Journal of Agriculture and Ecology Research International

13(2): 1-9, 2017; Article no.JAERI.36844
ISSN: 2394-1073

Optimal Resource Allocation in Integrated Fish-Based Farming Systems in Kaduna Metropolis, Nigeria

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Authors' contributions

This is the result of collaboration between all authors. Author CJM designed the study, supervised the data collection process and performed the statistical analysis. Author SSM managed the literature searches and wrote the first draft of the manuscript while author SAS supervised the entire work, she also edited the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAERI/2017/36844
Editor(s):
(1) Chandra Shekhar Kapoor, Department of Environmental Sciences, University College of Science, Mohan Lal Sukhadia University, India.
Reviewers:
(1) Sanusi Sadiq, Swami Keshwanand Rajasthan Agricultural University, India.
(2) A. A. Girei, Nasarawa State University, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/21428

Original Research Article

Received 19th September 2017
Accepted 8th October 2017
Published 16th October 2017

ABSTRACT

The broad objective of this study was to determine the optimal resource allocation in integrated fish-based farming (IFF) system in Kaduna metropolis of Nigeria. Primary data were generated and used for the study. The data were collected through the use of structured questionnaire administered to one hundred and thirty eight (138) fish-based farmers and were analyzed using linear programming model. The results of the linear programming model shows that resource allocation of integrated fish-based farming system showed that the mean labour input (131 man days) utilized in fish-vegetable farming was the highest among the three categories. Integrated fish-pig farming had the highest input of fingerlings with a mean of 3150. The results of the optimal base plan shows that the three integrated fish-based farming activities (decision variables) entered the final fish-based farming plan/solution as they had zero reduced cost (opportunity cost), indicating that these enterprises were in the best competitive positions. Finally, results of the

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resource use efficiency indicated that Day-old chicks, number of piglets and pond size were the limiting (binding) resources. The resources that were not binding were labour, number of fingerlings, feeds, drugs, lime, seeds, fertilizer, pesticides and pen size. It is therefore, suggested that some of the labour being employed be channel to non-agricultural sectors for productive use, feeds and drugs usage be minimized and excess be used for expansion of the farm and other related enterprises.

Keywords: Resource; allocation; optimal; integrated; fish-based.

1. INTRODUCTION

Fishes play an important role in human nutrition. However, the cost is beyond the reach of many consumers. One method of decreasing the cost of fish production, increasing output and preserving the ecosystem is by the use of integrated fish farming system [1]. Integrated fish farming is the blending of various compatible agricultural enterprises into a functional or unified whole farming system for the purpose of sustainability. It is a “no waste”, low cost and low energy production system in which the by-products of one enterprise are recycled into another as input. For example, animal dung can be used to improve the fertility of the soil, which will increase plant growth. Animal dung can also be used as fertilizer in a fish pond to increase fish production [2].

With integrated fish farming, many organic wastes are reclaimed, recycled and re-used. This system of farming has been proposed as an environmentally friendly way of recycling wastes, especially those produced through the cultivation of intensive fish species which require the supply of exogenous energy [1]. Reclamation, recycling and reuse help to solve the problem of waste disposal and scarcity of resource materials. In many of the integrated farming systems in Asia and other parts of the developing world, fish production remains the most important activity. Commercial pig/chick/duck production activity has also been accompanied by fish and crop production, mainly by using animal waste as fish feed and manure for crops [3]. The overall aim of integrated farming is to improve the productivity of the enterprises being considered.

Agricultural Productivity is defined as the index of the ratio of the value of total farm output to the value of total resources used in the farm. The input-output process of farm production is important in the allocation of resources, the measurement of productivity and the distribution of income [4]. Resource productivity is defined in terms of individual resource inputs or in terms of a combination of them. Thus, land, labour, capital and management productivities can each be defined as the ratio of total output to inputs of land, labour, capital and management, respectively.

Even though there are several successful practices of integrated fish farming in Nigeria, the system of farming using integrated agriculture, aquaculture and livestock farming are not yet wide-spread in the country [5]. It is essential that scientific research should be directed to upgrade the existing technology and evolve appropriate technology after examining the socio-economic and other production constraints under varying conditions.

This notwithstanding, there is substantial dearth of information on the types and extent of resource productivity of integrated fish farming system in Nigeria. This is due to the observed subsistence nature of fishing and poor levels of cash income realized by farmers in the area [6]. The study is therefore justified because information generated will not only enrich literature on integrated fish farming system but will provide information on the optimal resource allocation and efficiency among the few integrated fish farmers in the study area. This will perhaps encourage speedy adoption of a fully integrated fishing system in order to drastically reduce poverty and improve the standards of living of the farmers.

2. METHODOLOGY

2.1 Study Area

This study was conducted in Kaduna State, Nigeria. The study area lies between Latitudes 10° 21’ and 10° 33’ North of the Equator and Longitudes 7° 45’ and 7° 75’ East of the Greenwich Meridian (Kaduna State Government, 2011). The vegetation in the State is divided into Northern Guinea savannah in the North and the Southern Guinea savannah in the

South. The State occupies a total land mass of about 46,053 square kilometers and has an estimated population (projected to 2016) of 7,190,910 people using the prevailing population growth rate of 2.47 [7]. The State shares common boundaries with Abuja in the south-east and six other States, namely: Katsina, Kano and Zamfara in the North, Nassarawa and Plateau in the North-east, and Niger in the North-west.

2.2 Sampling Procedure

A two-stage sampling procedure was adopted for this study. In the first stage, all the four LGAs in Kaduna metropolis, namely: Chikun, Kaduna South, Kaduna North and Igabi, were selected. A reconnaissance survey conducted identified 138 integrated fish-based farmers in the four LGAs. The second stage was the selection of all the integrated fish farmers in the four LGAs to give a sample size of 138 fish based farmers in the study area.

Table 1. Distribution and selection of integrated fish-based farmers in Kaduna metropolis

L.G.As	Sampling frame*	Sample size (100%)
Kaduna South	32	32
Kaduna North	24	24
Chikun	27	27
Igabi	54	54
Total	138	138

**Based on reconnaissance survey (2016)*

2.3 Method of Data Collection

This study made use of primary data in achieving its objectives. The primary data were collected from the fish based farmers using structured questionnaire. Information collected includes: the quantity of inputs/costs (fingerlings, labour, pond size, drugs, seeds, fertilizer, feed, piglets, day old chicks, pen size, lime, pesticides) used in fish, poultry, vegetables and swine production as well as fish, poultry, vegetables and swine output realized from the production process.

2.4 Analytical Techniques

2.4.1 Linear programming (LP) model

The LP model was used to achieve the objective of the study. Linear programming is a tool used to identify the optimal performance of enterprises when combined and was used in identifying the performance of each enterprise in integrated fish farming. The linear programming model is generally stated as follows:

$$\text{Max } Z = \sum_{j=1}^{n} c_j x_i (j = 1,2,3 \ldots \ldots n) \quad (1)$$

Subject to

$$\sum_{j=1}^{m} a_{ij} x_i \leq b_i (j = 1,2,3, \ldots m) \quad (2)$$

and $X_j \geq 0$ for all

Where:

Z= objective function,
X_j = real activities,
C_j = marginal contributions of each variable,
b_i = total amount of i[th] resources available,
a_{ij} = resource requirements per unit of activity,
n = number of activities, and
m = number of resources.
For fish and poultry (activity 1)
Z = objective function (Net farm income),
Xj = the quantity of activities where there are n activities to be considered,
Cj = resource requirement per unit of activity,
bi = available productive resource in limited supply (constraints),
n = Number of activities and
m = Number of resources,

The linear programming model for this study was specified as,

$$\text{Max } Z = \sum_{j=1}^{m} p_{ij} x_j - \sum_{j=1}^{n} c_j x_j \quad (3)$$

subject to:

$\sum_{j=1}^{m} a_1 x_{1j} \leq b_i$ ....fingerlings restriction (4)
$\sum_{j=1}^{m} a_2 x_{1j} \leq b_i$ ....feeds restriction (5)
$\sum_{j=1}^{m} a_3 x_{1j} \leq b_i$ ....lime restriction (6)
$\sum_{j=1}^{m} a_4 x_{1j} \leq b_i$ ....labour restriction (7)
$\sum_{j=1}^{m} a_5 x_{1j} \leq b_i$...............drug restriction (8)
$\sum_{j=1}^{m} a_6 x_{1j} \leq b_i$.............pond size restriction (9)
$\sum_{j=1}^{m} a_7 x_{1j} \leq b_i$......day-old chick restriction (10)
$\sum_{j=1}^{m} a_8 x_{1j} \leq b_i$...... .....fertilizer restriction (11)
$\sum_{j=1}^{m} a_9 x_{1j} \leq b_i$...... .pen size restriction (12)
$x_j \geq 0$ (the non-negativity condition) (13)

For fish and vegetable (activity 2)

Z = objective function (Net farm income) or total gross revenue less total cost of production

Xj = the quantity of activities where there are n activities to be considered,
Pj = value per hectare of the j[th] activity,
Cj = cost per hectare of producing the j[th] activity,
Cj = resource requirement per unit of activity,
bi = available productive resource in limited supply (constraints),
n = Number of activities,
m = Number of resources,

The Linear programming model for this study was specified as:

$$\text{Max } Z = \sum_{j=1}^{n} p_j x_i - \sum_{j=1}^{n} c_j x_i \quad (14)$$

Subject to

$\sum_{j=1}^{m} a_1 x_{2j} \leq b_i$ …………fingerlings restriction (15)
$\sum_{j=1}^{m} a_2 x_{2j} \leq b_i$ ……….….feed restriction (16)
$\sum_{j=1}^{m} a_3 x_{2j} \leq b_i$ …………..lime restriction (17)
$\sum_{j=1}^{m} a_4 x_{2j} \leq b_i$ ……..….labour restriction (18)
$\sum_{j=1}^{m} a_5 x_{2j} \leq b_i$ ……..……drug restriction (19)
$\sum_{j=1}^{m} a_6 x_{2j} \leq b_i$ …………..pond restriction (20)
$\sum_{j=1}^{m} a_7 x_{2j} \leq b_i$ …….vegetable seed restriction (21)
$\sum_{j=1}^{m} a_7 x_{2j} \leq b_i$ …….…...fertilizer restriction (22)
$\sum_{j=1}^{m} a_8 x_{2j} \leq b_i$ ……..pesticides restriction (23)
$\sum_{j=1}^{m} a_9 x_{2j} \leq b_i$ ….…. land size restriction (24)
$x_j \geq 0$ (the non-negativity condition) (25)

For fish and pig (activity 3)

Z = objective function (Net farm income)
Xj = the quantity of activities where there are n activities to be considered,
Cj = resource requirement per unit of activity,
bi = available productive resource in limited supply (constraints)
n = Number of activities,
m = Number of resources

The Linear programming model for this study was specified as

$$\text{Max } Z = \sum_{j=1}^{m} p_j x_i - \sum_{j=1}^{n} c_j x_i \quad (26)$$

subject to

$\sum_{j=1}^{m} a_1 x_{3j} \leq b_i$ ………… fingerlings restriction (27)
$\sum_{j=1}^{m} a_2 x_{3j} \leq b_i$ …………feed restriction (28)
$\sum_{j=1}^{m} a_3 x_{3j} \leq b_i$ ………..lime restriction (29)
$\sum_{j=1}^{m} a_4 x_{3j} \leq b_i$ ………labour restriction (30)
$\sum_{j=1}^{m} a_5 x_{3j} \leq b_i$ ………drug restriction (31)
$\sum_{j=1}^{m} a_6 x_{3j} \leq b_i$ ….pond size restriction (32)
$\sum_{j=1}^{m} a_7 x_{3j} \leq b_i$ ………piglets seed (33)
$\sum_{j=1}^{m} a_8 x_{3j} \leq b_i$ ……..fertilizer restriction (34)
$\sum_{j=1}^{m} a_9 x_{3j} \leq b_i$ ……….pig pen size restriction (35)
$x_j \geq 0$ (the non-negativity condition) (36)

Where

$a_{i1} \ldots a_{i8}$ = resource requirement per unit of activity, that is, how much of a resource is required for each activity unit. The activities included in the LP model were as follows: fish-poultry production activity, which involved fingerling buying, feed buying, lime buying, labour hiring, drug buying, pond size construction, day-old chick buying, fertilizer buying and pen size. The fish-vegetable activity involved fingerling buying, feed buying, lime buying, labour hiring, drug buying, pond size construction, seed buying and fertilizer buying. Finally, for the fish-pig activity, which involved fingerling buying, feed buying lime buying, labour hiring, drug buying, pond size construction, piglet buying, fertilizer buying and pen size. The restrictions indicated the resource situation among the farm families and are as shown above. Each of the restrictions was specified in monetary units (Naira).

2. RESULTS AND DISCUSSION

3.1 Resource Allocation to Integrated Fish-based Farming Systems

The result of resource allocation to integrated fish farming systems in the study area is presented in Table 2. The result of the resources is discussed as follows:

3.1.1 Labour

The mean labour input utilized in fish-vegetable farming system was (131 man-days). It was the highest among the three integrated fish-based farming systems while the lowest was integrated fish-pig farming system (94 man-days). The coefficient of variation (CV) of 44% in the labour used by the fish-based farmers was highest in the integrated fish-poultry farming system and therefore, the influence of labour among the three integrated fish farming systems would have a higher tendency in the integrated fish-poultry farming system than either of the integrated fish-vegetable farming system or integrated fish-pig farming system.

3.1.2 Fingerlings

The resource allocation of fingerlings among the three integrated fish farming systems shows that the mean fingerlings of 3150 utilized in fish-pig farming system was the highest while the lowest (2367) was in integrated fish-poultry farming system. The coefficient of variation (CV) of 90% in the fingerlings used by the fish-based farmers was highest in the integrated fish-poultry farming system and therefore, the influence of fingerlings between the three integrated fish farming systems would tend to be higher in the integrated fish-poultry farming system. The output from a fish farm will be determined by the quantity and quality of fingerlings used [8].

3.1.3 Drugs

The mean input of drugs utilized in fish-vegetable farming system (₦25,120) was the lowest among the three integrated fish farming systems while the highest (₦42,811) was in integrated fish-poultry farming system. This may be attributed to the greater requirement of medication in fish-poultry farming for sustainable growth and production than in the fish-vegetable and fish-pig farming systems. The coefficient of variation (CV) of 22% in the drugs used by the fish-based farmers in fish-pig farming system was highest implying a wider variation in the drugs usage adequate by the fish-based farmers in fish-pig farming system over those of the fish-poultry farming system and fish-vegetable farming system. Therefore, the influence of drugs among the three integrated fish farming systems would have a higher tendency in the integrated fish-pig farming system than in the integrated fish-poultry farming system or integrated fish-vegetable farming system.

3.1.4 Lime

The mean input of lime of 41 kg utilized in fish-pig farming system was the highest between the three integrated fish farming systems while the lowest (24 kg) was in integrated fish-poultry farming system implying that a higher input of lime was allocated to integrated fish-pig farming system. The coefficient of variation (CV) of 51% in the input of lime used by the fish-based farmers was highest in the integrated fish-vegetable farming system as indicated by the standard deviation of 1964 and therefore, the influence of lime between the three integrated fish farming systems would tend to be higher in the integrated fish-pig farming system.

3.1.5 Feeds

The mean feeds input of 7464 kg utilized in fish-poultry farming system was the highest among the three integrated fish-based farming systems while the lowest (4957) was in integrated fish-vegetable farming. The coefficient of variation (CV) of 26% of feeds used by the fish-based farmers in fish-poultry farming system was highest implying a wider variation in the feeds input utilized by the fish-based farmers in fish-poultry farming system over those of the fish-vegetable farming system and fish-pig farming system and therefore, the influence of feeds between the three integrated fish farming systems would have a higher tendency in the integrated fish-poultry farming system than either of the integrated fish-pig farming system or integrated fish-vegetable farming system. With the present high cost of pelleted fish feeds, integrated fish farming stands to reduce the cost of feeding fish while simultaneously increasing the yield, leading to high economic returns [9]. This is because manure from poultry or pig can be used in fertilizing ponds to encourage growth of phytoplanktons for the consumption of fish.

3.1.6 Fertilizer

The mean fertilizer input utilized in fish-vegetable farming system (128 kg) was the highest among the three integrated fish farming systems while the lowest (44 kg) was in integrated fish-poultry farming system. This result is expected as crop (vegetable) farming integrated with fish farming requires a higher quantity of fertilizer application. Integration of fish farms with livestock reduces cost of fertilizer as livestock manure is used in pond fertilization [10]. The coefficient of variation (CV) of 94% in the fertilizer used by the fish-based farmers was highest in the integrated fish-vegetable farming system and therefore, the influence of fertilizer between the three integrated fish farming systems would have a higher tendency in the integrated fish-vegetable farming system than either of the integrated fish-poultry farming system or integrated fish-pig farming system. The cost of fertilizer incurred in integrated fish farming is not as high as conventional fish farming or crop farming. As reported by [11], integrated farmers with two rice crops used less fertilizer annually than alternate farmers with one rice crop because of the increase in soil fertility caused by fish.

Day-old chicks: The mean number of day-old chicks used in the fish-poultry farming system was 709.

Seeds: The mean quantity of seeds used in the vegetable farming system was 7 kg.

Pesticides: The mean quantity of pesticides used in the fish-vegetable farming system was 3 litres.

Piglets: The mean number of piglets used in the fish-pig farming system was 53.

3.2 Optimal Base Plan for Integrated Fish Farming Enterprises

The results of the linear programming model presented in Table 3 shows that the three integrated fish-based farming activities (decision variables) entered the final fish-based farming plan/solution as they had zero reduced cost (opportunity cost), indicating that these enterprises were in the best competitive positions. This further implies that exclusion of any of the three integrated fish-based enterprises will reduce the optimal value of the final fish-based farming plan. This result is to some extent similar to the results obtained by [12], where it was found that integrated fish-poultry and fish-pig entered the final plan,

Table 2. Resource allocation to integrated fish farming systems

Resources (unit)	Minimum	Maximum	Mean	SD	CV (%)
Fish-poultry					
Labour (man-days)	65.81	179.03	111.64	49	43.9
Fingerling (number of fingerlings)	705.67	6710.00	2367.07	2126	89.8
Drugs (₦)	5798	115961	42811	1836	4.3
Lime (kg)	8.17	90.84	24.33	10	41.1
Feeds (kg)	3184.38	13239.10	7464.30	1926	25.8
Day-old chicks (number of chicks)	238.00	14390.00	708.85	175	24.7
Fertilizer (kg)	5.17	284.60	44.65	38	85.1
Fish-vegetable					
Labour (man-days)	98. 13	196.01	131.45	12	9.1
Fingerling (number of fingerlings)	621.00	9303.00	2943.47	3310	44.5
Drugs (₦)	10834	98305	25120	2250	9.0
Lime (kg)	3.55	101.36	33.10	17	51.4
Feeds (kg)	2337.75	11507.93	4956.88	512	10.3
Seeds (kg)	2.50	22.00	7. 35	12	163.0
Fertilizer (kg)	50.00	260.50	128.33	121	94.0
Pesticides (litre)	1.50	12.00	3.18	2	62.9
Fish-pig					
Labour (man-days)	60. 12	124.01	94.25	15	15.9
Fingerling (number of fingerlings)	754.00	13703.00	3149.67	1664	52.8
Drugs(₦)	10950	39180	28311	6118	21.6
Lime (kg)	2.70	158.44	41.31	19	45.9
Feeds (kg)	2643.13	10258.75	6346.25	553	8.7
Piglets (number of piglets)	25.00	196.00	52.65	15	28.5
Fertilizer (kg)	12.5	158.33	68.20	13	19.1

SD = standard deviation, CV = coefficient of variation
Source: Analyzed data from field survey (2016)

Table 3. Result of the optimal base plan for integrated fish farming enterprises

Real activities/objective function	Existing plan	Optimal contributions (n)	Plan reduced cost (n)
Objective function value	2696202.78	2669731.30	
Integrated fish-poultry	1166441.8	1700618.84	0
Integrated fish-vegetable	770708.87	365753.19	0
Integrated fish-pig	759052.11	603359.27	0

Source: Analyzed data from field survey (2016) out of six fish-based livestock enterprises considered.

3.3 Resource Use Efficiency in Integrated Fish-based Farming Systems

The result of the resource use in the optimal base plan is shown in Table 4. The efficiencies of the farm resources were evaluated in terms of the marginal value product (shadow prices) of the resources as used by [13]. The resources with non-zero shadow prices were limiting (tight) resources and therefore, a unit increase in the use of any of these limiting resources would increase net farm income by the value of their shadow prices. Day-old chicks, piglets and pond size were the limiting (binding) resources and this implies that they were the resources that constrained the attainment of the objective function value. This result is in contrast with the findings of [12] to the effect that feeds and labour were the limiting resources. Pond size was the most limiting resource as it had the highest shadow price of ₦25,690.30, implying that a unit increase in pond size would increase the optimal income by ₦25,690.30. Day-old chicks were the second most limiting resource with shadow price of ₦1, 582.93, indicating that increasing the number of day old chicks by one unit will increase the optimal income by ₦1, 582.93. Piglet were the least limiting resources with shadow price of ₦377.30 implying that a unit increase in the number of piglets will increase the optimal income by ₦377.30. These limiting resources with zero levels of slacks (unused) resources were fully utilized in the final fish-based farming plan with no opportunity costs and therefore, are unavailable for further usage in the optimal plan. Hence, if these resources are made available, their usage will improve on the optimal income.

The resources that were not binding as shown in Table 4 were the non-limiting (loose) resources as they had zero shadow prices with slacks (unused resources) implying that these resources did not constrain the attainment of the objective function value. Labour, number of fingerlings, feeds, drugs, lime, seeds, fertilizer, pesticide and pen were the non-limiting resources in the final fish-based farming plan with varying opportunity costs. Labour input with zero shadow price had the highest slack value of ₦ 49, 299.52 and this implies that this input was not fully utilized with ₦49,299.52 worth of unused labour in the final fish-based farming plan. Pen had the lowest slack value of ₦970.37 among the non-limiting resources and this implies that this input was not fully utilized with ₦ 970.37 worth of unused pen in the final fish-based farming plan. This result agrees with that of [14] who found that there was labour resource misallocation among farmers in a study on integrated arable and fishery enterprises in Abia state, Nigeria. These non-limiting resources were underutilized by the fish-based farmers as the optimum income was attained without fully utilizing these resources.

Table 4. Resource use efficiency in the optimal farm plan

Resources	Existing plan resources used (₦)	Optimal plan resources used (₦)	Resource status	Slack (₦)	Shadow price (₦)
Labour	356952.11	307,652.60	Not Binding	49299.52	0
Fingerlings	286183.68	208,891.56	Not Binding	22984.72	0
Feeds	750697.58	542,824.75	Not Binding	20872.83	0
Drugs	96241.56	68355.21	Not Binding	27886.35	0
Lime	33959.88	28351.35	Not Binding	5608.53	0
Chicks	106, 328.15	106328.15	Binding	0	1582.93
Piglets	91, 984.00	91984.00	Binding	0	377.30
Seeds	22, 960.12	18470.97	Not Binding	4489.15	0
Fertilizer	114694.75	111613.80	Not Binding	3080.95	0
Pesticide	74, 360.00	10309.38	Not Binding	6191.12	0
Pen size	18167	38977.99	Not Binding	970.37	0
Pond size	39948.36	18167.00	Binding	0	25690.30

Source: Analyzed data from field survey (2016)

4. CONCLUSION AND RECOMMENDATIONS

The results of the resource allocation of integrated fish farming systems in the study area showed that the mean labour input (94 man-days) utilized in fish-pig farming system was the lowest between the three integrated fish farming systems while the highest (131 man-days) was in integrated fish-vegetable farming system implying that a higher labour input was allocated to integrated fish-vegetable farming system and the lowest was in integrated fish-pig farming system. The mean fingerlings/juveniles of 3150 utilized in fish-pig farming system were the highest between the three integrated fish farming systems. An average fish-based farmer in the integrated fish-vegetable farming system incurred a resource allocation of 7 kg on seeds in the study area. An average fish-based farmer in the integrated fish-vegetable farming system incurred a resource allocation of 3 litres on pesticides. An average fish-based farmer in the integrated fish-pig farming system incurred a resource allocation of 53 on piglets. The mean feed input of 7464 kg utilized in fish-poultry was the highest among the three integrated fish-based farming systems. The results of the optimal base plan shows that the three integrated fish-based farming activities (decision variables) entered the final fish-based farming plan/solution as they had zero reduced cost (opportunity cost), indicating that these enterprises were in the best competitive positions. The result of the level of resource use in the farm plan revealed that pond size, day old chicks and piglets were the limiting (binding) resources. Labour, fingerlings, feeds, drugs, lime, seeds, fertilizer, pesticide and pen size on the other hand, were the non-limiting resources with varying opportunity costs.

The following recommendations were made based on the findings of the study:

The results from linear programing shows slack values for labour, feeds and drugs were used in excess of requirements. It is therefore, suggested that some of the labour being employed be channel to non-agricultural sectors for productive use, feeds and drugs usage be minimize and excess be used for expansion of the farm or enterprise.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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