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Full Length Research Paper

Application of modified compromise weighted multi-objective programming in Fadama farming in Dass Local Government Area of Bauchi State, Nigeria

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The application of modified compromise weighted multi-objective programming to Fadama farming in Dass Local Government Area of Bauchi State was the main focus of the study. Samples of 106 Fadama vegetable cultivars were randomly selected from 12 Fadama user's associations in the study area. The farm sizes were grouped and formed into three categories namely: below 1 ha, 1 to 2.99 ha and 3 to 4.99 ha farms, with sample size of 37, 39 and 30 farmers, respectively. It was assumed that farming could be optimized using four specific objectives (maximization of income, and employment; minimization of fertilizer and ground water use). Modified compromise weighted multi-objective programming technique was used to analyze the four objectives, which were optimized individually and combined. The results disclosed that the 3 to 4.99 ha farm size had the best maximum income level of N302,199.26 (+28.11%) and employment of 1125 man days (+33.61%) and minimum level of fertilizer use of 182 kg (-8.08%) and ground water use of 3962 mm (-17.25%) at their respective existing farm levels compared to the other categories of farms. This implied that the farmers were characterized by preponderance of high level of adoption of agricultural technology, resulting from intensive cropping, leading to a high level of chemical fertilizer and increased use of ground water for irrigation which consequently led to reduction of ground water table in the study area. It was therefore recommended that the farmers in the study area should concentrate in the cultivation of the major Fadama crops like onion, tomato, pepper, okro, cabbage and lettuce instead of spreading out their resources to grow potato, carrot and garden-egg.

Key words: Organic farming, irrigation, multi-objective programming, Fadama farming.

INTRODUCTION

In agriculture, several economic activities compete for common resources available, resulting in different level of returns and employment. The level of various economic activities is interdependent in respect to its returns, resource requirements and resource availability on the farm. The interdependence of decisions concerning the level of economic activities require the best suited methodology of multi-objective programming, since it has the advantage of considering more than one farm objective simultaneously. The technique can be used to determine the level of various economic activities such as crop, and livestock that will make the most optimal use of land, labour, capital ground water and human resources. It is believed that agriculture in the form of settled cultivation of land began in Nigeria nearly thirty decades ago and because of the diversity of soil and climate, the country is endowed with rich flora and fauna. The choice of crops grown together was largely based on the domestic needs of farmers. During the colonial period, the demand of foreign markets influenced cropping pattern in Nigeria.

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Basically, the broad objective of the study was to analyze the application of modified compromise weighted multi-objective programming in Fadama farming in Dass Local Government Area of Bauchi State, Nigeria. The specific objectives of the study were to:

1) Determine maximization of income and employment; and
2) Minimization of fertilizer and ground water use over the existing farm level in the study area.

Howell (2001) reported that irrigated agriculture is an important component of total agriculture worldwide and covers a wide range of agricultural products such as vegetable, fruits and cereals. The author further stated that most agriculture in the Middle East countries rely on irrigation, for example, irrigated agriculture in Iraq, Saudi Arabia and Iran is expected to account for 92, 82 and 73%, respectively. The Sub-Saharan Africa is expected to use less than 5% of crop land (Calzadilla et al., 2010). FAO (2002) also revealed that it is expected that the developing countries as a whole, are to increase their irrigated land from 202 million ha in 1997 to 1999; to 242 million ha by 2030.

According to Douglas (1985), agriculture is the primary instrument for feeding the world through a combination of more resources and greater efficiency. Agriculture is also considered as an ecological phenomenon and an institution that impact on the social organization and culture of rural life. The Brundtland Report defined sustainable farming as a system that meets the demands of the peasants without compromising the ability of the future generations to meet their own demands. This involves eradication of hunger through sustainable food security. Edward (1987) defined sustainable agriculture as integrated systems, which are less dependent on high input of energy and systematic chemicals and more dependent on intensive management than conventional monoculture systems. These systems maintain an increased net income for the farmer, ecologically desirable and protective of the environment. It was concluded that sustainable agriculture should be able to in the long run enhance environmental quality and resource base on which agriculture depends, provided for basic human food and fibre needs that is economically viable and enhance the quality of life for farmers and society as a whole.

In a study conducted by Tahar (2010), it was concluded that increasing demand for food production worldwide, in regions where water is scarce, the improvement of agricultural water production became an urgent need. As irrigated agriculture remains virtually important as a means of food production, enhancing water use efficiency is one of the main approaches to make better use of water. Many options to improve water use efficiency in Fadama farming are available and the target is to produce yield with possible minimum amount of water. The author further opined that in order to assure water use efficiency in irrigated agriculture, farmers should be able to increase the economic crop production per unit of water in water scarce environment. The effective use by the crop of a limiting water supply can be achieved by manipulating crop penology or by using agronomic techniques and farm practices that are sustainable to the extent of improving water use efficiency. Spencer (1985) explained that the emphasis of sustainable agriculture is on design and management procedures that work with natural processes to conserve the resources, minimize waste and environmental damages, while maintaining or improving farm profitability. Sustainable farming system also aimed at ensuring the well being of rural communities to produce food that are nutritious and uncontaminated, that might harm human and livestock health (Warren, 1991).

In the words of Duffy (1990), sustainable agriculture is one of many terms used to describe alternative ways to evaluate an agricultural production system and other terms used are alternative low input and regenerative agriculture. The common link in these efforts is the desire to find profitable ways to produce environmental problems associated with current production practices. Sustainable agriculture therefore, is simply using the most appropriate agricultural production practices given the land, labour, capital and management available to the farmer. Lack of sustainability may be indicated by declining productivity but equally an experience suggest that collapse may occur without warning. Kushwaha et al. (1989) emphasized that sustainable agriculture is an integrated system of plants and animal production practices, having a site-specific applications that will over the long term satisfy human feeds, and fibre needs, enhance environmental quality and the natural resource, based upon which the agricultural economy depends; make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and control, sustain the economic viability of farm operations, and enhance the quality of life for farmers and society as a whole. Mamman (1997) opined that the concept of sustainable agricultural development embodies a believe that people should be able to alter and improve their lives, in accordance with criteria which take account of the needs of others and which protect the planet and future generations. In a way, sustainable agricultural development seeks to respond to five broad requirements:

1) Integration of conservation and development;
2) Satisfaction of basic human needs,
3) Achievement of equity and social justice,
4) Provision of social self-determination and cultural diversity and,
5) Maintenance of ecological integrity.

According to Reganold et al. (1990), an economically viable farming system, which reduces the use of off-farm inputs such as chemicals, produces adequate food of high quality and are environmentally safe, could reduce production cost and make farm more ecologically sound. In this regard, the author further emphasized soil building practices, natural pest control, crop and livestock diversity. Manos (1991) observed that the farms especially those which included livestock enterprises are often faced with multi-objectives such as the maximization of total costs, minimization of feed costs and that such problems can be solved by developing a

multi-objective programming model which can incorporate more than one goal. The aim of this study therefore, is to show how multi-objectives can be manipulated in farm planning. Kushwaha (1992) pointed out that if two or more objective functions generate the same set of activities with respect to its optimization through single objective linear programming function, then, there are no conflicts among the objectives in mind.

In such a situation, there is no use of multi-objective programming. However, conflicting nature of various economic activities with respect to farm resources is very common. The author concluded that a common set of activities, which would optimize the multiple objectives at a go, is developed and should be regarded as the most optimal. Sankhayan et al. (1988) developed optimum cropping plans for a typical farm with multiple objectives using combined planning. The limitations of traditional linear programming technique are too obvious as a decision-maker on a farm firm is seldom, confronted with a single objective. But in reality, multi-objectives are a rule in farm planning. With the help of multi-objective programming approach, the authors had developed ten alternative farm plans assigning different weights to the objective functions and found that in terms of unit of gross margins generated by plans the multi-objective programming (MOP) results were very close to existing farm plans. However, the cropping pattern in these plans is somewhat variant. Ciuchi and Penaechi (1990) examined one of the multi-criteria decision making methods that can be used for farm management, that is, weighted goal programming. After briefly describing the methods, some ways in which it can be applied to the farm was illustrated, taking into consideration different hypothesis about entrepreneurs' behaviors. The method appears useful as regards the possibilities offered to overcoming some of the limits of the single-criteria model. However, it is unsatisfactory, in that it was necessarily used to consider all the objectives.

Das and Haimes (1979) presented a multi-objective planning framework for a River Basin that considered both point and non-point source pollutants. The need for an integrated approach to pollution abatement originating from these two sources was discussed in the light of the public law 92 to 500. The need for including multi-objective functions in non-commensurable formats and units were also discussed. Two broad-based planning objectives considered are economic development and environmental quality. The environmental quality model include, the following multi-objectives: soil erosion, phosphorus and biological oxygen demanding load in the streams. Non-inferior solution and trade-off among the objectives are examined for several alternative-planning scenarios using the surrogate worth trade-off (swt) method.

The study recognizes the fact that agriculture is still in bad shape in Nigeria in general and the study area in particular thereby causing the growth of output to lag seriously behind the geometrically population growth and the nation that is becoming progressively incapable of feeding itself and supplying agro-allied industries the needed agricultural raw materials. The study was therefore carried out in the study area in view of this situation, and considering the interdependent nature of various competing farm economic activities which made farmers nowadays to maximize farm objectives thereby causing uncertainty of net returns, variation in expected yields due to random weather changes and the unpredictable nature of farm produce prices.

MATERIALS AND METHODS

The study area

Keeping in mind the need for sustainable Fadama farming, the study was carried out in Dass Local Government Area of Bauchi State. The State is located between Latitudes 90° 30'N and 12° 30'N of the equator and Longitudes 8° 42'E and 11° 50'E of the Greenwich Meridian. Dass Local Government Area of Bauchi State is one of the paramount regions in the state regarding Fadama irrigated crop production. The farmers practiced both rained and dry season cropping. Fadama land irrigation in the study area was widely practiced and cultivated compared to other regions of the state. The Fadama farmers in the study area were mostly small and marginal land holdings.

According to NBS (2006), the study area has a total population figure of 280,468 people. It has wet and dry seasons with wet season spanning from April to October and dry season commencing in November to March. The inhabitants are mostly farmers. A sample size of 106 Fadama farmers categorized into 37, 39 and 30 for farmers operating below 1 ha, 1 to 2.99 ha, and 3 to 4.99 ha, respectively were selected using multi-strata random sampling technique for this study. The data were analyzed using Modified Compromise Weighted Multi-objective Programming, taking into consideration irrigated crops such as onion, tomato, pepper, okro, carrot, cabbage potato and garden-egg.

Model specification

The adoption index (Kushwaha and Sani, 1998) of individual farmer was developed as follows:

$$AI = \sum_{j-1}^{m} [\frac{FYMA_j}{FYMR_j} + \frac{AH_j}{CA_j} + \frac{PA_j}{PR_j} + \frac{FA_j}{FR_j} + \frac{IA_j}{IR_j GCA}] X \frac{CA_j}{} \quad (1)$$

where, j = 1,2,3...m, and m= total number of major crops; A = Adoption index of farmers; $FYMA_j$ = Amount of FYM applied per unit of area in jth crop; $FYMR_j$ = Amount of FYM recommended for application per unit of area of jth crop; AH_j = Area under HYV of jth crop; CA_j = Cropped area (HYV + Local) of jth crop; FA_j = Amount of fertilizer (N+P+K) applied per unit of area of jth crop; FR_j = Amount of fertilizer recommended per unit of area for jth crop; PA_j = Amount of pesticide applied as plant protection chemicals (weedicide, pesticide, insecticide) per unit of area in jth crop; PR_j = Amount of pesticide recommended for jth crop; IA_j = Number of irrigation applied to jth crop; IR_j = Number of irrigation recommended for jth crop; GCA = Gross cropped area.

The compromise weighted multi-objective programming approach used was expressed mathematically as follows:

$$Optimize\ Z(x) = \begin{cases} MAX.\ I_c(x) \\ MAX.\ I_l(x) \\ Max.\ E(x) \\ MIN.\ K(x) \end{cases} \quad (2)$$

Subject to:

$$[a_{ij}][x_j] \; \begin{matrix} \leq \\ = \\ \geq \end{matrix} \; [b_i] \quad (3)$$

$$x_j \geq 0\ \forall ij \quad \begin{matrix} i = 1, 2, \ldots, n \\ j = 1, 2, \ldots, m \end{matrix} \quad (4)$$

Where, n = number of constraints; m = number of decision variable; I_c = objective function optimum Gross Income for all crops; I_L = objective function of optimum Gross Income for all livestock rearing; E = objective function of optimum family labour in man days; K = objective function of optimum energy conservation in both crop production as well as livestock production in Megajoul (M J); a_{ij} = matrix of the constraint coefficients; x_i = decision variables vector; and b_i = constraint level vector.

All objectives in Equation 2 were optimized (maximized and minimized) individually and obtained as:

$$\begin{aligned} MAX.\ I_c(x) &= I_{cmax}. \\ MAX.\ I_L(x) &= I_{Lmax}. \\ Max.\ E(x) &= E_{MAX} \\ MIN.\ K(x) &= K_{MIN}. \end{aligned} \quad (5)$$

The common set of x decision variables was determined from the following combined objective functions:

$$MAX.\ W(x) = \sum_{n=1}^{s} \frac{I_c(x)}{I_{cmax}} + \sum_{m=1}^{t} \frac{I_l(x)}{I_{lmax}} + \sum_{o=1}^{u} \frac{E(x)}{E_{Max}} - \sum_{p=1}^{v} \frac{K(x)}{K_{MIN}} \quad (6)$$

Subject to the constraint (7) and (8):

$$I_{cmax} > 0\ \forall n \quad (7)$$

$$I_{lmax} > 0\ \forall m \quad (8)$$

$$E_{MAX} > 0\ \forall o \quad (9)$$

$$K_{MIN} > 0\ \forall p \quad (10)$$

where, (11), (12), (13) and (14) revealed the limitation of the application. The results from new compromise multi-objective programming can then be shown as:

$$\sum_{n=1}^{s} \frac{I_c(x)}{I_{cmax}} < I_{cmax} \quad (11)$$

$$\sum_{m=1}^{t} \frac{I_l(x)}{I_{lmax}} < I_{lmax} \quad (12)$$

$$\sum_{o=1}^{u} \frac{E(x)}{E_{Max}} < E_{Max} \quad (13)$$

$$\sum_{k=1}^{v} \frac{K(x)}{K_{MIN}} < K_{MIN} \quad (14)$$

Taking the aforestated into consideration, the individual objective functions can be specified as thus explained.

Objective function I (maximization of income)

$$MAX\ Z_1 = \sum_{o=1}^{n} C_o X_o + \sum_{l=1}^{m} C_l X_l \quad (15)$$

where, Z_1 =Total annual returns (Income) over variable costs in Naira; C_o =Annual returns over variable costs per unit of Oth crop activity; X_o =Level of Oth crop activity; C_L =Annual returns over variable costs per unit of Lth livestock activity; X_l = Level of Lth Livestock.

Objective function II (maximization of employment)

$$MAX\ Z_2 = \sum_{o=1}^{n} Y_o X_o + \sum_{l=1}^{m} Y_l X_l \quad (16)$$

Table 1. Maximization and minimization of the variables over the existing level on sampled farmers operating below 1 ha.

Particulars	Existing level	Max. of income	Max. of employment	Min. of fertilizer use	Min. of ground water use	Multi-objective programming (MOP)
Income (=N)	33,999.57	49,980 (+47.00)	37,060(+9.00)	30,259.62 (-11.00)	30,259.62 (-11.00)	48,960 (+44.00)
Employment (man days)	389	424 (+9.00)	455 (+16.97)	342.00 (-12.08)	342.00 (-12.08)	447 (+14.19)
Fertilizer use (kg)	68.73	85 (+23.67)	87 (+26.58)	56 (-18.52)	58 (-15.61)	60 (-12.70)
Ground water use (mm)	522	930 (+78.16)	910(+74.33)	510 (-2.30)	490 (-6.13)	500 (-4.21)

Figures in parentheses shows the percentage of each variable over existing farm level. Source: Updated field survey data, 2009.

where, Z_2 =Total employment in days on different farm sizes, Y_o = Requirement of labour working days per unit for Oth crop activity, Y_L =Requirement of labour working days per unit of Lth Livestock activity, X_L= Level of Lth Livestock activity.

Objective function III (minimization of fertilizer use)

$$\text{MIN} \quad Z_3 = \sum_{o=1}^{n} F_o X_o \qquad (17)$$

where, Z_3 =Total annual requirement of fertilizer in kg, F_o = Fertilizer applied per unit of Oth crop activity in kg, X_o = Level of Oth crop activity.

Objective function IV (minimization of ground water use)

$$\text{MIN} \quad Z_4 = \sum_{o=1}^{n} G_o X_o \qquad (18)$$

where, Z_4 =Total requirement of ground water annually, G_o =Requirement of ground water per unit of Oth crop activity, X_o = Level of Oth crop activity.

From the earlier stated four objectives of income and employment maximization and minimization of fertilizer and ground water use, the single objective linear programming could be derived as:

$$\text{MAX.} \quad Z_1 = \sum_{j=1}^{k} C_j X_j = W_1 \qquad (19)$$

$$\text{MAX.} \quad Z_2 = \sum_{j=1}^{k} Y_j X^2{}_j = W_2 \qquad (20)$$

$$\text{MIN.} \quad Z_3 = \sum_{j=1}^{k} F_j X^3{}_j = W_3 \qquad (21)$$

$$\text{MIN.} \quad Z_4 = \sum_{j=1}^{k} G_j X^4{}_j = W_4 \qquad (22)$$

where W_1, W_2, W_3, and W_4 are the maximum level employment, the minimum level of fertilizer and ground water use, respectively.

From the aforestated, the common objective function to obtain the most optimal solution is constructed as:

$$\text{MAX} \quad Z^* = \frac{\sum_{j=1}^{k} C_j X_j}{W_1} + \frac{\sum_{j=1}^{k} Y_j X_j}{W_2} - \frac{\sum_{j=1}^{k} F_j X_j}{W_3} - \frac{\sum_{j=1}^{k} G_j X_j}{W_4} \qquad (23)$$

RESULTS AND DISCUSSION

Table 1 disclosed the results of the level of annual income, employment, fertilizer and ground water on sampled farmers operating below 1 ha. The result indicated that conflicts exist among objectives, that is, optimization of one objective has negative effect on the rest objectives. If the annual income and employment was maximized alone one by one, the increment in the income was found to be 47.00% over existing level of income. But the employment, fertilizer, and ground water use has to be increased by 9.00, 23.67 and 78.16% over existing level, respectively. The minimization of fertilizer use envisaged decline in fertilizer use by 18.52% over existing level. Income and employment level has also increased by 11.00 and 12.08% over existing level, respectively. Similarly, the minimization of ground water use indicated the decline in the ground water use by 4.21%, while the fertilizer use and income have declined by 11.00 and 15.16% over existing level, respectively. This result implies that income and employment cannot be increased more than 47.00 and 9.00% over the existing level, respectively. The fertilizer and ground water use cannot be increased more than 18.52 and 6.13% respectively over the existing level. Kushwaha (1992) confirmed this when he emphasized that because of the conflicting nature of several objectives, the multi-objective programming technique was modified in the form of compromise weighted multi-objective programming technique. David et al. (2009) also agreed with these findings stating that even though small-scale vegetable Fadama agriculture is profitable, farmers can

Table 2. Maximization and minimization of the variables over the existing level on sampled farmers operating on 2 to 3.99 ha.

Particulars	Existing level	Max. of income	Max. of employment	Min. of fertilizer use	Min. of ground water use	Multi-objective programming (MOP)
Income (=N)	73,437.97	113,829(+55)	82,985 (+13)	85922 (+17)	88,860(+21)	109,723(+49)
Employment (man days)	995	1106 (+11)	1204 (+21)	1134 (+14)	1119(+13)	1184 (+19)
Fertilizer use (kg)	104.35	132.52 (+27)	96.00 (-8)	87.65(-16)	92.87 (-11)	91.25 (-12.5)
Ground water use(mm)	2106	1993 (-5.36)	1903(-9.73)	1569(-25.48)	1407 (-33.19)	1481 (-29.67)

Figures in parentheses shows the percentage of each variable over existing farm level. Source: Updated field survey data, 2009.

Table 3. Maximization and minimization of the variables over the existing level on sampled farmers operating 3 to 4.99 ha.

Particulars	Existing level	Max. of income	Max. of employment	Min. of fertilizer use	Min. of ground water use	Multi-objective programming (MOP)
Income (N)	235,890.45	310,125.18(+32.0)	298,849.61 (+26.69)	208,692.27 (-11.53)	200,789.96 (-14.88)	302,199.26(+28.11)
Employment (Man days)	842	1108(+31.59)	1153 (+36.94)	752 (-10.69)	712 (-15.44)	1125 (+33.61)
Fertilizer Use (kg)	19.8	213(+7.58)	221 (+11.62)	179 (-9.60)	186 (-6.06)	182 (-8.08)
Ground Water use (mm)	4788	5228(+9.19)	4557 (-4.82)	4240 (-11.45)	3851 (-19.57)	3962 (-17.25)

Figures in parentheses shows the percentage of each variable over existing farm level. Source: Updated field survey data, 2009.

obtain high profit through rational resource inputs adjustment and re-allocation. Table 2 shows the maximization of income, employment and fertilizer and ground water use of sampled farmers in the study area operating on 1 to 2.99 ha. It reveals again that conflict existed between income and employment, income and fertilizer use, income and ground water use.

However, the compromise solution obtained through optimization of combined objective functions reveals that income has increased by 49.00% which is less than its individual optimization level, that is 55.00% but definitely higher than its levels and the rest of the three objectives. The employment has increased by 19.00%. This is less than individual optimization, that is, 21.00%; the amount of fertilizer use annually declined by 12.50% which is higher than its individual minimization rate (16.00%) but certainly lesser than its declining rate under the rest three objectives. Similarly, the amount of ground water use has decreased by 29.27% which is larger than its individual minimization rate (33.19%) but certainly lesser than its increasing rate under maximization of income and employment objective and lesser than declining rate under minimization of fertilizer use by multi-objective. These results disagreed with Ani (1999) revealing that despite various agricultural programmes such as Community Based-Agricultural and Rural Development Projects (CBARDP), National Programme for Food Security (NPFS), Operation Feed the Nation (OFN) and Green Revolution (GR), rural home household uses farm resources generally below the profit maximization level because of their low capital base signifying that there is the need for resource adjustment by farmers in order to obtain maximum profit.

Table 3 revealed the level of income, employment and fertilizer and ground water use of sampled farmers operating on 3 to 4.99 ha farm size. The result indicated that income alone was maximized by 32.00% while employment, fertilizer and ground water use by 31.75, 7.58 and 9.19%, respectively, over the existing level. The maximization of employment alone shows the increase in employment by 36.91%. Ndanitsa et al. (2010) confirmed this, recommending that since the gross margin of vegetable production was higher and profitable, especially for tomato enterprise, its production should be intensified by smallholder farmers and school leavers should be encouraged and motivated into it, especially now that the ‘white collar jobs’ are almost becoming extinct in the Nigerian labour market. On the other hand, income and fertilizer use increased by 26.69 and 11.62%, respectively, while the use of ground water decreased by 4.82% over the existing level. The minimization of fertilizer use has declined the fertilizer use by 6.06% income, and employment levels and ground water use also decreased by 11.53, 10.72 and 11.45%, respectively over the existing level. Similarly, the minimization of ground water use has declined by 19.57%, income, employment and fertilizer use by 14.88, 15.46 and 6.06%, respectively over the existing level. The findings of this result indicate a significant level of conflicts among all the four objectives. These disclosures are in line with Tahar (2010) that irrigated agriculture remains virtually important as a means of food production, enhancing water use efficiency is one of the main approaches to make better use of water.

CONCLUSION AND POLICY IMPLICATIONS

From the study, it was realized that conflicts existed among the four specific objective functions. Therefore, the solution obtained through the multi-objective programming technique was selected as the best compromising optimal solution for sustainable Fadama farming. As a result of the conflicting nature of several objectives, the multi-objective technique was modified in the form of compromise weighted multi-objective programming technique, to generate the best fit compromise optimal solution for decision making to obtain alternate sustainable Fadama farming. The technique is therefore, free from subjective weights as well as multi-dimensional aggregation. It was therefore recommended that these categories of farmers should have multiple farm objectives in order to complement each other and improve the farming operations and well being of the farmer and the study area in general.

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