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Energy Inputs and Fish Yield Relationship for Open and Greenhouse Pond

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Abstract: A greenhouse experiment was carried out to investigate the energy output-input relation and their specific growth yield relationship for production of rohu fish (*Labeo rohita*). The results revealed that the yield was found 5.01 and 10.38 kg in open and greenhouse pond, respectively. The operational energy and energy source requirement were found to be 505.26 and 325.27 MJ/18 m^3 in case of open and 542.22 and 580.23 MJ/18 m^3 for greenhouse fish production. The energy ratio, specific energy and energy productivity were calculated 0.078, 12.88 MJ/18 m^3 and 0.0154 MJ/18 m^3 for open condition, where as 0.090, 11.09 and 0.0178 MJ/18 m^3 for greenhouse, respectively. Fish yield increased as a function of energy inputs. Mathematical relations were fitted to the growth yield and energy input. The best data fitting was obtained between specific growth yield and energy input in open and greenhouse are Nelder's curve ($R^2 = 82.66\%$) and Gupta and Nigam ($R^2 = 66.16\%$), where as between specific growth yield and feed energy was found to be best suited in the form of Quadratic for both the condition, as it gave the maximum coefficient of determination.

Key words: Fish, embodied energy, energy ratio, specific energy, yield

Introduction

Energy, being the capacity to do work, is at the heart of all human activities, especially those concerning the production of goods and services (Hetz, 1992). Energy is a crucial input to aquaculture production. Energy is primarily used in fish culture operations for pond preparation, water filling, weed control, fertilizer application, cow dung application, feeding, aeration, water exchange/replacement, monitoring of water quality parameters, fish sampling, cleaning up, harvesting and finally transportation etc. Hence, it is important to note that to increase yield, one should use the efficient methods of mechanized systems, efficient electrical appliances and pumps etc.

Aquaculture productivity is closely linked with the energy inputs in the form of direct sources derived from human, electric motors, aerator, diesel engines and pump sets and indirect energy sources in the form of fish seeds, feed, fertilizers, chemicals, manures etc. In any production activities output is directly proportional to the input energy. Higher the energy input resulting higher output and vice-versa.

Several researchers have been reported on energy use pattern and their relationships of field crops such as wheat, rice, cotton and sugarcane etc. A case study was performed by Singh and Pannu (1998)

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in Punjab during 1990-1992 for energy requirement in fish production and reported energy ratio in the range of 0.15-0.20 of a village fish pond. Canakci and Akinci (2005) studied the energy use patterns in greenhouse vegetable production by a questionnaire method in Antalya province for a period of one year, to determine the energy ratio, specific energy and energy productivity. The energy ratio of four major greenhouse vegetables used i.e., tomato, pepper, cucumber and eggplant, were calculated at 0.32, 0.19, 0.31 and 0.23, respectively. Another case study was carried out by Hatirli *et al*. (2006) in Antalya province of Turkey for greenhouse tomato production and reported output-input, specific energy and energy productivity were 1.2, 12380.3 MJ t^{-1} and 0.09 kg MJ^{-1}, respectively. Singh and Singh (1992) reported that the yield is linearly correlated with the total energy input for wheat and maize crop. Singh *et al*. (1999) reported that yield can be increased by an additional energy input and any additional increase in yield would require a large additional energy input for wheat crops. However, the study related to energy inputs and their yield relationship in fish production is not available. Therefore, the aim in this communication were to determine the energy output-input ratio, specific energy and energy productivity and to determine the relation between specific growth yield versus energy input by different mathematical relations for open and greenhouse fish production.

Materials and Methods

An energy analysis study was carried out at solar energy park, IIT Delhi during October, 2004 to February, 2005 (Latitude-28°35′ N, Longitude-77°12′ E and an altitude of 216 m above mean sea level). Two cemented tanks of 4×3×1.7 m each were constructed for open and greenhouse purpose. The ponds were prepared with soil base (0.1 m) and filled with water at desired level (18 m^3) and stocked with fingerlings (average wt. 10.1 g) of Indian major carps, rohu, *Labeo rohita* (Hamilton). Supplementary feed comprising rice bran and groundnut oil cake in equal proportions was provided daily at the rate of 2% of the body weight, with bi-monthly samplings for fish growth yield. Water qualities were monitored as per standard methods. Fish growth rate was assessed for both the

Fig. 1: View of experimental greenhouse

Table 1: Calculation of embodied energy for Quonset shape greenhouse (5×4 m)

Items	Density	Total length (m)/ Quantity	Weight (kg)	Embodied energy ($MJ\ kg^{-1}$)	Total embodied energy (MJ)
G.I. Pipe					
1.5" diameter	1.87 kg m^{-1}	7.61	14.25	49.97*	712.43
1" diameter	1.10 kg m^{-1}	49.00	54.09	49.97*	2703.17
Iron strip (2" width and 5 mm thickness)	2.00 kg m^{-1}	18.28	36.56	27.73*	1013.80
UV-stabilized LDPE film (m^2)	0.231 kg m^{-1}	55.44 m^2	12.80	92.32*	1182.30
Screw	-	-	1.00	31.06*	31.06
Bricks	2.5 kg $unit^{-1}$	540 nos	1350	1.80*	2430.00
Sand	2.66 g cc^{-1}	8 cft	602.58	0.10+	60.26
Stone chips (20 mm)	2.64 g cc^{-1}	3 cft	224.26	0.79+	177.16
Cement	3.15 g cc^{-1}	3 bags	150	7.80+	1170.00
Greenhouse construction					
Cutting, bending and fixing, etc. (Man/h)	48h	-	-	1.96**	94.08
Earth work (Man/h)	16h			1.96**	31.36
Brick work, plastering and grouting etc. (Man/h)	24h	-	-	1.96**	47.04
Fixing of plastic film (Man/h)	24h	-	-	1.96**	47.04
Total embodied energy					9699.70

*: Tiwari, 2003; +: http://www.Google.co.in-Embodied energy coefficient; **: Canakci and Akinci, 2005

Table 2: Use of energy sources in various operations in open and greenhouse (18 m^3)

Operation	Open	Greenhouse
Soil laying at bottom		
Man (h/1.2 m^3)	1.2	1.2
Water filling		
Man (h/18 m^3)	01	01
Electric pump-kWh (h/18 m^3)	15	15
Lime application		
Man (h/18 m^3)	0.5	0.5
Weed control		
Man (h/18 m^3)	0	0
Fertilizer application		
Man (h/18 m^3)	0.5	0.5
Cow dung application		
Man (h/18 m^3)	0	0
Feeding of fish		
Women (h/18 m^3)	19.33	19.33
Aeration		
Man (h/18 m^3)	1.5	02
Air blower-kW h (h/18 m^3)	72.00	86.25
Water exchange/replacement		
Man (h/18 m^3)	0.5	01
Electric pump-kW h(h/18 m^3)	12.5	16.5
Testing of water quality parameters		
Women (h/18 m^3)	12	12
Cleaning up		
Man (h/18 m^3)	1.5	1.5
Fish sampling and harvesting		
Man (h/18 m^3)	11	11

condition at the end of the culture period and the total production/18 m^3 was calculated from the experimental values. Fish culture operations and the energy inputs and outputs values in open and greenhouse fish culture were determined from the experimental data.

Energy use in various forms of operations was calculated by using the following energy equivalents: Feed = 10.76 MJ kg^{-1} (Sifa, 1987); Output of fish = 5.04 MJ kg^{-1}

(Ayyappan *et al*., 1990); 1 Man = 1.96 MJ h^{-1}, 1 Woman = 1.57 MJ h^{-1}, P_2O_5 = 15.80 MJ kg^{-1}, Electric = 10.59 kW h, Lime = 120 MJ kg^{-1} (Canakci and Akinci, 2005). The data was collected from experimental results.

The embodied energy required of a Quonset type greenhouse was estimated for calculating the energy input to the system (Fig. 1). The effective floor and water surface area of greenhouse are 20 and 12 m^2, respectively. The central height of the greenhouse is 2.5 m and the volume of the greenhouse enclosure is 37 m^3. The brick wall of 0.25 m was constructed on the perimeter of floor area as the foundation of the greenhouse. Table 1 gives the details of different materials used to construct the typical greenhouse including man-hour for construction. The greenhouse usage life was taken as 25 years (Tiwari, 2003).Under the circumstances, greenhouse embodied energy is 161.66 MJ per production area of 20 m^2 for five months. The embodied energy for pond is 285.28 MJ per production area of 18 m^2 for five months. However, this energy was not considered while calculating the total energy input as both the system energy consumption is same.

Table 2 shows the use of power sources for fish production in the greenhouse. The aqua cultural implements used in the greenhouse operations were an electric pump and small aerator. The water filling was done by electric pump. Since the fish culture operation is carried out in small tanks, the operation required for weed control and cow dung applications were avoided. The application of fertilizer was generally applied once in a month on water to provide as nutrient for fish food organism. The aeration was provided as supplementary oxygen to the fish. It was done by small aerator. During water exchange or replacement the operation was preferably done by electric pump and no manual operation was needed. Manpower was used to sample the fish for growth performance. The total operation was done by manually; no mechanized systems were used for this purpose, since this pond

Table 3: Energy use pattern for open and greenhouse fish production

Operation	Open (MJ/18 m^3)	Greenhouse (MJ/18 m^3)
Pond construction	285.28 (56.46)[a]	285.28 (52.61)
Soil laying at bottom	1.88 (0.37)	1.88 (0.35)
Water filling	57.58 (11.40)	57.58 (10.62)
Fertilizer application	0.98 (0.19)	0.98 (0.18)
Lime application	0.98 (0.19)	0.98 (0.18)
Feeding of fish	30.35 (6.00)	30.35 (5.60)
Aeration	48.68 (9.64)	58.72 (10.83)
Water exchange/replacement	36.19 (7.16)	63.11(11.64)
Water quality parameters	18.84 (3.73)	18.84 (3.47)
Cleaning up	2.94 (0.59)	2.94 (0.54)
Fish sampling and harvesting	21.56 (4.27)	21.56 (3.98)
Total	505.26 (100)	542.22 (100)
Sources (Inputs)		
Human	83.88 (25.79)	85.84 (14.80)
Electricity	147.66 (45.40)	171.54 (29.56)
Fertilizer	2.37 (0.73)	1.89 (0.32)
Feed	86.56 (26.61)	152.10 (26.21)
Lime	4.80 (1.47)	7.20 (1.24)
Greenhouse structure	-	161.66 (27.87)
Total	325.27 (100)	580.23 (100)
Energy variables		
Fish yield (kg/18 m^3)	5.01	10.38
Energy output (MJ/18 m^3)	25.25	52.31
Energy ratio (decimal)	0.078	0.090
Specific energy (MJ/18 m^3)	12.88	11.09
Energy productivity (MJ/18 m^3)	0.0154	0.0178

[a]Figure in parenthesis indicates a percentage of the energy inputs

was very small. During the water quality monitoring process, manpower was used for collecting and testing of water samples such as dissolved oxygen, free CO_2, total alkalinity, ammonia, pH and phosphate-phosphorous. The manpower consumed in this process depending upon the number of parameters to be carried out and frequency of testing.

The data were analyzed for operation and source-wise energy consumption (inputs), energy ratio (output/input) and specific energy use (energy use per unit of fish production) and energy productivity is given in Table 3. Various mathematical equations were fitted for open and greenhouse pond systems e.g., Linear, $Y = a+bX$, Log-Linear, $Y = aX^b$, Reciprocal, $1/Y = a+bX$, Exponential, $Y = ae^{bX}$, Log-quadratic, $Y = a\ X^b\ X^{2c}$, Quadratic, $Y = a+bX+cX^2$, Nelder's curve, $Y = X/(a+bX+cX^2)$, Gupta and Nigam, $Y = a+bX+c/X$, Robb's parabolic, $Y = ae^{bX}+cX^2$, Wood's curve, $Y = aX^b\ e^{(-cX)}$ (Singh *et al*., 1994, 1999) to evaluate the energy input and specific growth yield relationship with 5% confidence limit. All the equations were solved by MATLAT 7.0 software.

Results and Discussion

Operational Energy

The total operation-wise energy consumption was 505.26 MJ/18 m^3 in open and 542.22 MJ/18 m^3 for greenhouse, respectively (Table 3). The pond construction consumed the maximum energy 285.28 MJ/18 m^3 in both the condition, the share was 56.46 and 52.61% in case of open and greenhouse, respectively. This may attributed for high-energy value was used for constructing the ponds. The human energy use for soil laying at bottom require 1.88 MJ/18 m^3 in both the system. This energy was required for maintaining the desired water quality. Water filling required 57.58 MJ/18 m^3 in open and greenhouse pond, respectively. This energy requirement was equal due to same volume of the tanks. Fertilizer application required 0.98 MJ/18 m^3 in both the condition. This energy was required mainly for supplying additional nutrients for fish. The energy use through lime was 0.98 MJ/18 m^3 in both the system, it was required for maintaining the desired water quality. Feeding of fish was done manually and it required 30.35 MJ/18 m^3 (6.0%) and 30.35 MJ/18 m^3 (5.6%) in open and greenhouse, respectively. The energy used in aeration was 48.68 MJ/18 m^3 and 58.72 MJ/18 m^3 in open and greenhouse, respectively and it was done by a small aquarium aerator to supply additional oxygen to the fish. To maintain stable water quality, water exchange was done by electric pump and it required 18.84 MJ/18 m^3 in both the cases. The application of human energy for water quality parameters, cleaning-up and fish sampling and harvesting required 18.84, 2.94 and 21.56 MJ/18 m^3 in open and greenhouse, respectively.

Energy Sources

The total energy input for fish farming was 325.27 MJ/18 m^3 in open and 580.23 MJ/18 m^3 in greenhouse. The contribution of energy from human sources for fish production was 83.88 MJ/18 m^3 (25.79%) and 85.84 MJ/18 m^3 (14.80%) in open and greenhouse fish farming, respectively. The use of human energy was slight higher in greenhouse due to demand of more oxygen. The energy use through electricity was 147.66 and 171.54 MJ/18 m^3 in open and greenhouse, respectively. The share was 45.40% in open and 29.56% for greenhouse of the total energy input. The electricity use in greenhouse was quite high as compared to open condition; this was due to the fact that, in greenhouse operation more electricity was used for aeration and water exchange purpose. The energy input through fertilizer was 2.37 and 1.89 MJ/18 m^3 in open and greenhouse, respectively. The use of fertilizer energy was lowest in greenhouse. The energy use through feed was 86.56 and 152.10 MJ/18 m^3 in

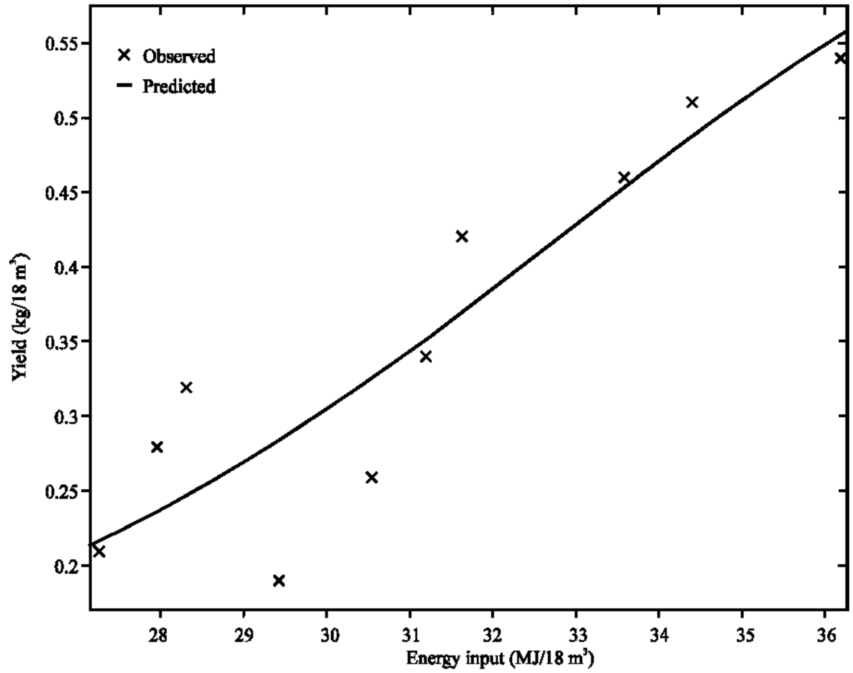

Fig. 2: Relation between specific growth yield and energy input for open

open and greenhouse, respectively. It contributes 26.61 and 26.21% for open and greenhouse, respectively. There was an increase in feed consumption in greenhouse due to prevailing higher water temperature as a result the metabolic activity of fish is increased. On the other hand, energy contributed from lime was 4.80 (1.47%) and 7.20 MJ/18 m^3 (1.24%) in open and greenhouse fish farming, respectively. The use of lime energy also increased in greenhouse. This was caused for improvement of pond condition.

The greenhouse structure was the highest energy input. It provided 161.66 MJ/18 m^3, which was 27.87% of the total energy input. This higher value of the greenhouse structure can affect the ratio of the other energy sources in the total inputs. The greenhouse structure (G.I. pipes) and plastic film, which was covered on the frame, had a high energy value. Therefore, this material significantly increased the structure energy of the greenhouse.

Energy Variables

Fish yield was 5.01 and 10.38 kg/18 m^3 in open as well as in greenhouse farming. The higher yield was observed in greenhouse due to prevailing higher water temperature, as expected. The total energy output was calculated multiplying by the equivalent energy inputs and outputs coefficients and the values are 25.25 MJ/18 m^3 in case of open and 52.31 MJ/18 m^3 for greenhouse farming. It can be concluded that the energy output is directly proportional to the energy input, as input increases the yield is also increased and vice-versa.

Output-input ratio is one of the important indicators that provide an understanding the efficiency of the system. The energy output-input ratio was found to be 0.078 and 0.090 in open and greenhouse fish farming, respectively. The lower value of energy ratio in open farming was mainly due to high inputs and no significant increase in yield. Due to this reason, the specific energy requirement was higher. But, in the case of greenhouse fish farming, the energy ratio was higher due to lower inputs and the specific energy showed lower value due to higher yield. The results reflects that specific energy requirement was 12.88 and 11.09 MJ/18 m^3 of energy to produce 1 kg of fish in open and greenhouse fish farming, respectively. The energy productivity in open and greenhouse was found to be 0.0154 and 0.0178 MJ/18 m^3, respectively. In comparison with the previous studies, Singh and Pannu (1998) Canakci and Akinci (2005) and Hatirli *et al*. (2006) reported higher values of energy ratios, specific energy and energy productivity but they have estimated these values for a case study and questionnaire method for a period more than one year and larger area.. But in our case the result differed from previous studies due to shorter culture period and smaller experimental tank.

Energy Input and Specific Growth Yield Relation

The specific growth yield (Y) and energy input (X) were obtained by various mathematical relations. This procedures were also repeated for feed and energy input.

A Nelder's curve exhibited best relation between specific growth yield and energy input in open condition as it gave the maximum coefficient of determination (R^2= 82.66%) with the following relation

$$Y = X/(841.1-40.86x\ X+0.5365x\ X^2,\ R^2 = 82.66\% \qquad (1)$$

where,

Y = Specific growth yield (kg/18 m^3)
X = Energy input in open condition (MJ/18 m^3)

The variation of specific growth yield and energy input for open condition is shown in Fig. 2. The results show that when the energy input is decreased, the yield is declined and further increase of

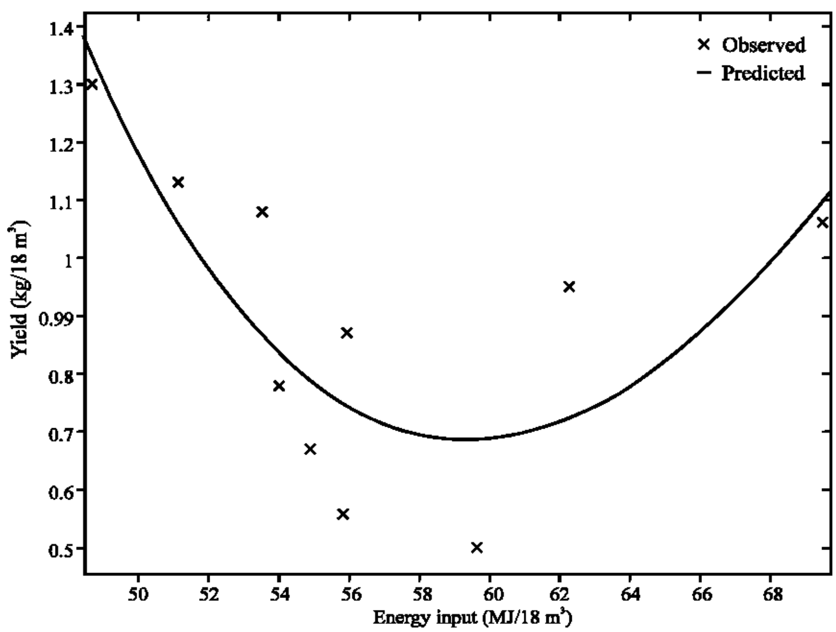

Fig. 3: Relation between specific growth yield and energy input for greenhouse

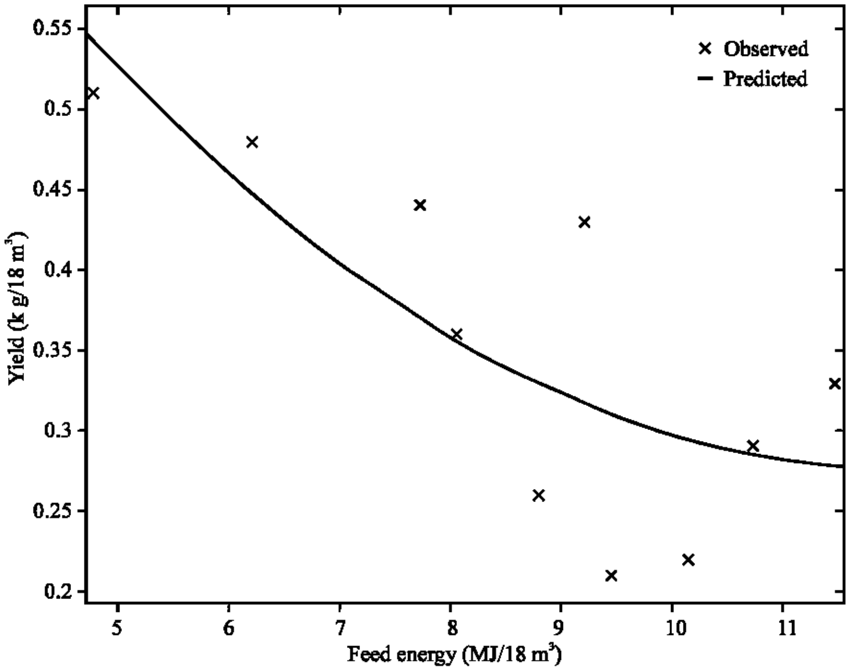

Fig. 4: Relation between specific growth yield and feed energy for open

energy input, simultaneously yield also shows in increasing trend. It clearly indicates that the yield is directly proportional to the energy input as a function of time.

Similarly, Gupta and Nigam curve exhibited the best relations between specific growth yield and energy input for fish inside greenhouse (Fig. 3). The coefficient of determination (R^2) between the specific growth yield and energy input was 66.16%.

The Gupta and Nigam curve relations between yield and energy input is

$$Y = -32.69+0.2809x\ X+991.1/X,\ R^2 = 66.16\% \tag{2}$$

where,

Y = Specific growth yield (kg/18 m^3)

X = Energy input in greenhouse (MJ/18 m^3)

The fish specific growth yield increased 10.38 kg/18 m^3 with the energy input of 565.40 MJ/18 m^3. The specific growth yield is declined with increasing of energy input and after certain period yields starts to increase with increase of energy input. However, the growth yield was higher in comparison to open system due to greenhouse effects and prevailing higher water temperature. The input energy was varied from 48.66 to 69.50 MJ/18 m^3 during five months operation.

According to quadratic relation, corresponding to the maximum coefficient of determination for open condition between specific growth yield and feed energy is

$$Y = 1.012-0.1226x\ X+0.005106x\ X^2,\ R^2 = 59.39\% \tag{3}$$

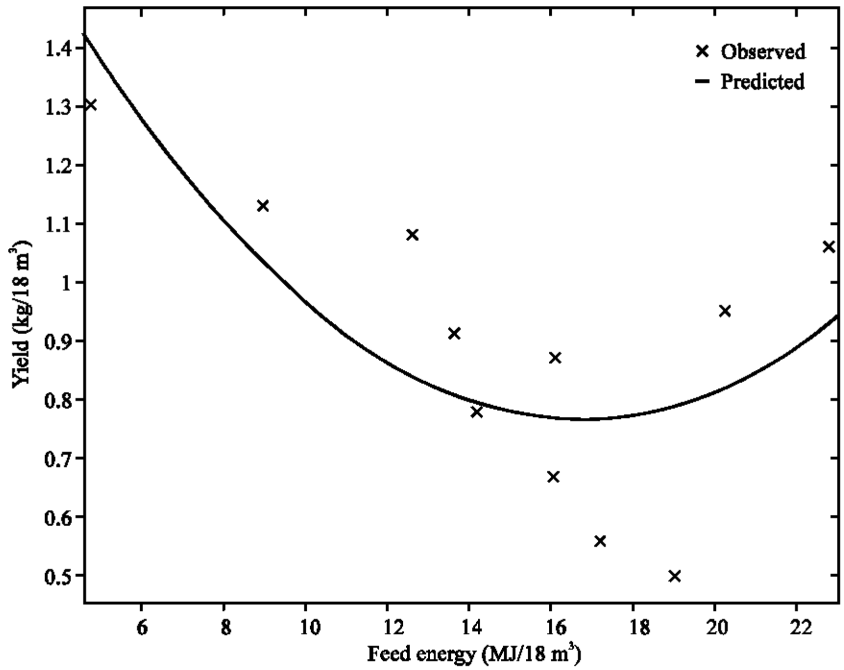

Fig. 5: Relation between specific growth yield and feed energy for greenhouse

where,

Y = Yield (kg/18 m^3)

X = Feed energy in open condition (MJ/18 m^3)

Fish growth yield is increased to 5.01 kg/18 m^3 with an increase of total feed energy 86.62 MJ/18 $m^{-3.}$ The input feed energy was varied from 4.78 to 11.47 MJ/18 m^3 for a particular period. This clearly shows (Fig. 4) that the growth yield is decreased proportionately with the increase of feed energy due to lower water temperature where as, in case of greenhouse the best relationship was found in quadratic form for maximum coefficient of determination

$$Y = 2.017\text{-}0.1499x\ X+0.00448x\ X^2,\ R^2 = 58.34\% \qquad (4)$$

From Fig. 5, it is clearly indicated that fish growth yield in greenhouse is decreased with increase of feed energy. Further, yield is increased with increase of feed energy due to increasing water temperature. In comparison with open pond system, it was observed that feed intake was more in case of greenhouse and showed better yield.

Conclusions

On the basis of the present study, the following conclusions were drawn

- The operational energy and energy source (inputs) requirements of fish production were found to be 505.26 and 325.27 MJ/18 m^3 in case of open and 542.22 and 580.23 MJ/18 m^3 for greenhouse fish production, respectively.

- The yield was obtained 5.01 and 10.38 kg incase of open and greenhouse, respectively.
- The energy ratio, specific energy and energy productivity were calculated 0.078 and 0.090, 12.88 and 11.09 MJ/18 m^3 and 0.0154 and 0.0178 MJ/18 m^3 for open and greenhouse fish farming, respectively.
- The best curve fitting exhibited between specific growth yield and energy input were Nelder's curve for open and in case of greenhouse it was Gupta and Nigam curve. The quadratic relation shows the best relation between specific growth yield and feed energy for both the condition.

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