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Forecasting Rice Production in Jigawa State, Nigeria using Fuzzy Inference System

[1*]Ali Maianguwa Shuaibu, [2]Maryam Nuraini Muhammad and [3]Yusuf Abu-Safyan

[1,2,3]Department of Mathematics,
Federal University Dutse,
Jigawa State, Nigeria

Email: Shuaibuali16@gmail.com

Abstract

In this work, we used fuzzy inference system to forecast rice production covering the period 2021-2030 in Jigawa state, Nigeria. This is done by designing a fuzzy inference system using MATLAB. The system consists of two input functions and a single output function. Each function has its membership functions from which 49 inference rules of the system were formed. Three variables were considered in the course of this research. The variables are rainfall, land and rice production. Furthermore, linguistic variables were defined on each input. A rule based system was then formed which is defuzzified and a crisp value is obtained as the forecasted value. The result of this research shows that in 2022, 177950ha is required with 873mm of rainfall to produce 1070000TN of rice. Similarly, prediction is made of the required area, rainfall and rice yield up to 2030 in Jigawa state.

INTRODUCTION

Rice is one of the major staple foods in Nigeria, consumed across all geopolitical zones and socioeconomic classes (Kamai *et al*, 2020). Jigawa state is one of the major producers of rice in the country and the state has a projected population of 6,346,156 people as of 2018 (Ogunleye *et al*, 2018). Despite the huge comparative advantage enjoyed by Jigawa state including its 1.8 million hectares of cultivable land, over 0.4 million hectares of fertile fadama lands suitable for all-year round cultivation and a huge reservoir of bodies of water and able-bodied youths. The state is beset with a myriad of challenges (Jennifer, 2012).

To optimize the production of rice, scientific methods must be adopted through which the outcome of the production is predicted, this will enable proper allocation of funds, fertilizers, farm equipments and land to be used.

Kumar and Kumar (2015) compared the rule based system using fuzzy logic and the K-means algorithm for the prediction of crops yields. The two methods are then compared. Analysis of both predictions are done using the "MATLAB" software, and a valid conclusion is drawn as to which of the models is more accurate. The method is much more accurate than the prediction done by experienced farmers on the basis of assumption.

Though, there are quite a good number of prediction exercises reported in the literature (Jayaram and Marad, 2012), almost all of them are based on theory of statistics. Not much attempts seem to have been made in applying fuzzy reasoning in building input–output

*Author for Correspondence

mappings related to crop yield estimation. Therefore, the intent of this work is set to apply the fuzzy inference system architecture for rice yield estimation.

BACKGROUND OF THE RESEARCH

If X is a collection of objects x, then a fuzzy set A in X is defined as a set of ordered pairs:

$$A = \{(x, \mu_A(x)), x \in X\},$$

where $\mu_A : X \to [0,1]$ is called the membership function (MF) for the fuzzy set A and $\mu_A(x) \in [0,1]$ is the grade of membership of x in A.

Fuzzy modelling is the standard method for constructing a fuzzy inference system (FIS). In general, we design a fuzzy inference system based on the past known behavior of a target system (Ross, 2010).

The most commonly used fuzzy inference technique is the so-called Mamdani method (Passino and Yurkovich, 1998). The Mamdani-style fuzzy inference process is performed in four steps: Fuzzification of the input variables, Rule evaluation (inference), Aggregation of the rule outputs (composition), and Defuzzification. The FIS used in this study is the Mamdani model and is built based on input and output variables with their respective membership functions and linguistic variables; the system follows a set of fuzzy membership rules after which a model is created using MATLAB.

Monthly rainfalls in (mm) data were sourced from Jigawa State Agricultural and Rural Development Agency (JARDA), Dutse office. JARDA had been the only agency responsible for the collection and compilation of rainfall and agricultural data for over twenty (20) years in the state with weather stations in almost all the 27 local governments' area.

Algorithm for Forecasting Rice Production

In this work, a fuzzy inference system for production of rice is designed and the implementation is done on MATALB using the following steps:

1. Open MATLAB and type fuzzy on command window (Fig. 1),
2. Create a fuzzy inference system variable. In this case, rainfall and area as input and forecast as output (Fig. 2).
3. In this step, the linguistic variables are clearly defined and each linguistic variable defined is assigned to its fuzzy set, i.e., rainfall, area and production. Table 1, table 2 and table 3 gives the linguistic variables with its respective fuzzy sets.
4. Create the membership function by the use of triangular membership function (Fig. 3, fig. 4 and fig. 5). The function uses a range of three values; lower limit, mid-point, and upper-limit.
5. Rule editor and viewer. The rule editor as shown in fig. 6 contains rules inputted based on the application of the FIS. The rules can be changed using the change button, deleted and also new rules can be added. The rules added are joined by either AND or OR operator.

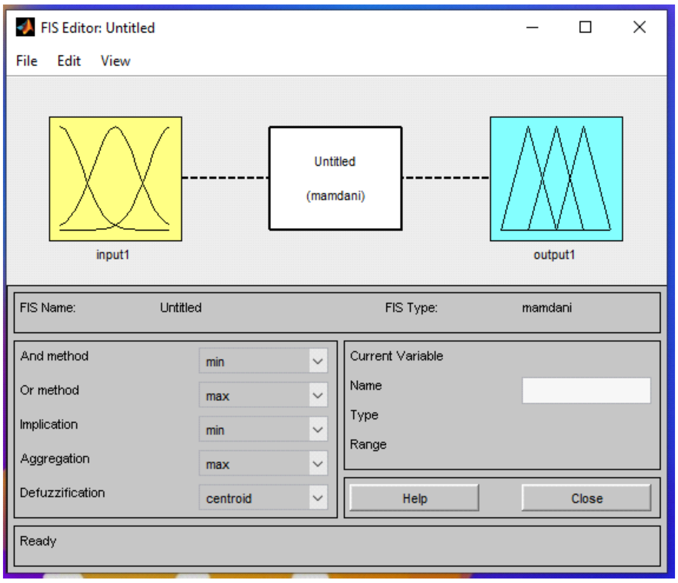

Figure 1: Fuzzy inference system on command window

Table 4 offers an explanation as to how the maximum and minimum value for each linguistic variable is defined. After the maximum and minimum value has been defined, a mid-point is found for each linguistic variable which is now applied to the fuzzy inference system.

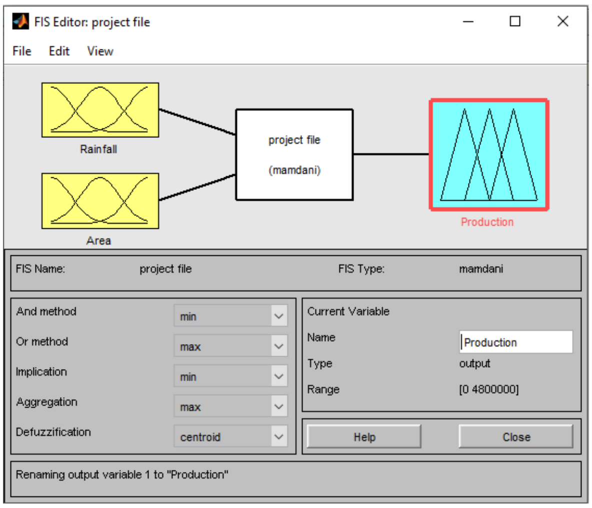

Figure 2: Fuzzy inference system variables

Table 1: Linguistic variables for rainfall

Rainfall	Extremely light
	Light
	Below Moderate
	Moderate
	Rather Heavy
	Heavy
	Very Heavy

Table 2: Linguistic variables for area

Area	Extremely less
	Very less
	Less
	Less than average
	Average
	Good
	Very good

Table 3: Linguistic variables for production

Production of Rice	Extremely low
	Very low
	Low
	Less than average
	Average
	Above average
	Good
	Very good
	Extremely good

Table 4: Input variables

INPUT	AMOUNT	MIN-VALUE	MAX-VALUE
Rainfall	Extremely light	0	228.5
	Light	229	457
	Below Moderate	458	685.5
	Moderate	686	914
	Rather heavy	915	1142.5
	Heavy	1143	1371
	Very heavy	1372	1600
Area	Extremely less	0	57144
	Very less	57145	114288
	Less	114289	171432
	Less than average	171432	228576
	Average	228577	285720
	Good	285721	342864
	Very good	342864	400011

Table 5: Output data

OUTPUT	AMOUNT	MIN-VALUE	MAX-VALUE
Production	Extremely low	0	46667
	Very low	46668	93334
	Low	93335	140001
	Less than average	140002	186668
	Average	186669	233335
	Above average	233336	280002
	Good	280003	326669
	Very good	326670	373336
	Extremely good	373337	420000

Membership Function

The membership function (MF) is a curve that shows the mapping of data input points into membership values that have an interval between 0 and 1. One way that can be used to get membership value is through a functional approach (Wawan *et al*, 2021). A fuzzy set is completely characterized by its MF. In case of a single linguistic variable the MFs are one-dimensional and combining the universes of different linguistic variables, MFs of higher dimensions may be derived.

In this work, the triangular MF is applied using MATLAB. A triangular MF, μ(x) is a function of a vector x, and specified by three parameters $\{a, b, c\}$ as follows:

$$\mathrm{f}(x,a,b,c)=\begin{cases} 0, & x \le a \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ \dfrac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases}$$

It may also be described by min and max as

$$triangle(x,a,b,c)=\max(\min(\frac{x-a}{b-a},\frac{c-x}{c-b}),0)$$

The parameters a and c locate the "feet" of the triangle and b its peak. Triangular-shaped built-in membership function in the software MATLAB is used as shown:.

Matlab sytanx: y = trimf(x,params)

y = trimf(x,[a b c])

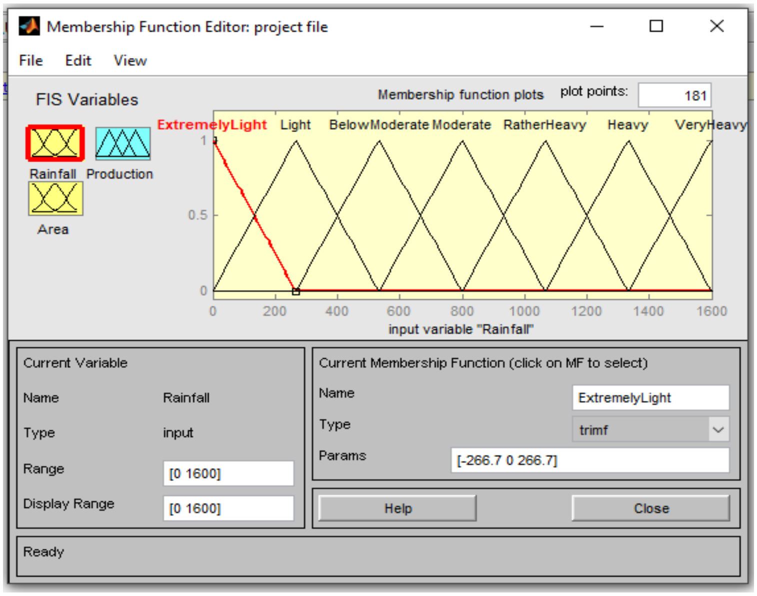

Figure 3: The membership function of rainfall

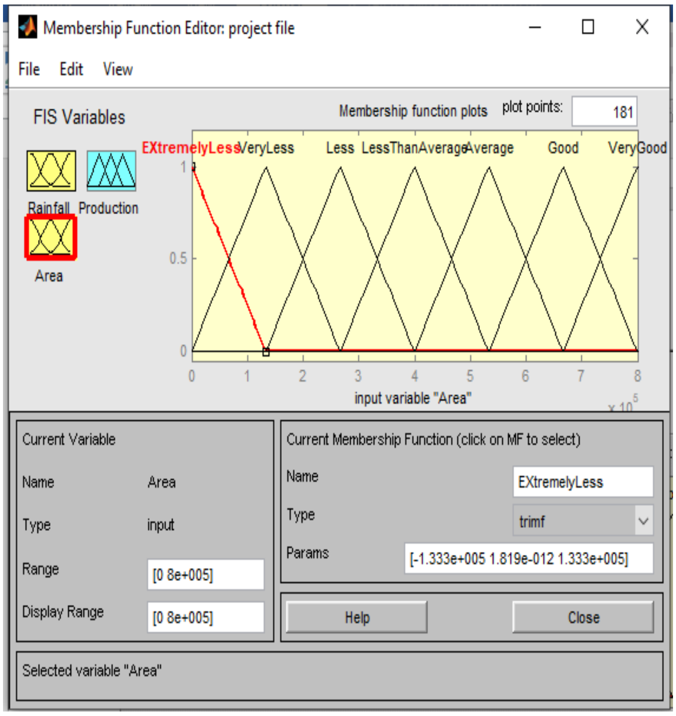

Figure 4: The membership function for Area

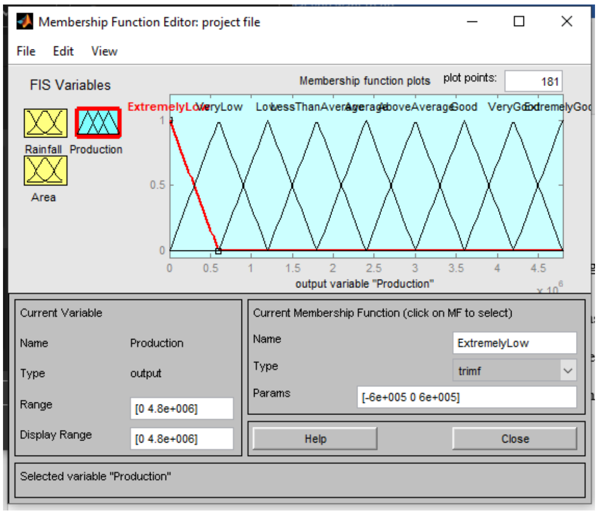

Figure 5: The membership function for rice production

There are 49 rules used in the FIS as listed below and demonstrated in fig. 6.

i. If rainfall is extremely low and area is extremely less, then production is very low,
ii. If rainfall is moderate and area is average then production is above average,
iii. If rainfall is heavy and area is good then production is very good and so on.

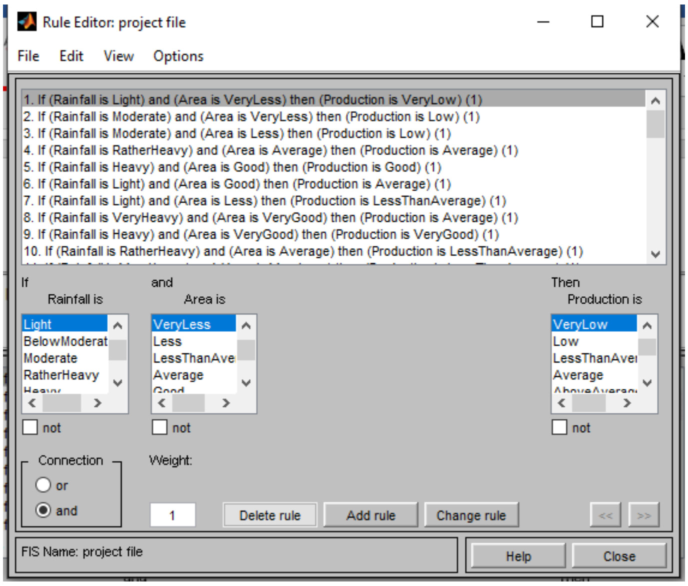

Figure 6: The rule editor

Rule viewer allows the input to see the effect of each input on the output based on the rules inputted which gives the defuzzified results (production of rice).
The rules used in the system are given as follows:

#	RULES
1	If (Rainfall is Light) and (Area is VeryLess) then (Production is VeryLow)
2	If (Rainfall is Moderate) and (Area is VeryLess) then (Production is Low)
3	If (Rainfall is Moderate) and (Area is Less) then (Production is Low)
4	If (Rainfall is RatherHeavy) and (Area is Average) then (Production is Average)
5	If (Rainfall is Heavy) and (Area is Good) then (Production is Good)
6	If (Rainfall is Light) and (Area is Good) then (Production is Average)

7	If (Rainfall is Light) and (Area is Less) then (Production is LessThanAverage)
8	If (Rainfall is VeryHeavy) and (Area is VeryGood) then (Production is Average)
9	If (Rainfall is Heavy) and (Area is VeryGood) then (Production is VeryGood)
10	If (Rainfall is RatherHeavy) and (Area is Average) then (Production is LessThanAverage)
11	If (Rainfall is VeryHeavy) and (Area is VeryLess) then (Production is LessThanAverage)
12	If (Rainfall is Heavy) and (Area is Less) then (Production is Low) (1)
13	If (Rainfall is Light) and (Area is VeryGood) then (Production is VeryLow)
14	If (Rainfall is VeryHeavy) and (Area is Average) then (Production is Low)
15	If (Rainfall is VeryHeavy) and (Area is Good) then (Production is Average)
16	If (Rainfall is RatherHeavy) and (Area is VeryGood) then (Production is Average)
17	If (Rainfall is Light) and (Area is VeryLess) then (Production is VeryLow)
18	If (Rainfall is Light) and (Area is Average) then (Production is LessThanAverage)
19	If (Rainfall is RatherHeavy) and (Area is Average) then (Production is Average)
20	If (Rainfall is Heavy) and (Area is Less) then (Production is LessThanAverage)
21	If (Rainfall is ExtremelyLight) and (Area is EXtremelyLess) then (Production is ExtremelyLow)
22	If (Rainfall is ExtremelyLight) and (Area is VeryLess) then (Production is ExtremelyLow)
23	If (Rainfall is ExtremelyLight) and (Area is LessThanAverage) then (Production is VeryLow)
24	If (Rainfall is ExtremelyLight) and (Area is Less) then (Production is Low)
25	If (Rainfall is BelowModerate) and (Area is Less) then (Production is LessThanAverage)
26	If (Rainfall is BelowModerate) and (Area is Average) then (Production is LessThanAverage)
27	If (Rainfall is BelowModerate) and (Area is Good) then (Production is Average)
28	If (Rainfall is VeryHeavy) and (Area is EXtremelyLess) then (Production is ExtremelyLow)
29	If (Rainfall is VeryHeavy) and (Area is VeryLess) then (Production is VeryLow)
30	If (Rainfall is VeryHeavy) and (Area is Less) then (Production is Low)
31	If (Rainfall is VeryHeavy) and (Area is LessThanAverage) then (Production is Average)
32	If (Rainfall is VeryHeavy) and (Area is Average) then (Production is AboveAverage)
33	If (Rainfall is VeryHeavy) and (Area is Good) then (Production is VeryGood)
34	If (Rainfall is VeryHeavy) and (Area is VeryGood) then (Production is ExtremelyGood)
35	If (Rainfall is Heavy) and (Area is ExtremelyLess) then (Production is ExtremelyLow)
36	If (Rainfall is Heavy) and (Area is VeryLess) then (Production is VeryLow)
37	If (Rainfall is Heavy) and (Area is VeryGood) then (Production is VeryGood)

38	If (Rainfall is Moderate) and (Area is LessThanAverage) then (Production is Average)
39	If (Rainfall is Moderate) and (Area is Average) then (Production is AboveAverage)
40	If (Rainfall is Moderate) and (Area is Good) then (Production is Good)
41	If (Rainfall is RatherHeavy) and (Area is EXtremelyLess) then (Production is ExtremelyLow)
42	If (Rainfall is RatherHeavy) and (Area is VeryLess) then (Production is VeryLow)
43	If (Rainfall is RatherHeavy) and (Area is LessThanAverage) then (Production is AboveAverage)
44	If (Rainfall is RatherHeavy) and (Area is Average) then (Production is Good)
45	If (Rainfall is Heavy) and (Area is LessThanAverage) then (Production is Average)
46	If (Rainfall is Heavy) and (Area is Average) then (Production is Good)
47	If (Rainfall is Heavy) and (Area is Good) then (Production is VeryGood)
48	If (Rainfall is VeryHeavy) and (Area is VeryGood) then (Production is ExtremelyGood)
49	If (Rainfall is VeryHeavy) and (Area is VeryGood) then (Production is ExtremelyGood)

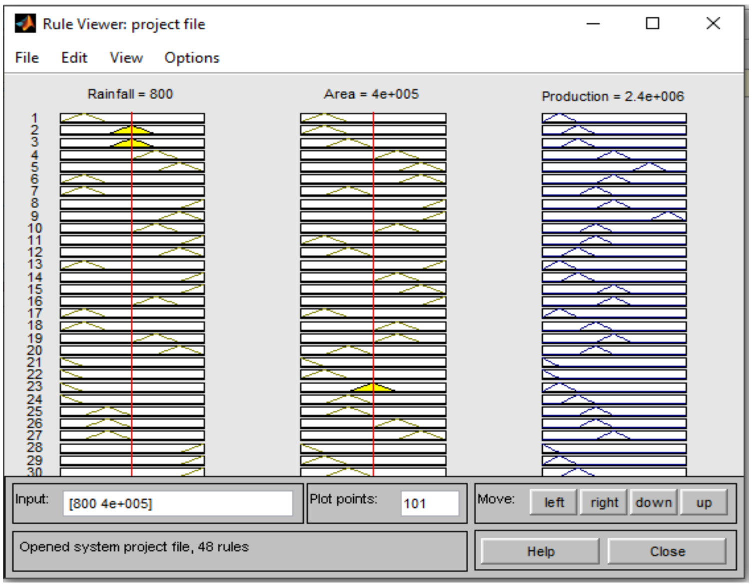

Figure 7: Rule viewer

The rule editor as shown in the figure 6 gives the prediction (forecast) for the rice production while simultaneously recommending the quantity of rainfall (water) to be applied on the provided area to ensure the forecasted value is achieved with minimum errors.

RESULTS AND DISCUSSION

The estimated cultivated area for rice in 2020 in Jigawa state was 117950Ha, which represented an increase of about 2.24% over the 113150 Ha cultivated in 2019(NAERLS AND FMARD, 2020).This area cultivated in the year 2020 was used in the FIS to generate the land area required in the subsequent years and the corresponding rice yields up to 2030. The result from the implementation of the fuzzy inference system is shown in table 6.

Table 6: Recommended rainfall and Rice production

Year	Area(ha)	Rainfall (mm)	Production (tons)
2020	117950	727	756000
2021	147950	844	826000
2022	177950	873	1070000
2023	207950	888	1340000
2024	237950	932	1420000
2025	267950	1108	1660000
2026	297950	1138	1770000
2027	327950	1152	1980000
2028	357950	1182	2190000
2029	387950	1314	2390000
2030	417950	1343	2550000

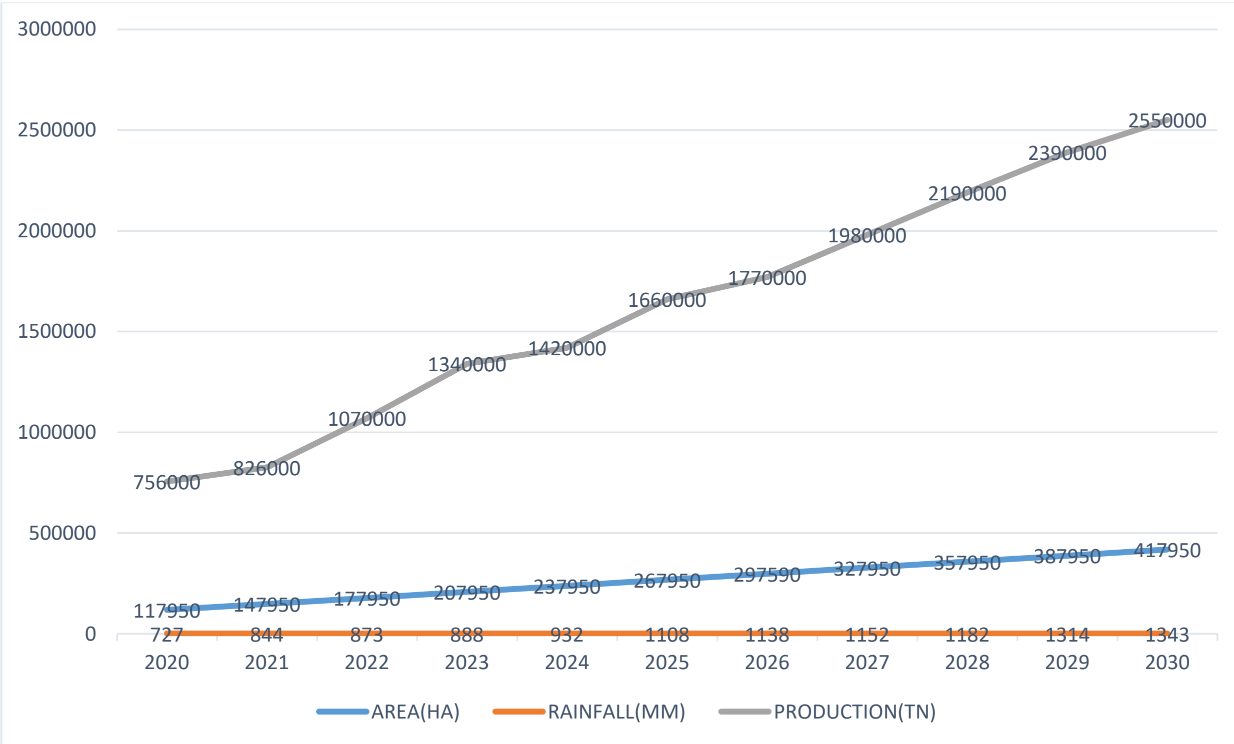

Figure 8: Relationship between rainfall, area and Rice production

Table 6 and graph in Figure 8 depicts the relationship between rainfall, area and rice production for a period 2020 to 2030.

It is shown that a farmer is required to get 727mm of rainfall on 117950 ha of land in order to obtain a yield of 7560000 TN of rice in the year 2020. If 147950 ha of land have been cultivated, 844mm of rainfall is required for the area in order to obtain 826000TN of rice for 2021. In 2022, 177950ha is required with 873mm of rainfall to produce1070000TN of rice. Similarly, prediction is made of the required area, rainfall and rice yield for up to 2030 in Jigawa state.

CONCLUSION

This research presents application of FIS for analysis of yield of rice. It is aimed at achieving the prediction of rice production in Jigawa state from 2021-2030.The rice data set is initially processed and the crisp values are converted into fuzzy values in the stage of fuzzification. The FIS then executes rules to make a decision on yield of rice. Finally defuzzification is adopted to convert the fuzzy output set to a crisp output.

It is important to note that fuzzy logic applications hold potentials in agricultural operations. Most significant is the application of fuzzy logic in rice production under non-deterministic or stochastic environment. The uncertainties arise from difficulties of obtaining data, errors in measurement, imprecision or vagueness. In general, fuzzy sets theory is a very useful technique to increase effectiveness and efficiency of forecasting. The conventional time series is not applicable when the variable of time series are words variables (.i.e. variables with linguistic terms).

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