for the chemical composition of the feeds used is summarised in Table 7. For the sake of comparison, the standing crops of ducklings during the indoor period were also converted to kg $ha^{-1}$.

### Duck feeding programme one (Table 2; Figure 1)

The indoor period for the ducklings was characterised by an extremely efficient feed conversion ratio (FCR) during the first 20 rearing days (FCR: 1,6-2,4; Table 2). There was a sudden increase in feed conversion during the last seven indoor days when the FCR increased by more than one over this period. Standing crop increased from an initial 170 kg $ha^{-1}$ to exceed 3,2 t $ha^{-1}$ after 27 days. Transfer of the ducks to the ponds negatively affected the feed conversion ratio (FCR: 3, 6) which again improved during the 2nd week on the ponds to below three. During the last fortnight of the feeding programme there was a drastic increase in feed conversion with the poorest results (FCR: 11,1) obtained during the last seven days of the trials.

The standing crop of the ducks increased markedly during their stay on the ponds. Best yield increments occurred during weeks 3 and 6 which also coincided with the highest production rates of 168 and 161 kg $ha^{-1}.d^{-1}$, respectively. Considering the standing crop, the yield increments and production obtained during week eight were disappointing.

### Duck feeding programme two (Table 3 and Figure 2)

Although the initial standing crop of the ducklings in this feeding programme was on average lower than in the first feeding programme, the standing crop increments for the consecutive weeks during the 28 d indoor period, were consistently higher than in the first feeding programme. The highest yield increments were, however, also obtained for the periods during weeks three and six as was the case in feeding programme one.

As in the first feeding programme, the best feed conversion was also obtained during the first three weeks with a pronounced FCR increase towards week 4. The further deterioration in feed conversion during week 6 revealed the same tendency as in the first feeding programme. This rapid deterioration in feed conversion during the last week of the feeding programme followed a pattern similar to feeding programme one.

Feed used during the programme when the ducks were on the ponds showed superior growth and yield increment over the entire period than was the case in the first feeding programme. (Compare Figures 1 and 2.)

### Fish production

Growth and production results obtained for the fish ponds were roughly similar. Mean values obtained are presented in Tables 4 and 5 and Figure 3.

Fish mortalities were minimal (Tables 4 and 5) and were confined to the silver carp only. Standing crop increased dramatically between day 32 and 85 when an increment of over 4,5 t $ha^{-1}$ was achieved within 53 days. Production declined however during the last 64 d period (Figure 3) which also coincided with a pronounced increase in feed conversion (Table 4).

When the production performance of the individual fish species is considered (Table 5) the importance of the detritus and phytoplankton feeding silver carp can be clearly seen with the highest relative yield and standing crop increase. The common carp, being numerically dominant and receiving formulated feed, produced the highest yield over the 149 d growth period of 5 646 t $ha^{-1}$. Of the other species the grass carp showed the poorest yield followed by the bighead carp. Even so, the value of the latter two fish species in the fish pond management programme and the total utilisation of the fish pond food web should not be underestimated.

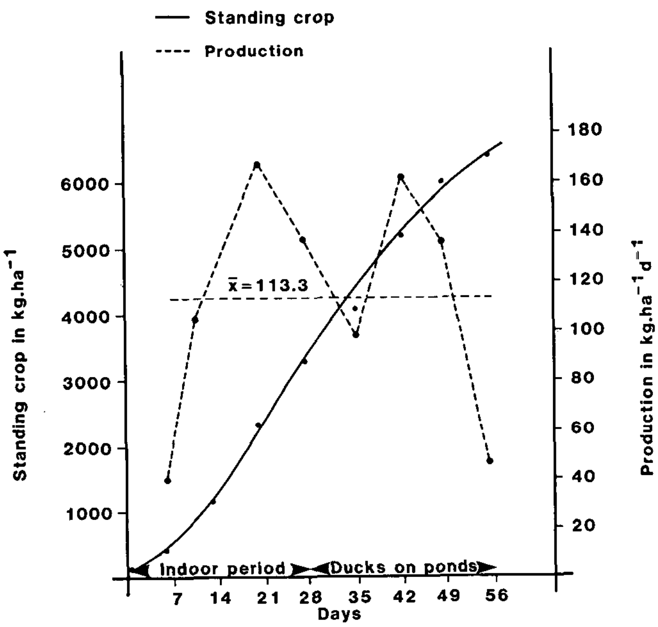


*Figure 1*
*Standing crop (kg $ha^{-1}$) and production (kg $ha^{-1}.d^{-1}$) over a 55 d period of ducks fed on chicken broiler starter mash during the first 27 (indoors) d period followed by chicken broiler finisher mash (14 d) and chicken broiler post finisher mash (14 d) during which time the ducks were kept on fish ponds*

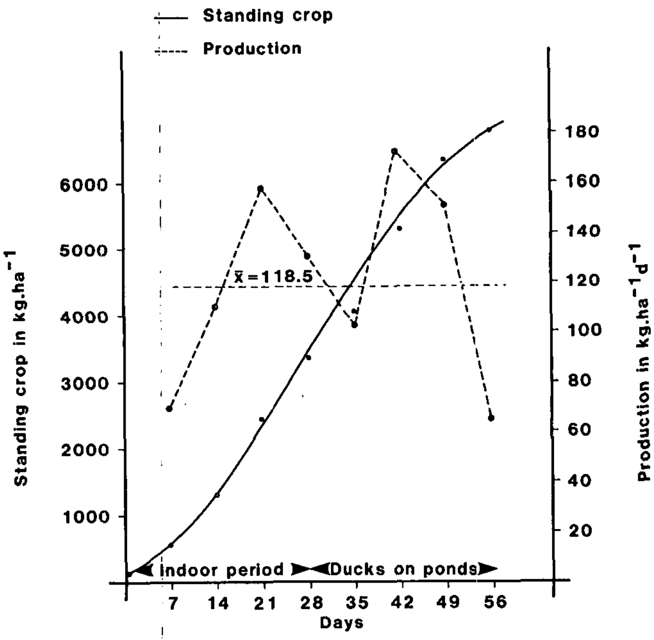


*Figure 2*
*Standing crop (kg $ha^{-1}$) and production (kg $ha^{-1}.d^{-1}$) over a 56 d period of ducks fed on chicken broiler starter mash during the first 14 (indoor) d followed by chicken broiler finisher mash (14 indoor d) and chicken broiler post finisher mash (28 d) during which period the ducks were kept on fish ponds*

### Vegetable production

The choice of the different vegetable crops planted during the present investigation was largely influenced by local demand. Results obtained during the six-month summer growing season between October 1985 and March 1986 for each crop are converted to production per hectare for the two types of irrigation water used (Table 6). Tomatoes clearly provided the highest yields $ha^{-1}$ for both types of irrigation water used with the duck manured water showing an exceptionally high yield of almost 96 t $ha^{-1}$. Spinach and lettuce provided the next highest results with the duck manured water also producing the highest yields. In the case of the potatoes and beetroot a reverse situation was found with freshwater irrigated land being more productive.

## Discussion

One of the possible reasons why some forms of intensive fish culture have not yet succeeded in South Africa, is the cost of land and pond construction. Another serious constraint is the escalating cost of fish feed in recent years. The series of investigations conducted in Transkei (Schoonbee *et al.*, 1979; Cronje, 1981; Prinsloo and Schoonbee 1984 a, b, c; Prinsloo and Schoonbee, 1986a) was aimed at reducing the cost input in aquaculture systems developed for local conditions whilst increasing the protein production per unit pond area.

TABLE 6
VEGETABLE PRODUCTION OBTAINED USING DUCK MANURED AND FRESH WATER FOR FIVE DIFFERENT VEGETABLES. RESULTS EXPRESSED IN PRODUCTION PER HECTARE

| Vegetables | Relative sizes of plots per crop ($m^2$) | (%) | Duck Manured water: Production in kg $plot^{-1}$ | Duck Manured water: Production in t $ha^{-1}$ | Fresh water: Production in kg $plot^{-1}$ | Fresh water: Production in t $ha^{-1}$ |
|---|---|---|---|---|---|---|
| Beetroot | 2 220 | 22,2 | 7 105,2 | 32,0 | 7 281,6 | 32,8 |
| Lettuce | 1 110 | 11,1 | 6 338,1 | 57,1 | 5 860,8 | 52,8 |
| Potatoes | 2 780 | 27,8 | 10 591,8 | 38,1 | 11 648,2 | 41,9 |
| Spinach | 1 670 | 16,7 | 9 301,9 | 55,7 | 6 880,4 | 41,2 |
| Tomatoes | 2 220 | 22,2 | 21 267,6 | 95,8 | 14 319,0 | 64,5 |
| Total | 10 000 | 100,0 | 54 604,6 | | 45 990,0 | |

Available information on the integration of duck and fish farming conducted elsewhere in the world (Woynarovich, 1979; Barash *et al.*, 1982; Sin, 1980) clearly points towards a further increase in cost-effectiveness and an increase in protein production per unit area whilst at the same time disposing of unwanted animal wastes.

In South Africa the relative scarcity of water is an important factor which must be taken into consideration in the establishment of any form of aquaculture production system. The multipurpose use of the same water in an integrated system therefore necessitates the further use of water, for e.g. vegetable production.

Based on our experience in Transkei, fish polyculture alone, despite its advantages over monoculture systems (Hepher and Pruginin, 1981) stands little chance of success if the total costs involved to produce one kilogram of fish using supplementary feed alone is taken into consideration. By integrating duck/animal production on the one hand and by utilising the nutrient rich effluent water from such ponds to irrigate vegetable crops, a virtually complete reuse of available water is achieved. At the same time, the accumulation of excessively high nutrient loads in the fish ponds which may inhibit the growth of fish and ducks, is alleviated considerably. Furthermore, by using the effluent water for irrigation, the undue pollution of streams is largely avoided.

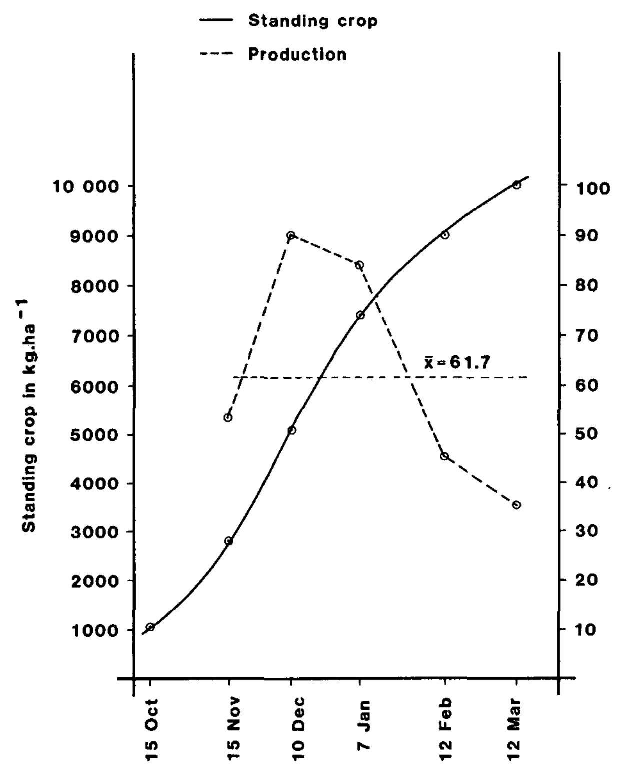


*Figure 3*
*Fish standing crop (kg $ha^{-1}$) and production (kg $ha^{-1}.d^{-1}$) in ponds receiving duck manure and formulated feed*

Problems experienced in the duck-cum-fish-cum-vegetable integrated system in Transkei concerning the pond water chemistry, are mainly the decline in oxygen levels and the danger of anoxic conditions in the ponds. The manure loads released into the pond water by a number of ducks (2 500 ducks $ha^{-1}$) on the water, as well as the density of fish maintained in the ponds (12 500 fish $ha^{-1}$) were two of the major factors responsible for these conditions. The continuous aeration of the pond water using an air blower as well as the regular supplementing of the pond water with freshwater, produced the best results at the lowest cost under local conditions. The beneficial use of the effluent water in vegetable production contributed further to the optimal management of this kind of integrated system.

Despite the merits spelled out by research workers such as Woynarovich (1979) and Sin (1980) on duck-cum-fish integrated systems in Europe and the Far East, the acceptability of ducks amongst the local inhabitants in Transkei had to be investigated. Apart from a small number of ducks sold to a butchery on an experimental basis, all ducks produced were sold live to the local inhabitants at R2,50 $kg^{-1}$. At an age of 8 weeks an average mass of 2,65 kg $duck^{-1}$ was achieved. The marketing of live ducks proved to be extremely popular amongst the local population. Based on the actual quantities of feed used and the prices paid for this at the time of investigation, feed costs comprised an average of 57% of the actual price obtained per live mass of duck.

If the results of the ten replicates on the production of ducks over a period of 6 months are converted to kg of live ducks produced $ha^{-1}$ pond space an average yield of 32 181,25 kg $ha^{-1}$ was obtained.

From the results obtained on duck production, it is clear that undue handling inhibits the feed conversion of ducks. During the initial indoor grow-out period, space availability had a similar influence, (Marais and Joubert, undated report), when the feed conversion increased dramatically over the last seven days of the 28 d indoor period (Tables 2 and 3). The most pronounced increase in feed conversion occurred immediately after transfer of the ducks to the ponds (Period 5; Tables 2 and 3). This condition is ascribed to the fact that the ducks had to be trained initially to enter the duck houses at night and had to be chased into the duck houses repeatedly for about seven days before they got accustomed to the procedure. The last pronounced increase in feed conversion was during period eight (49 to 56 d). By marketing the ducks after 48 to 49 d at a mean live individual mass of 2,5 kg the mean feed conversion could be reduced to an average of 2,55. This would mean an almost 7% saving in total feed costs.

Fish yields obtained over a period of five months during the present series of investigations on the integrated duck-cum-fish-cum-vegetable production system were the highest obtained so far in the Transkei (8 943 t $ha^{-1}$).

The mean fish production of 61,7 kg $ha^{-1}.d^{-1}$ achieved for the present investigations (Figure 3), also compares favourably with fish production results obtained in countries such as Israel (Moav *et al.*, 1977; Barash *et al.*, 1982). Compared to production results obtained by Prinsloo and Schoonbee (1984 a to c) where the highest mean daily fish production using pig, cattle and chicken manure with pelleted fish feed amounted to 24,4 kg $ha^{-1}.d^{-1}$, the use of duck manure in fish ponds appeared to be far superior. However, it must be taken into consideration that in the previous studies by Prinsloo and Schoonbee, (1984a, b, c) juveniles were used, spawned during the same summer season. An important observation from the findings is the fact that the detritus feeding silver carp benefited most from the pond conditions (Table 5), increasing its biomass share from an initial 5,8% to 20,7% at the end of the study. This also points towards the possible inclusion of the grey mullet *Mugil cephalus* L. in this kind of integrated aquaculture-agriculture system (Thomson, 1963; De Silva and Wijeyaratne, 1976).

An important aspect emanating from the present fish production results was the fact that all the fish in the ponds could be grown to sizes acceptable for marketing under local conditions. This was achieved by using overwintered juveniles for all the fish species concerned.

As mentioned earlier, the high protein supplementary feed used in fish production systems is one of the most serious problems facing the development of aquaculture in South Africa. By feeding only the common carp and by adjusting the feed dosage levels on the mass increment of the common carp only, the feed cost based on the total production of the pond fish was considerably reduced. If the total production of pond fish is taken into consideration at the minimum marketing price of R1,50 $kg^{-1}$ live mass, feed cost amounted to 50% of the actual income realised. It must be emphasised however that the fresh manure input from the ducks probably contributed much towards the eventual total fish production of 8,943 t $ha^{-1}$, a phenomenon verified by research workers such as Woynarovich (1979) and Sin (1980).

The acceptability and popularity of warm water pond fish on the local market has been substantiated repeatedly over a number of years in Transkei (Roode, 1978; Nakani, 1983; Personal observations). The inclusion of vegetable production in particular and the production of ducks together with fish make this system completely acceptable as a farming practice in Transkei. The overall economic viability of this system needs further evaluation.

## Recommendations

The present investigations on integrated-duck-cum-fish-cum-vegetable production in Transkei concludes the series of research projects concerning the development of a freshwater fish industry for this country. In our view an integrated system such as the present one will be acceptable for community development programmes throughout Transkei. In addition, such units can contribute substantially towards the total food production in Transkei. The fish species used for which large-scale spawning techniques and successful rearing of larvae and juveniles were specifically developed for local conditions (Prinsloo and Schoonbee, 1983; Schoonbee and Prinsloo, 1984; Prinsloo and Schoonbee, 1986b) are all cold water tolerant and grow well under local conditions.

In view of our experience on fish polyculture and integrated aquaculture-agriculture systems the following recommendations are made for Transkei:

### Type of system recommended

Integrated aquaculture-agriculture systems with fish in polyculture using combinations of pig, cattle and poultry manure, with supplementary feeding restricted to the common carp only, would be the system of choice for community development programmes. Best results are obtained using ducks on the ponds whilst the fish species recommended for the temperate climatic conditions prevailing in Transkei, are the benthic European common carp, *C. carpio,* the plant eating Chinese grass carp, *C. idella,* the zooplankton feeding bighead carp *A. nobilis* and the detritus and phytoplankton feeding silver carp *H. molitrix.* The grey mullet may be an excellent substitute for the silver carp in a fish polyculture system. Should this kind of integrated aquaculture-agriculture system be considered in other

TABLE 7
ANALYSES OF EPOL BROILER STARTER AND FINISHER MASH USED AS DUCK FEED AND POULTRY LAYING PELLETS USED AS SUPPLEMENTARY FEED FOR THE COMMON CARP *C. CARPIO* IN THE FISH PONDS

| Feed composition | | Broiler starter mash | Broiler finisher mash | Poultry laying pellets |
|---|---|---|---|---|
| Protein | g/kg | 220 | 195 | 175 |
| Methionine | g/kg | 5,6 | 5,4 | 4,4 |
| T.S.A.A. | g/kg | 9,0 | 8,3 | 7,0 |
| Lysine | g/kg | 13,2 | 11,6 | 9,7 |
| Isoleucine | g/kg | 8,7 | 7,7 | 6,6 |
| Tryptophan | g/kg | 2,9 | 2,3 | 2,0 |
| Arginine | g/kg | 11,9 | 10,5 | 9,3 |
| Threonine | g/kg | 8,5 | 7,9 | 6,9 |
| Fat | g/kg | 78 | 76 | 72 |
| Fibre | g/kg | 44 | 40 | 40 |
| Calcium | g/kg | 9,9 | 9,9 | 9,9 |
| Phosphorus (Total) | g/kg | 7,0 | 6,9 | 6,9 |
| Phosphorus (Avail) | g/kg | 5,1 | 4,8 | 4,8 |
| Salt | g/kg | 4,0 | 4,0 | 4,0 |
| Metabolisable Energy | MJ/kg | 12,97 | 13,4 | 13,4 |

warmer regions of South Africa, the inclusion of the tilapia *Oreochromis mossambicus* and the sharptooth catfish *Clarias gariepinus* should be considered in a polyculture system. Vegetable crops which proved very popular included spinach, potatoes, beetroot, pumpkins and cabbage.

Should integrated aquaculture-agriculture systems be developed, it will be necessary to establish one or more vegetable nurseries as well as duck production units in Transkei to cater for the anticipated growing demand for seedlings and day-old ducklings.

### Establishment of a fish hatchery

A prerequisite for an integrated aquaculture-agriculture system is the establishment and availability of a commercial fish hatchery where adequate numbers of the candidate fish species suitable for production under climatic conditions of a certain area, can be produced on a large scale. For Transkei this aspect has been fully investigated and reported on.

### Location of integrated systems

Availability of water, good quality soil suitable for pond construction and vegetable production in the proximity of relatively high density rural communities would constitute ideal focal points for the establishment of small-scale family community units. The availibilty of electricity will determine the overall stocking density and production of fish as well as the successful initial rearing period of ducklings.

### Pond construction and size of units

In order to reduce evaporation to the minimum, ponds should be 1,5 to 2 m deep. For the purpose of management, individual ponds should preferably not exceed 1 000 $m^2$ in size. Total pond space recommended for a family/community unit is 0,5 to 1 ha. Depending on the availability of water and land, multiple units can be established in the same area. Irrigable land allocated to each unit can be one to two times the size of the pond space occupied depending on water availability. Ponds should be constructed above the lands so that no pumping would be necessary for irrigation.

### Marketing of products

Where possible, local marketing outlets in the proximity of the units should be established so that live and fresh produce can be available on demand.

### Extension service

For this system to succeed, suitable qualified and trained extension officers must be appointed. The necessary information on the management of the pond systems, fish and duck feeding programmes, the cultivation of the various vegetable crops and the marketing strategies should be prepared in the form of brochures, lectures, workshops and practical demonstrations.

### Need for research

The considerable amount of information generated by the research on aquaculture development in Transkei emphasises the need for research workers to be constantly involved in development projects of this nature. Research workers may also play a very important role in the training of extension workers and the preparation of the necessary technical brochures.

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