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The implication of financial constraint

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Production analysis of composite fish culture in drought prone areas of Purulia: The implication of financial constraint

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ABSTRACT

Purulia is a drought-prone and socio-economically underdeveloped district in West Bengal. Resource-poor social groups dominate the population in the district with a high incidence of poverty. The West Bengal Accelerated Development of Minor Irrigation Project (WBADMIP), a flagship project of the Govt. of West Bengal, India, supported by the World Bank, took the initiative in Northeast Purulia to develop composite culture of carps as a viable livelihood option for this section of people. WBADMIP incentives on 172 water bodies in Northeast Purulia revealed that training of the farmers to manage resources and inputs was crucial to succeed in the composite culture of carps. WBADMIP developed a corpus fund out of the profit generated from each water body and motivated the farmers to start the culture independently. This study revealed that the farmers with limited financial capacity could not achieve the targeted production when they started the culture independently, despite proper training. Attempts were made to solve the management of inputs that maximize production under financial constraints. We analyzed the production process of the WBADMIP supported 172 water bodies with a three-stage decision support system: pre-analysis to screen 137 water bodies based on ideal culture duration (>10 months) and ideal depth of the water body (>4 ft) followed by TOPSIS with Shanon entropy analysis to select 73 best water bodies. Then, regression analyses of the inputs of these 73 water bodies were made. Production derived from the quadratic regression equation was found close to actual production in these 73 water bodies. Finally, we solved a constraint optimization to explore the variations in inputs that maximize total production under limited financial conditions. It was revealed that the cost of seed (fingerlings) and supplementary feed were the principal constraints of the resource-poor farmers. While production linearly increased with investment in quality formulated feed, expenditure increased principally on the purchase of fingerlings and the formulated feed. The farmers could maximize production with their limited resources if they would restrict stocking density to 5000 fingerlings per ha and share a part of the capital in purchasing formulated feed. However, if farmers are unable to procure an adequate quantity of formulated feed, an excess input of organic fertilizers along with a limited amount of inorganic fertilizers can be a cost-effective management practice to optimize the production of carps from the composite culture of carps by the resource poor independent farmers.

1. Introduction

Purulia is a socio-economically underdeveloped district of West Bengal in India. The population of people in the district is dominated by resource-poor social groups, primarily marginal agricultural farmers and daily wage labourers (Bagli and Tewari, 2019; Guchhait and Sengupta, 2020). A high incidence of poverty, marked by lack of employment opportunity, illiteracy, and malnutrition, is a persistent social issue in the district (Chandra, 2021). The average per capita monthly income of the majority of households in Purulia is only 1000 INR (Bagli and Tewari, 2019). The main occupation of these households is daily wage labour followed by agricultural activities. Recently we evaluated incentives provided to the small and marginal farmers in the north-eastern parts of this district by the West Bengal Accelerated

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Development of Minor Irrigation Project (WBADMIP), a flagship project of the Govt. of West Bengal, India, supported by the World Bank to develop a commercially viable composite culture of carps as a viable livelihood option (Mishra et al., 2021; World Bank, 2013). Successful culture of carps can ensure supply of fish to the local markets and accessibility of fish to poor (Genschick et al., 2018), provide food security to people and fight against malnutrition and poverty (Béné et al., 2015; Fiedler et al., 2016; Filipski and Belton, 2018; Silva et al., 2021). It also creates many other livelihood opportunities associated with fish culture, like the development of hatcheries, feed mills, trading of pond fertilizers, and daily wage labors (Belton and Azad, 2012; Ali et al., 2018; Ndanga et al., 2013).

While evaluating WBADMIP incentives to popularize the composite culture of carps in Northeast Purulia, it was revealed that proper management of inputs like stocking density of fingerlings, feed, lime, inorganic fertilizers, and organic fertilizers, as well as resources like size and depth of water bodies were the key factors to make the composite culture of carps a success in this part of the district (Mishra et al., 2021). WBADMIP helped the farmers make a substantial increase in the production of carps from the baseline production of carps of this district. However, production was far from satisfactory when the farmers started composite culture of carps independently without any institutional support of WBADMIP. High initial costs in terms of pond preparation, stocking, supplementary feeding, post stocking management, and harvesting are the major constraints of participation of the resource-poor farmers in commercial aquaculture in rural areas (Obiero et al., 2019; Mulokozi et al., 2020; Uddin et al., 2021). WBADMIP encouraged the farmers of Northeast Purulia to generate a corpus fund out of the profit made from the WBADMIP supported culture and start composite culture of carps independently. However, the corpus fund generated was inadequate for most farmers to support inputs required for post stocking management. The most critical input that influences the production of carps and shares about 60 percent of the production cost is the supplementary feed. As formulated compound feed is costly and scarcely available in remote villages, the majority of the marginal farmers in Indian villages depend on the conventional mixture of rice bran and oil cake as the common supplementary feed (Nandeesha et al., 2013; Biswas et al., 2019). As a result, production declines despite maintaining all other scientific methods of culture. The farmers of Northeast Purulia also could not maintain the quality and quantity of the inputs similar to the WBADMIP supported culture and improvised the inputs due to financial constraints, which critically affected the overall production of carps. Since freshwater aquaculture in India is dominated mostly by the small and marginal farmers (Duarah and Mall, 2020), management of inputs based on the local situation is crucial to make the composite culture of carps successful.

In this study, we compared inputs and investments between WBADMIP supported culture and the culture adopted by the independent group of farmers, and explored means to adjust inputs to maximize production by the capital-constrained farmers. We proposed a three-step decision support system to determine inputs that maximized production under financial constraints. First, we evaluated the production process of the 172 water bodies covered by WBADMIP during 2015–2018 (Appendix A, Table A1). Seasonal drought and drying of water bodies are the most critical factors that heavily influence the success of composite carp culture in Purulia (Biswas et al., 2019; Das et al., 2019). We observed that the water bodies that could hold water above 4 feet for a culture period of 10 months or more were ideal for the composite culture of carps (Mishra et al., 2021). Accordingly, we made a preliminary screening based on these two criteria to select water bodies that could be ideal for the composite culture of carp. Then we applied the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to further screen out water bodies that exhibit maximum production with minimum investments. Several tools are used for management of inputs and optimization of aquaculture production based on socio-economic conditions of people (Wijenayake et al., 2016; Silva et al., 2021). In this direction, Multiple-criteria decision-making (MCDM) tools can handle several criteria in different ways and assist the decision-makers in mapping out the problem (Dhanalakshmi et al., 2020). Recently Luna et al. (2020) used MCDM tools, namely TOPSIS, to integrate the biological variables of aquaculture farms management with economic, environmental and product quality decisions. The authors employed Particle Swarm Optimization (PSO) technique to provide a production strategy under some operational and commercial constraint. In the context of aquaculture management, MCDM can be an appropriate tool to find proper mix of inputs and help to achieve the operative and strategic decisions (Luna et al., 2019). We used TOPSIS (Hwang and Masud, 2012) in order to choose the preferable options and referred the recent review work by Salih et al. (2019), Shih et al. (2007), Behzadian et al. (2012), Dutta et al. (2019) for the detail discussion on this method and its extensions. Note that the decision process of the TOPSIS method is based on the closeness measures to the ideal and non-ideal solution, and it is straightforward and easily understandable. The Shannon entropy (Tang et al., 2019) method was used to determine weights. A comparison of performances between the two groups of water bodies (maximum production with minimum investment and the rest) was also made using a radar chart to evaluate differences in the pattern of distribution of the inputs. Finally, we employed regression analyses to determine the importance of the parameters affecting production and formulated an optimization problem to explore how financial constraints can influence production in such semi-arid conditions. Further, we evaluated the production from the composite culture of carps carried out by trained farmer groups independently in 42 water bodies without any institutional support (Appendix A, Table A2). Due to financial constraints, these farmers could not use the high cost formulated feed in the culture. Instead, they used locally available cheaper farm made feed and tried to compensate the nutritional requirements of the fish through application of a higher quantity of organic fertilizers (OF). The main objective of this study was to identify the factors affecting the production mismatch between WDADMIP supported culture and the composite culture of carps adopted by the farmers independently. Given the economic condition of the local farmers, an effort was made to develop strategies for the WBADMIP to facilitate the adoption of good practices with judicious use of farmers' financial resources and maximize the returns from carp culture.

2. Methods

The scheme of analysis used in this study has been presented in Fig. 1. We used a three-stage system to analyze the input data of 172 water bodies. In the first stage, a preliminary screening of the water bodies was made based on culture period (CP) (≥10 months) and depth of water (WD) (≥4 ft), which led to the selection of 137 water bodies. In the second stage, TOPSIS with Shannon entropy was applied on these 137 water bodies to select 73 water bodies that exhibited good production of carps based on the closeness index. Then we carried out multiple regression analyses between the inputs given to these 73 water bodies and attempted to analyse production performance followed by nonlinear programming and production estimation under budgetary restrictions.

2.1. TOPSIS with Shannon entropy

After preliminary screening, we used a multi-criteria decision-making method, namely TOPSIS with Shannon entropy, to select water bodies that yielded good production among 137 water bodies. MCDM methods are the process of determining a compromise solution according to the decision maker's preferences. Note that several conflicting criteria often characterize practical problems, and there may be difficulties to satisfy all criteria simultaneously. Consequently, MCDM has been proved as a useful tool in such situations. In general, the evaluation problems can be split into different types, namely choice, ranking,

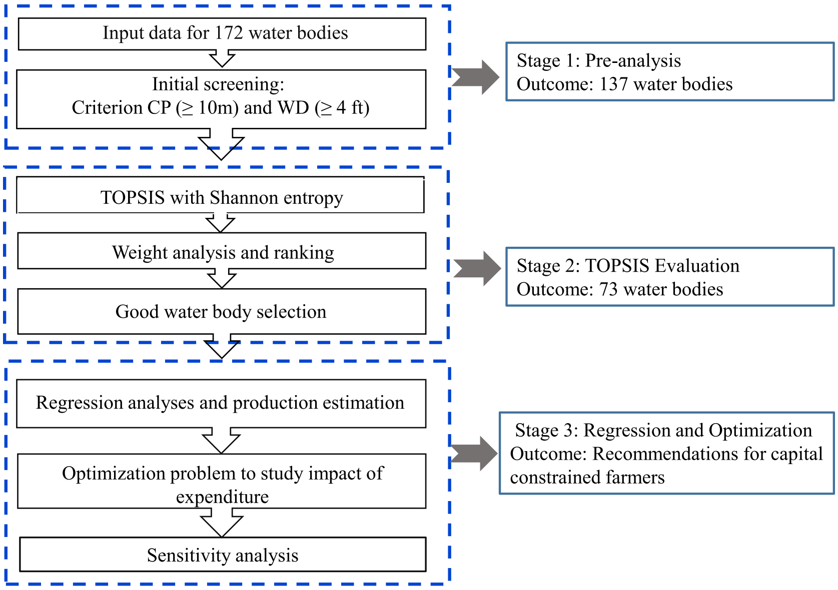

Fig. 1. Data analysis scheme.

sorting, or classifying a set of explicitly known alternatives. For this purpose, Analytical Hierarchical Process (AHP), TOPSIS, ELimination Et Choice Translating REality (ELECTRE), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), etc. have been widely applied (El-Gayar and Leung, 2001; Luna et al., 2019; Vasegaard et al., 2020; Dutta et al., 2021). To determine weights for each criterion, different methods such as Delphi method, Shannon entropy, etc., are used because indicators weights are always an important step. In this study, we used Shannon entropy to generate weights based on the measurement of uncertain information in the different criteria of the decision matrix. Note that an indicator with a small entropy value implies that the indicator has a higher weight. The method consists of the following three steps (Tang et al., 2019; Dutta et al., 2019):

Step 1: It is assumed that a typical decision matrix with m alternatives (number of water bodies), A_1, A_2, …, A_m, and n number of criteria, C_1, C_2, ⋯, C_n, is precisely formulated. Consequently, a decision matrix $X = (x_{\mathrm{ij}})_{m\times n}$ is formulated. Then, the entropy for each criteria j is computed as $E_j = -\frac{1}{\ln(M)}\sum_{i=0}^{N} p_{i,j}\log\left(p_{i,j}\right)$, where $p_{i,j} = \frac{x_{i,j}}{\sum_{i=0}^{N} x_{i,j}}, \quad \forall \left.\{i,j\right\} \in \left.\{1,\dots,m\right\} \times \left.\{1,\dots,n\right\}.$

Step 2: Next we determine weights (w_j) for each criteria based on the degree of divergence (d_j) by using the following relation: (i) $d_j = 1 - E_j$ and (ii) $w_j = \frac{d_j}{\sum_{j=0}^{n} d_j} \quad \forall j \in \{1,\dots,n\}$.

Step 3: In order to compare different kinds of criteria, the normalized decision matrix: $r = (r_{\mathrm{ij}})_{m\times n}$, where $r_{\mathrm{ij}} = \frac{x_{\mathrm{ij}}}{\sqrt{\sum_{i=1}^{n} x_{\mathrm{ij}}^2}}$ is computed.

In this regard, one can use other normalization technique also (Shih et al., 2007). Using the weights (w_j) obtained previously, the weighted normalization matrix is calculated as $v = r.\mathrm{diag}(w)$, where $\mathrm{diag}(w)$ is a diagonal matrix where the diagonal elements are the weights (w_j).

Step 4: Next, we determine the Ideal (A^+) and Anti-ideal (A^-) solutions as presented below:

$$\begin{aligned} A^+ &= \left\{ \left(max_i\, v_{\mathrm{ij}} | j \in J_1\right), \left(min_i\, v_{\mathrm{ij}} | j \in J_2\right) \middle| i = 1, 2, \cdots m \right\} \\ &= \left\{ {v_1}^+, {v_1}^+, \cdots, {v_j}^+, \cdots, {v_m}^+ \right\} \\ A^- &= \left\{ \left(min_i\, v_{\mathrm{ij}} | j \in J_1\right), \left(max_i\, v_{\mathrm{ij}} | j \in J_2\right) \middle| i = 1, 2, \cdots m \right\} \\ &= \left\{ {v_1}^+, {v_1}^-, \cdots, {v_j}^-, \dots., {v_m}^- \right\} \end{aligned}$$

where J_1 and J_2 are the benefit and loss indicators, respectively. In this study, SDF, stocking density of fingerlings (no/ha); PF, project feed (kg/ha); FF, farmer feed (kg/ha); LM, lime (kg/ha); INF, inorganic fertilizer (kg/ha); OF, organic fertilizer (kg/ha); CP, culture period (m); PROD, production (kg/ha); NOB, number of beneficiary involved in culture are considered as benefit criterion. And EXP – expenditure (INR/ha), as a sum of expenditure by farmer (EXP_F) and project (EXP_P), is considered as a loss indicator because total expenditure can be reduced through a judicious combination of inputs. Therefore, the ideal solution considers the best performances, and the anti-ideal solution considers the worst performances from the normalized decision matrix.

Step 5: Finally, the distance of each indicator from A^+ and A^-, the classical Euclidean distance, are calculated as $D_i^+ = \sqrt{\sum_{j=i}^{n}\left(v_{\mathrm{ij}} - v_j^+\right)^2}, \quad D_i^- = \sqrt{\sum_{j=i}^{n}\left(v_{\mathrm{ij}} - v_j^-\right)^2}, \quad \forall i = 1, 2, \dots, n.$

Using those distance measures, the relative closeness measures ($C_i^* \in (0,1)$) is computed for each alternative, where $C_i^* = \frac{S_i^-}{S_i^- + S_i^+}, \quad i = 1, 2, \dots m$. By arranging closeness (C_i^*) measures, the alternatives are ranked from best to worst (Papathanasiou and Ploskas, 2018).

2.2. Generalized quadratic regression models

We applied regression analyses on different inputs of the 73 water bodies that yielded good production. First we applied linear regression, which is based on the fact that the relationship between the dependent and independent variables is linear, which is not always true (Siemsen et al., 2010; Brix et al., 2017; DeForest et al., 2018). Consequently, quadratic regression (QR) models were used to consider interaction effects between the independent variables. In this study, we fitted the following form of the equation to estimate production.

$$\mathrm{PROD} = a_0 + \sum_{i=1}^{n} a_i X_i + \sum_{i=1}^{n} \sum_{j=1}^{n} a_{i,j} X_i X_j + \varepsilon. \tag{1}$$

Since the input data of the water bodies showed curvilinearity, polynomial regression appeared more appropriate. We selected a simple, multiple linear regression (MLR) approach that considers eight independent variables (X_i) to predict their impact on production. The coefficient a_i, $i = 0, 1, \dots 8$ and $a_{i,j}$, $j = 0, 1, \dots, 8$ represents parameters of the model, indicating how much the dependent variable (PROD) varies with the change in the independent variables (PF; FF; LM; OF; INF; NOB; SDF; CP) (DeForest et al., 2018). Note that if $a_{i,j}$ are zero, then the above equation represents a simple multiple linear regression equation. By comparing, R^2, Mean Absolute Percentage Error (MAPE) $= \frac{1}{73}\sum_{t=1}^{73}\left|\frac{A_t - f_t}{A_t}\right|$, and Mean Squared Error (MSE) $= \frac{1}{73}\sum_{t=1}^{73}(A_t - f_t)^2$, we identified the best-fitted curve. Note that, R^2 represents the proportion of variance in the dependent variable that can be explained by a change in the independent variables (Cameron and Windmeijer, 1997; Ghosh et al., 2021). However, in a field data set containing outliers, R^2 value depends on the sample size and the number of variables to be selected (Kasuya, 2019; Woodside, 2013). Sometimes, exclusion of some variables may lead to higher R^2 value, but that might not lead to tangible decision support tool for the policy maker. Therefore, we used MAPE and MSE as alternative measures to evaluate the accuracy of estimation of production function (Ostertagová, 2012).

2.3. Nonlinear optimization

Finally, we solve an optimization problem to provide pragmatic suggestions for the capital-constrained farmers. Note that the expenditure varies a lot while farmers are motivated to engage in carp culture without WBADMIP support. Since the objective function is quadratic in nature and there is financial constraint, we encounter a constraint optimization problem (Cottle and Thapa, 2017; Fishback, 2019). Such quadratic programming problems are encountered in many real-world applications and researchers have been made substantial effort to develop and evaluate many algorithms (Turlach and Wright, 2015). To solve this class of optimization problem, several commercially available software packages are available (Drezner and Kalczynski, 2017). We solve the problem by using Mathematica- 11 (www.wolfram.com/mathematica). The sensitivity analysis was conducted under budgetary restriction to explore the variations in inputs that maximize total production. Note that while solving the optimization problem, we maintained the bounds for the inputs to ensure minimum needs for the feasible carp culture under the semi-arid condition of Purulia.

3. Results

Fig. 2 presents average expenditure and production of carps from 172 water bodies of Northeast Purulia as compared to baseline expenditure and production of the Purulia districts.

Table A1 (Appendix A) presents descriptive statistics of inputs given in these 172 water bodies used for composite culture of carps in three successive years. Standard deviations of the mean values for most of the inputs were very high, indicating that the inputs were not evenly distributed (Mishra et al., 2021). While some water bodies received a given input in excess quantity, the same remained insufficient in others. It indicates that production can be further increased if inputs are adjusted judiciously.

The main objective of this research was to determine the quantum of inputs that could result in a higher production under financial restriction. Therefore, we made maximization criteria for all these inputs and carried out TOPSIS. The entropy value, divergence, and weighted value of different inputs have been presented in Table A4 (Appendix A). The entropy value ranged between 0.94 and 0.98, and the weights ranged between 0.043 and 0.249. This result also indicates that the distribution of the inputs needs to be redefined, and farmers need to be trained to make judicious use of their resources to streamline production. Therefore, we ranked the water bodies into two groups, first seventy three water bodies exhibiting higher production with less expenditure, followed by the rest sixty four water bodies exhibiting less production with higher expenditure as shown in Fig. 3 and Table A6. The results indicate that for a given stocking density and culture duration, the production is limited by the supplementary project feed. The results also suggest that management of OF, LM, and INF influence the production of carps.

Then we determined correlation coefficients between different inputs as shown in Table A4. It revealed that production was positively and significantly correlated with EXP, FF, LM, and OF. As input parameters are significantly correlated with production, we attempted to estimate production based on the input parameters. First, we derived linear regression ($PROD_L$) as presented in Eq. (2).

$$\begin{aligned}\mathrm{PROD}_L &= 2145.73037 - 0.0522\mathrm{PF} + 0.14382\mathrm{FF} + 0.27503\mathrm{LM} - 0.01513\mathrm{INF} \\ &\quad + 0.19827\mathrm{OF} + 4.36601\mathrm{NOB} - 0.09572\mathrm{SDF} + 78.29539\mathrm{CP}\end{aligned} \tag{2}$$

Note that we found $R^2 = 0.311$, Durbin-Watson statistic $= 1.705$, MAPE $= 40860.49$, and MSE $= 0.0632$ for Eq. (2). Similarly, we derived the quadratic regression equations for various forms and found the following Eq. (3) ($PROD_Q$) as one of the suitable one.

Note that the accuracy measures, $R^2 = 0.461$, Durbin-Watson statistic $=$ 1.763, MAPE$=$ 33862.91, and MSE$=$ 0.05656, are improved compared to linear regression. We used quadratic regression instead of linear regression because of considerable improvement in R^2, MAPE, and MSE measures. The functional form helps the decision maker to estimate all the necessary inputs associated with composite culture of carps. Fig. 4 presents the actual production of carps in seventy three selected water bodies which exhibited good production simultaneously with the estimated production of carps in each water body as per the linear regression and the quadratic regression. The production estimated as per the

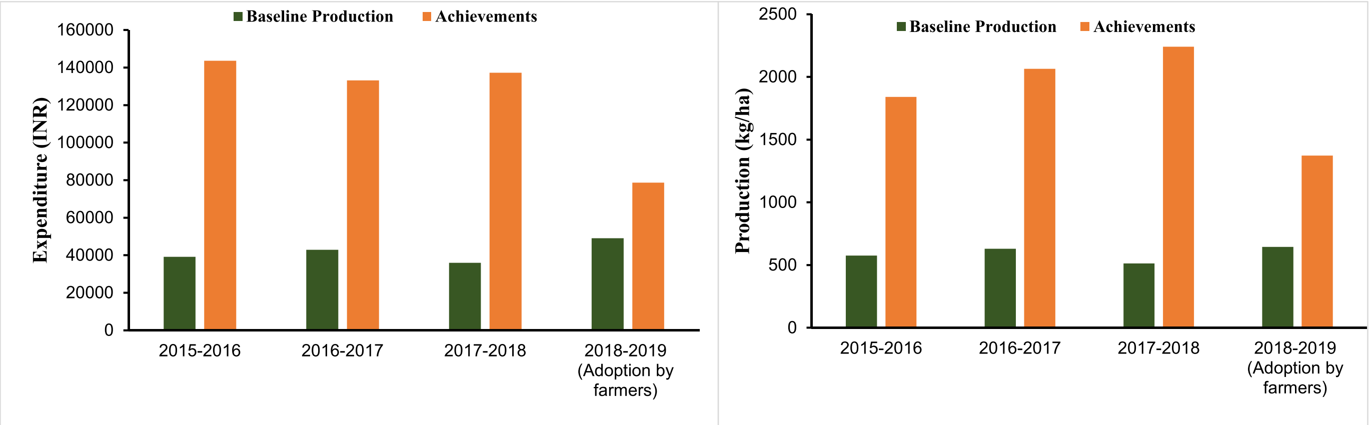

Fig. 2. (A) Expenditure and (B) production in WBADMIP supported culture (2015–2018) and Farmers' adoption culture (2018–2019) compared to baseline data.

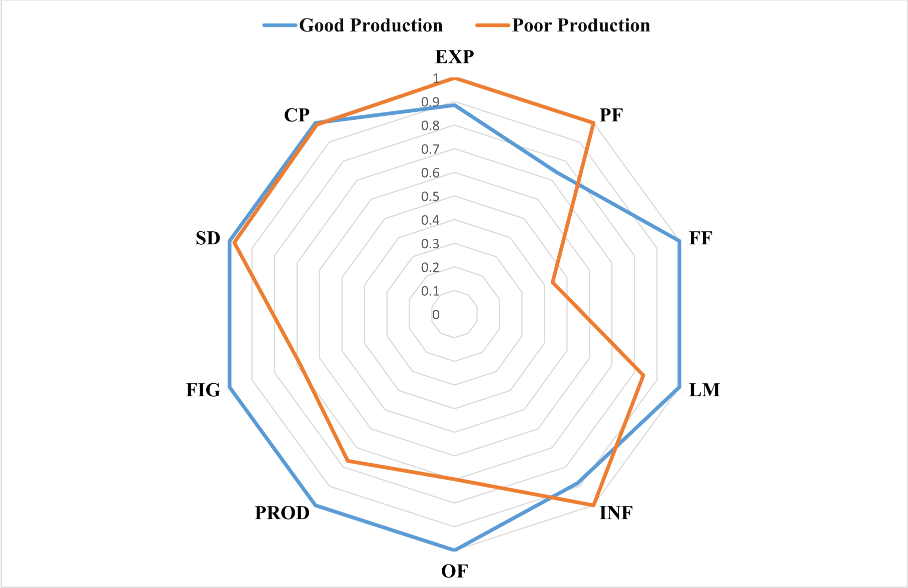

Fig. 3. Radar chart showing the comparison between 73 water bodies with good production and 64 water bodies with poor production.

$$\begin{aligned}\mathrm{PROD}_Q \quad &= -3180.44481 + 2.07154\mathrm{PF} + 0.45438\mathrm{FF} + 0.39063\mathrm{LM} + 0.03941\mathrm{INF}\\ &+0.45061\mathrm{OF} + 3.72062\mathrm{NOB} + 0.45521\mathrm{SDF} + 75.29216\mathrm{CP} + 0.00021\mathrm{PF}^2\\ &-0.00013\mathrm{FF}^2 - 0.00008\mathrm{OF}^2 - 0.00004\mathrm{OF}\times\mathrm{FF} - 0.00027\mathrm{PF}\times\mathrm{SDF}\end{aligned} \tag{3}$$

quadratic regression appears close to the actual production.

Residuals statistics for Eqs. (2) and (3) are measured and presented in Table A5. Based on Equation (3) we explored the quantum of input possible under the farmers' budget so that the farmers can obtain maximum production within their financial capacity. Consequently, we derived the following optimization problem:

$$\text{Max } \ \mathrm{PROD}_Q \tag{4}$$

s.t $\quad 35PF + 15FF + 15LM + 9INF + 2OF + 6SDF \le B; \quad PF \ge 1000;$ $FF \ge 0; \ PF + FF \ge 2000; \quad 300 \le LM \le 800; \quad 1000 \le OF \le 5000;$ $100 \le INF \le 600; \ NOB \in [5, 30]; \ SDF \in \{5000, 8000, 10000\}.$

Where B represents the budget of the farmers. The limits of inputs are adjusted according to the average value of 73 good water bodies. As per market price, the cost of each fingerling was INR 6, while those of PF, FF, LM, OF, and INF was set at INR 35, 15, 15, 2, and 9 per kg, respectively. We solved the problem by keeping the culture period constant at 11 months (CP=11) at three different levels of stocking density (SDF $\in$ {5000, 8000, 10000}). The results of optimization are presented in Table 1. The results indicate that with a budget of INR 90 000, it is not possible to stock more than 5000 fingerlings per ha. With this stocking density, the farmers can obtain a production of 1896 kg/ha with maximum investment on project feed followed by farmers' feed, lime, organic fertilizer, and inorganic fertilizer. Production can be further increased with more investment on project feed, which is a critical input for the growth and production of carps. But if stocking density is increased, the budget on project feed may have to be compensated for

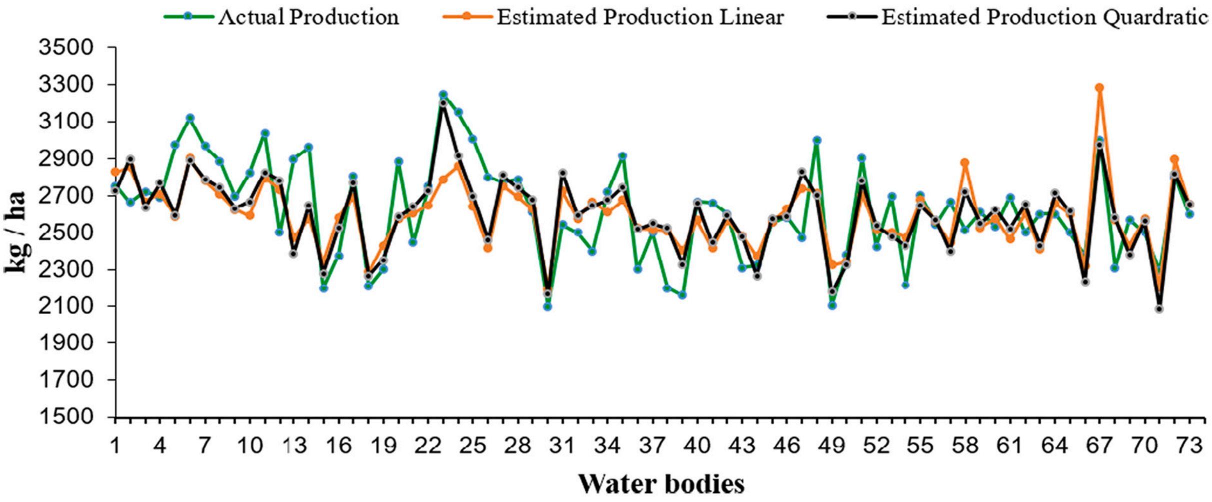

Fig. 4. Actual and estimated production of carps in 73 water bodies selected through TOPSIS.

Table 1
Input distribution under the financial constraint.

Exp. (INR/ha)	90000			110000			130000			150000		
SDF (no/ha)	5000	8000	10000	5000	8000	10000	5000	8000	10000	5000	8000	10000
$PROD_Q$ (kg/ha)	1896.25	-	-	2790.65	2477.86	-	3672.83	2792.35	2994.76	4686.79	3166.79	3022.14
PF(kg/ha)	1049.51	-	-	1802.17	1000	-	2377.95	1626.88	1000	2953.73	2204.05	1000
FF(kg/ha)	950.49	-	-	500	1000	-	500	503.34	1157.57	500	500	1417.27
LM(kg/ha)	300	-	-	300	464.85	-	300	800	800	300	800	800
INF(kg/ha)	100	-	-	100	100	-	100	100	120.42	100	100	600
OF(kg/ha)	1804.92	-	-	2012	2036.69	-	1935.89	2304.64	2276.31	1859.79	2229.14	2265.07
NOB(no/ha)	30	-	-	30	30	-	30	30	30	30	30	30

the cost of increased number of fingerlings resulting in the reduction of production as compared to low stocking density (5000 /ha), though production gradually increased with the increase in budget.

Note that we maintain the lower bound of each input based on the general requirements for composite culture of carps (Jhingran, 1991; Yadava and Garg, 1992).

4. Discussion

The present study demonstrates how farmers in the 16 villages of Northeast Purulia can obtain more production from the composite culture of carp with their limited financial capacities. Small scale rural aquaculture is a viable source of income and alternative livelihood option for marginal farmers in many developing countries, including India (Ahmed and Flaherty, 2014; Pant et al., 2014; Genschick et al., 2018; Gupta, 2018; Duarah and Mall, 2020). But the success in rural aquaculture is often heavily counteracted by several constraints like harsh climatic condition, fluctuation in water quality, non-availability of quality fish seed, high cost of supplementary feed, disease problem, illiteracy and above all poor economic condition of the farmers (Dauda et al., 2015; Elfitasari and Albert, 2017; Alam et al., 2019; Mulokozi et al., 2020; Duarah and Mall, 2020; Adeleke et al., 2021). Therefore, training and experience are vital to overcome the constraints and to manage the inputs rationally to maximize production in pond based aquaculture (Dey et al., 2010; Dickson et al., 2016; Kassam and Dorward, 2017). Present study reveals that average production from the composite culture of carps carried out by the farmers in 42 water bodies spread over 16 villages of Northeast Purulia, without any support from WBADMIP, is only 1372 kg per ha which is far below the average production obtained by these farmers under WBADMIP support (Mishra et al., 2021) and the average yield of pond based aquaculture in India (Duarah and Mall, 2020).

The maximum running expenditure for a successful composite culture of carps is required for procuring seed and quality feed followed by lime and fertilizers to maintain water quality standard for optimum growth of the fish (Sheheli et al., 2014; Dauda et al., 2015; Adeleke et al., 2021). Procurement of feed is assumed to share maximum cost of production in semi-intensive culture of fish (Asche and Oglend, 2016; Khan et al., 2018; Prodhan and Khan, 2018). While the productivity of an aquaculture pond depends largely on the quality and quantity of feed given, it is influenced by several other factors like stocking density, frequency of feed use, and farmers' knowledge on the management of the inputs (Khan et al., 2021). Poor management in stocking density, fertilization schedule and feed ration may produce negative impact on production (Sheheli et al., 2014; Elfitasari and Albert, 2017; Prodhan and Khan, 2018; Mulokozi et al., 2020). High cost of feed coupled with inadequate capital is the principal constraint in most rural aquaculture in India (Nandeesha et al., 2013) and in many other Asian and African countries (Dauda et al., 2015). Results of the present study indicate that the use of quality formulated feed is a critical factor that influences production in the composite culture of carps. Poor economic return from smallholder systems, including aquaculture, is a major issue of socio-economic stability in rural areas of the developing nations (Ghosh et al., 2017). As a result, farmers can hardly rely on aquaculture as a single source of income. Under such a situation, it is imperative to trade-off inputs to minimize expenditure for a given production target.

Using quadratic regression analysis the results of the present study indicate that cost involved in the purchase of seed (fingerlings) and feed are the most critical factors that influence the production of fish in the composite culture of carps by the resource constraint farmers. The farmers of the Northeast Purulia could not afford to purchase the commercially formulated feed used during WBADMIP supported culture. Fish meal (FM) and fish oil (FO) are two expensive ingredients that make the commercially formulated feed costly and almost out of reach of the poor and marginal farmers. Success and propagation of aquaculture in rural areas depend on reduction in dependency on FM and FO in feed formulation (Béné et al., 2015; Turchini et al., 2019). Although there have been landmark research achievements during the last two decades in using less expensive ingredients to replace FM and FO in the formulation of aquafeed (Gatlin et al., 2007; Turchini and Francis, 2009; Hardy, 2010; Samaddar et al., 2015; Ali et al., 2020; Samaddar et al., 2021), the feed manufacturers are still reluctant to commercialize feed using these ingredients. As a result, economically constrained farmers rely on locally available farm-made feed to reduce feed cost (Nandeesha et al., 2013; Gabriel et al., 2007; El-Sayed et al., 2015; Limbu, 2020).

In Purulia only 2.1% of the rural farmers use formulated feed, while 22.58% use farm-made feed and 75.32% of farmers do not use the supplementary feed at all, allowing fish to grow at the expense of natural feed (Biswas et al., 2019). The farmers of the 16 villages of the Northeast Purulia used locally available inferior quality farm-made feed, which was cheaper (approximately 15 INR per kg) than the formulated feed (approximately 35 INR per kg) and yielded less production. Combination of improved quality commercial feed and the traditional feed is a viable option to optimize production under financial constraints in rural aquaculture (Hasan and New, 2013; Amankwah and Quagrainie, 2019). However, the farmers need appropriate guidance to make successful adoption of improved feed mixing to optimize production (Mitra et al., 2019). Table 1 developed based on Eq. (3) states that a satisfactory production with limited investment is possible if the farmers judiciously use a mixture of commercially formulated feed and locally made feed and make a balance between the cost incurred on seed (fingerlings) and feed. It is revealed that if farmers start with a capital of 90000 INR and a stocking density of 5000 fingerlings per ha, they can obtain a production of 1896 kg/ha if they use a combination of commercial formulated feed @ 1050 kg/ha, farm-made feed @ 950 kg/ha and organic fertilizer @ 1804 kg/ha. In the actual situation, the farmers obtained an average production of 1372 kg/ha by using a stocking density of 5000 fingerlings /ha, farm-made feed @ 2140 kg/ha, and organic fertilizer @ 5000 kg/ha for an average investment of 78707 INR. Table 1 indicates that if the expenditure is increased on formulated feed, keeping stocking density unchanged at 5000 fingerlings/ha, production increases linearly with the increase in the amount of the formulated feed. However, if stocking density is increased, a considerable expenditure is incurred on the procurement of seed (fingerlings), thereby reducing investment in formulated feed, resulting in a substantial reduction in production. An increase in fingerling density increases the risk of production in the semi-intensive culture of carps (Khan et al., 2021). Since lack of capital to invest is the principal constraint in rural aquaculture in India

(Somashekar and Majagi, 2020); Bangladesh (Uddin et al., 2021) and in many other developing countries (Akpabio and Inyang, 2007; Onuche et al., 2020) and major share of the investment is consumed by procuring feed and seed (Ali et al., 2018; Uddin et al., 2021; Adeleke et al., 2021), a proper management of these two inputs is important for production optimization in rural aquaculture.

The resource-constrained farmers of Northeast Purulia were unable to procure high-quality formulated feed. Results of the present study offer a few viable options to maximize production by these farmers: (i) Restricting stocking density of fingerlings at 5000 /ha and inputs like lime, inorganic fertilizers, farm-made feed, and organic fertilizers at 300, 100, 500–950, and 1800–2000 kg/ha, respectively, farmers can expect an increase in production with the increase in formulated feed. (ii) Farmers can reduce the cost of feed by adopting a judicious mix of formulated feed and locally made farm-made feed. (iii) Organic fertilizers play an important role in productivity, and a judicious trade-off between supplementary feed (formulated or farm-made) and organic fertilizer would enhance net production from the composite culture of carps by capital constrained farmers. Regular or periodic application of fertilizers and supplementary feeding in ponds results in a greater yield of fish compared to supplementary feed alone (see Reviews by Boyd (2018)). Cow dung is the main form of organic fertilizer used in aquaculture ponds in Purulia (Biswas et al., 2019) as well as in most Indian villages (Nandeesha et al., 2013). Both organic and inorganic fertilizers stimulate the growth of phytoplankton and zooplankton necessary to sustain the growth of Indian major carps in semi-intensive carp culture system (Jhingran, 1991). Organic fertilizers contain relatively less nitrogen, phosphorus, and potassium but are less expensive than commercial inorganic fertilizers. In India, cow dung is applied in fish ponds at 5000 to 15000 kg/ha either in a single installment or in equal monthly or fortnightly installments (Nandeesha et al., 2013). But the total amount of organic fertilizers required and frequency of its application depend on several factors such as the quantity of inorganic fertilizers and supplementary feed used, nutrient levels (N:P:K) in the pond, growth of phytoplankton and zooplankton, and physicochemical properties of water. Organic fertilizers are found most effective when these are applied in combination with inorganic fertilizers (Boyd, 2018). Results of the present study indicate that an excess input of cow dung in fish culture ponds along with a limited amount of inorganic fertilizers can be an important management practice to alleviate the cost of feed.

5. Conclusion

It is concluded from this study that the high cost of fingerlings and formulated feed are the principal constraints of the resource-poor farmers of the Northeast Purulia to maximize production from their composite culture of carp. Due to financial constraints, the farmers could not afford to purchase formulated feed, as supplied under WBADMIP supported culture and used an inferior quality farm-made feed, which in turn reduced the production of carps. Additionally, the farmers often used a high stocking density of fingerlings, which involved additional expenditure, but the fingerlings were deprived of required nutrition due to less investment in quality and quantity of feed required for optimum production. This study reveals that the farmers need to make a balance in expenditure between stocking density of fingerlings and purchase of quality formulated feed to maximize production with their limited resources. Restricting stocking density to 5000 fingerlings per ha can reduce input cost as well as the risk of the culture. Further, the farmers of Northeast Purulia can make a mixture of formulated feed, local farm-made feed, and organic fertilizer to ensure the nutrition of fish and maximize production within their limited budget.

Marginal and poor farmers of Purulia always face financial constraints to adopt the composite culture of carps successfully. It remains a challenge for the policy makers to suggest proper inputs under budgetary constraints to achieve desired production goal. The present data analysis scheme and evaluation process are able to overcome this challenge from the perspective of farmers' constraints and input management for propagating carp culture. WBADMIP promoted various practices to build the capacity of the farmers' community and empower them to adopt the composite culture of carps independently. This study reveals that WBADMIP needs to develop strategies further to educate the farmers/adoption farmers on judicious use of their financial resources. The farmers should prioritize their investment on fingerlings, stocking density, feed, organic fertilizers, etc. and management of revolving funds to maximize the returns from carp culture under semi-arid climatic conditions and multidimensional poverty in Purulia.

This study provides a guideline for the entire fisheries sector including the funding agencies such as multinational institutions and government agencies etc. for estimating inputs under financial and resource constraints. Fund flow can be suitably designed using the findings of this study to bridge the critical gaps in the sector to optimize fish production and maximize farmers' income.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Additional statistical results

Table A1

Descriptive statistics of inputs given in WBADMIP supported composite culture of carps during 2015–2018.

	WD ft	CP month	EXP_P INR/ha	EXP_F INR/ha	PF kg/ha	FF kg/ha	LM kg/ha	INF kg/ha	OF kg/ha	NOB no/ha	SDF no/ha	PROD kg/ha
						Year 2015–2016						
Mean	4.72	8.97	141167.37	2439.96	2633.69	38.79	225.31	176.24	886.37	20.33	8013.40	1840.32
SE of Mean	0.23	0.53	6595.26	627.62	196.37	27.12	24.15	5.37	177.15	3.71	265.01	172.44
Median	4.50	9.00	124757.69	2066.67	2100.00	0.00	190.22	175.00	943.40	15.15	8000.00	1913.04
S.D.	0.99	2.30	28748.07	2735.74	855.97	118.22	105.25	23.43	772.16	16.18	1155.14	751.66
Min	2.70	3.00	112750.00	0.00	2100.00	0.00	123.08	141.51	0.00	6.67	6000.00	163.33
Max	7.10	12.00	191184.85	10000.00	4296.97	433.96	464.15	262.50	2727.27	76.92	12000.00	3393.94
						Year 2016–2017						
Mean	5.12	10.87	121427.03	11691.31	1761.10	503.91	393.11	52.75	875.95	20.82	9875.37	2064.92

(*continued on next page*)

Table A1 (*continued*)

	WD ft	CP month	EXP_P INR/ha	EXP_F INR/ha	PF kg/ha	FF kg/ha	LM kg/ha	INF kg/ha	OF kg/ha	NOB no/ha	SDF no/ha	PROD kg/ha
SE of Mean	0.13	0.20	4472.97	1176.07	104.21	58.96	32.69	18.32	74.04	1.94	124.63	78.06
Median	4.90	12.00	110122.50	12530.61	1500.00	500.00	384.62	0.00	846.15	15.00	10000.00	2206.90
SD	1.02	1.60	36612.87	9626.54	853.01	482.57	267.57	149.92	606.07	15.87	1020.11	638.97
Min	3.50	7.00	69125.00	0.00	500.00	0.00	0.00	0.00	0.00	3.38	1650.00	346.15
Max	8.00	14.00	225902.73	47700.00	4125.00	2200.00	1200.00	625.00	2700.00	76.92	10000.00	3000.00
						Year 2017–2018						
Mean	5.21	11.71	129030.55	8256.23	1552.17	416.37	625.50	308.43	739.64	20.80	9945.28	2240.99
SE of mean	0.10	0.14	3433.44	572.47	23.84	32.85	13.43	13.20	69.70	1.56	42.22	59.92
Median	5.00	12.00	122797.22	7678.98	1500.00	389.68	628.95	300.00	764.61	17.11	10000.00	2229.35
SD	0.90	1.27	31840.45	5308.89	221.04	304.66	124.55	122.41	646.34	14.42	391.51	555.68
Min	3.50	6.00	91056.82	0.00	1378.38	0.00	172.73	0.00	0.00	5.50	6500.00	727.27
Max	7.80	14.00	366392.05	19300.00	3189.19	1038.96	1000.00	1368.75	2972.97	104.17	10352.94	3267.57

Table A2
Descriptive statistics of inputs given in farmers' adoption culture of carps during 2018–2019.

	CP month	EXP_F INR/ha	FF kg/ha	LM kg/ha	INF kg/ha	OF kg/ha	NOB no/ha	SDF no/ha	PROD kg/ha
Mean	12	78707.14	2140.47	434.29	30.00	5353.57	6.89	5208.33	1372.27
SE of Mean	0	4082.36	169.03	23.10	14.70	299.32	0.65	230.92	73.15
Median	12	77500.00	2233.33	435.00	0.00	5000.00	6.55	5000.00	1260.99
SD	0	21601.80	894.44	122.25	77.79	1583.83	3.43	1221.91	387.06
Min	12	20000.00	266.67	0.00	0.00	0.00	1.31	2166.67	905.56
Max	12	121000.00	3733.33	650.00	300.00	9000.00	13.04	8000.00	2307.69

Table A3
The weights of different indicators of 173 water bodies by TOPSIS.

Indicator	Entropy	Divergence	Weight
EXP	0.98204035	0.01795965	0.04412902
PF	0.97335108	0.02664892	0.06547961
FF	0.91695343	0.08304656	0.20405542
LM	0.97024334	0.02975665	0.07311569
INF	0.89842055	0.10157944	0.24959293
OF	0.93478949	0.06521051	0.16023007
PROD	0.98218846	0.01781154	0.04376509
NOB	0.94824286	0.05175713	0.12717351
SDF	0.98678996	0.01321003	0.03245864
CP	0.98665016	0.01334983	0.03317795

Table A4
Correlation matrix of inputs give 73 best water bodies.

	FF	LM	INF	OF	PROD	NOB	SDF	CP
PF	-0.133	0.055	0.100	0.207	0.061	-0.144	-.497**	0.070
FF	1	0.192	-.346**	.291*	.285*	-0.133	0.201	0.008
LM		1	.315**	0.187	.299*	0.092	0.146	0.080
INF			1	-0.224	0.047	.318**	-0.007	.337**
OF				1	.359**	-.287*	-0.219	-0.191
PROD					1	0.139	-0.015	0.198
NOB						1	0.038	0.173
SDF							1	.248*

[*] Correlation is significant at the 0.05 level.
[**] Correlation is significant at the 0.01 level.

Table A5
Residuals statistics for Eqs. (2) and (3).

	Min.	Max.	Mean	SD
Residuals statistics for Eq. (2)				
Predicted value	2205.55	3283.88	2597.73	171.89
Std. predicted value	-2.28	3.99	0.00	1.00
SE of predicted value	36.99	252.14	86.15	40.88
Adjusted predicted value	2191.06	3441.36	2609.80	201.95
Residual	-522.53	511.70	0.00	255.72
	Residuals statistics for Eq. (3)			
Predicted Value	0.06	2975.98	2597.7291	185.09
Std. Predicted Value	-2.75	2.04	0.00	1.00
SE of Predicted Value	44.69	271.68	106.37	54.08
Adjusted Predicted Value	1995.18	9276.20	2693.96	813.91
Residual	-546.68	511.58	0.00000	246.33

Table A6
Selection of water bodies based on TOPSIS.

	EXP INR/ha	PF kg/ha	FF kg/ha	LM kg/ha	INF kg/ha	OF kg/ha	PROD kg/ha	NOB no/ha	SDF no/ha	CP month
Good prod	131778.38	1495.40	671.47	590.03	194.85	1058.34	2597.72	21.64	9962.08	11.79
Poor prod	149035.08	2020.66	292.91	495.27	220.18	740.28	1995.14	14.84	9754.95	11.68

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