Fuzzy time series forecasting of wheat production

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Abstract: The present study provides a foundation for the development and application of fuzzy time series model for short term agricultural production forecasting. The present study can provide an advantageous basis to Farm administration for better post harvest management and the local industries in planning for their raw material requirement management. The fuzzy time series forecasting can be optimally utilized in agri-business management.

Keywords: Fuzzy time series; high-order model; forecasts; fuzzy relationship; linguistic value.

I. INTRODUCTION

The present work is to develop time invariant fuzzy time series models and its implementation testing for forecasting of wheat crop production. The scope of the work is limited to provide computational framework for improved fuzzy time series forecasting, when there is some content of vagueness and imprecision. The major objective of present work is to provide practical computational techniques having simple algorithm with output at higher degree of accuracy. The historical time series data used for present study have been collected from the Farm of G. B. Pant University of Agriculture and Technology, Pantnagar, (U.S. Nagar), INDIA, for the period 1981 to 2002.
The objectives of the present work are:

1. To build, implement and test the time invariant fuzzy time series models for forecasting.
2. Application of developed models for the forecasting the yield wheat crop.
3. Comparison of the results of various forecasting models.

The motivation of applying the fuzzy time series forecasting models is to find ways of modeling the prediction of crop yield, a real non-deterministic process. Further, the area specific crop yield forecasting for a lead year may be applied to help the crop planning and agro based business planning of the area and can be used in economics and business analysis.

1.1. REVIEW OF FUZZY SET THEORY AND FUZZY TIME SERIES

A. Fuzzy Set Theory

In the fuzzy set concept, the membership of an individual in a fuzzy set is a matter of degree [4]. A function, called a membership function, assigns to each element a number in the closed unit interval (0,1) that characterizes the degree of membership of the element.
While classical relations describe solely the presence of association between elements of two sets, fuzzy relations are capable of capturing the strength of association.

B. Fuzzy Time Series

In this study, the fuzzy relationship will be employed to model fuzzy time series. In this approach, the values of fuzzy time series are fuzzy sets [4]. And, there is a relationship between the observations at time t and those at previous times. To develop fuzzy relations among the observations at different times of interests.
This section is concerned with development of algorithms for computational procedures required in fuzzy time series forecasting. The models have been developed using three fuzzy time series techniques, namely Chen's type arithmetic model[2], modified weighted average model and fuzzy time series: time invariant model[3]. The developed models have been fine tuned and implemented in view of its application domain. The models tuning and application have been studied in three different cases, in which forecasting have been done for the agricultural production based on time series data.
The time series data used for the study belong to the University farm of G.B.Pant University of Agriculture and Technology, Pantnagar, INDIA and have been obtained through the courtesy of farm administration of the University for scientific uses. The agricultural production database used in the study is the time series data of twenty one years starting from 1981-82 to 2001-02 for the wheat crop.

C. Fuzzy time series production forecasting Algorithm

The development of fuzzy time series forecasting models and there implementation can be made with the following steps:

1. Define the universe of discourse with given time series data on which fuzzy sets are to be defined.
2. Partitioning the universe of discourse into several even length intervals.
3. Define the fuzzy sets (linguistic variables) on universe of discourse.
4. Fuzzification of time series data for fuzzy input
5. Computing the fuzzy relationships.
6. Computing the forecasted production (fuzzy out put).
7. Defuzzification of fuzzy out put for crisp forecasting.

II. FORECASTING WHEAT PRODUCTION

2.1 Computational Procedures

The implementation of the above algorithm for the production forecasting of the wheat crop is based on the 21 years (1981-82 to 2001-2002) time series production data of the University farm.

Step 1. Define the universe of discourse to accommodate the time series data. It needs the minimum and maximum production and set as D_{min} and D_{max}.

Thus universe of discourse U is defined as [$D_{min} – D_1$, D_{max} - D_2], here D,

and D_2 are two proper positive numbers. In the present case of production

forecasting universe of discourse computed is U = [1400 - 3500]

Step 2. Partition the universes of discourse into 7 equal length intervals

$U_1, U_2, ..., U_7$ such that

U_1 = [1400-1700],

U_2=[1700-2000],

U_3=[2000-2300],

U_4=[2300-2600],

U_5= [2600-2900],

U_6=[2900-3200],

U_7=[3200-3500].

Step 3. Define 7 fuzzy sets $A_1, A_2, ..., A_7$ having some linguistic values on

the universe of discourse U . The linguistic values to these fuzzy variables are as follows:

A_1: poor production,

A_2: below average production

A_3: average production

A_4: good production

A_5: very good production

A_6: excellent production

A_7: bumper production

These fuzzy sets in terms of its membership to different intervals are expressed as follows:

A_1 :[$1/u_1,.5/u_2,0/u_3,0/u_4,0/u_5,0/u_6,0/u_7$]

A_2 :[$.5/u_1,.l/u_2,.5/u_3,0/u_4,0/u_5,0/u_6,0/u_7$]

A_3 :[$0/u_1,.5/u_2,l/u_3,.5/u_4,0/u_5,0/u_6,0/u_7$]

A_4 :[$0/u_1,0/u_2,.5/u_3,1/u_4,.5/u_5,0/u_6,0/u_7$]

A_5 :[$0/u_1,0/u_2,0/u_3,.5/u_4,l/u_5,.5/u_6,0/u_7$]

A_6 :[$0/u_1,0/u_2,0/u_3,0/u_4,.5/u_5,l/u_6,.5/u_7$]

A_7:[$0/u_1,0/u_2,0/u_3,0/u_4,0/u_5,.5/u_6, l/u_7$]

Step 4. Fuzzification of the time series data for the fuzzy input to the models are obtained as in table 1.

Step 5. The fuzzy logical relations have obtained from the table 1 are in table 2:

The fuzzy time invariant relation R from 15 logical relations of table 2 can be obtained as:

R = *U* R_i, here *U is* the Union operator Where as the computations of R_i (i=l, 2,...., 15) are carried out by "IF...THEN" with the procedure:

If sets A and B are row vectors of order p and the logical relation between them is such that A → B , then fuzzy relation Ri is obtained in form of a matrix C= $A^T \times B$ of dimension P X P, here Cij = min (Ai,Bj); (i, j = 1,………,P).

Thus computing all the fuzzy logical relations R_1 ,....,R_{15} and taking the union of these computed relations, we obtain a fuzzy time invariant relation R as :

$$R=\begin{Bmatrix} 0 & .5 & 1 & .5 & 0 & 0 & 0 \\ 0 & .5 & .5 & .5 & .5 & .5 & .5 \\ 0 & 0 & .5 & .5 & 1 & 1 & .5 \\ 0 & .5 & .5 & 1 & 1 & .5 & .5 \\ 0 & .5 & 1 & 1 & 1 & 1 & 1 \\ .5 & .5 & .5 & 1 & .5 & .5 & 1 \\ 1 & .5 & 1 & .5 & 1 & .5 & .5 \end{Bmatrix}$$

Step 6:-Computation of fuzzy forecast of the crop production have been carried

by the three models: Chen's arithmetic model (Model-1) , refined arithmetic model (Model-2) and Song and Chissom model (Model-3) Computation of fuzzy forecast of the crop production has been carried as follows:-

Model-1

(1)If the fuzzified production of the year i is Aj , and there is only one fuzzy logical relationship in the fuzzy logical relationship groups in Table 3 in which the current state of the production is Aj , then the fuzzy forecasted production of the year i+ 1 is Aj .

(2)If the fuzzified production of the year i is Aj and there are fuzzy logical relationships in the fuzzy logical relationship group as:

Aj → A_ki, Aj → A_ki ... Aj → A_kp, the Aj forming a relation with A_{k1}

, A_{k2},....., Akp is the fuzzy forecasted production for the year i+1

Model-2

Similar to model-1 but it also counts the repeated relations as shown in Table 2 and the frequency is recorded and is used for defuzzification (crisp output).

Model-3

It uses the fuzzy time invariant relation R computed in step 5. If A_{i-1} is the production of the year i-1 , the fuzzy forecasted production for the year i will be A_i and will be computed by $A_i = A_{i-1} \text{ o } R$.

Step 7. Defuzzification is the process by which fuzzy output of model is transformed to crisp values for getting the forecasted values. The output of the model is defuzzified in the following ways:-

Model-1

(1) If the production of the year i is Aj, and fuzzy logical relation is Aj→A_k and A_k has max membership in interval U_k , then the forecasted production for the year i = l will be midpoint of A_k.

(2)If the fuzzified production of the year i is Aj, and there are fuzzy logical relationships in the fuzzy logical relationship group as:

Aj → A_{k1}, Aj → A_{k1},.....Aj →A_{kp}

A_{k1}, A_{k1} ,..... , A_{kp} has max membership in the intervals U_{k1}, Uk2,….., Ukp

respectively and m1 , m2 ,....mp are their respective midpoints , then the forecasted production for the year i+1 will be (m1 + m2+…..+mp)/p .

(3)If the fuzzified production of a year i is *Aj,* and no logical relationship is

found in logical relationship groups, whose current state of production is Aj ,where the maximum membership value of Aj occurs at interval U*j* and the midpoint of Uj is m_i then the forecasted production of year i+1 is m_i.

Model-2

Similar procedures of defuzzification as in model-1 with additional concept of repeated relations and according weighted mean is computed keeping in view of their frequencies.

Model-3

A combined approach is proposed to have the defuzzification of the fuzzy output

into crisp output. The rules are as follows;

(1) If fuzzy output set has only one max, then choose the mid point of the interval corresponding to that max as forecasted production.

(2) If the fuzzy output has only one consecutive max, then choose the midpoint of the corresponding conjunct interval as the forecasted value.

(3) If more than one non consecutive max and that lies in min set and in max set then choice will depend on the previous year production. If previous year production is closer to min set then select the min set and vice-versa.

(4) If the rule 3 is not applied and other type of non consecutive max appear in fuzzy output then compute the weight function w_f for selection

First weight function :

W_{f1}= Max [min (U_i, Ui_{-1}) + min (U_i, Ui_{+1})]

The set with higher W_{f1} will be selected.

If first weight function is equal, compute the second weight function

W_{f2} = Min [min (U_i ,U_{i-2}) + min (U_i ,U_{i+2})]

The set with lower W_{f2} will be selected.

(5) If there occurs a consecutive max followed by another relative consecutive max, compute the weighted mean of the means of two streams of max and relative max.

(6) Otherwise compute the forecasted value by computing the average of all max intervals.

III. RESULTS AND DISCUSSIONS

Forecasting Wheat production

Model 1

The fuzzy logical relations obtained for the case of wheat production are placed in table 3 and the production forecast of wheat obtained have been placed in table 5.

Table 1 Fuzzification of time series data of wheat production

Year	Production Kg/hect.	A_1	A_2	A_3	A_4	A_5	A_6	7	Fuzzified production
81-82	2730	0	0	.2	.7	1	.5	0	A_5
82-83	2957	0	0	0	.3	.8	1	.5	A_6
83-84	2382	0	.3	.8	1	.5	0	0	A_4
84-85	2572	0	0	.5	1	.8	.3	0	A_4
85-86	2642	0	0	.3	.8	1	.5	0	A_5
86-87	2700	0	0	.2	.7	1	.5	0	A_5
87-88	2872	0	0	0	.5	1	.8	.3	A_5
88-89	3407	0	0	0	0	.3	.5	1	A_7
89-90	2238	0	.5	1	.8	.3	0	0	A_3
90-91	2895	0	0	0	.5	1	.8	1	A_5
91-92	3276	0	0	0	0	.3	.8	1	A_7
92-93	1431	1	.5	.2	0	0	0	0	A_1
93-94	2248	0	.5	1	.8	.3	0	0	A_3
94-95	2857	0	0	0	.5	1	.8	.3	A_5
95-96	2318	0	.3	.8	1	.5	0	0	A_4
96-97	2617	0	0	.3	.8	1	.5	0	A_5
97-98	2254	0	.5	1	.8	.3	0	0	A_3
98-99	2910	0	0	0	.3	.5	1	.8	A_6

99-00	3434	0	0	0	0	.3	.5	1	A_7
00-01	2795	0	0	0	.5	1	.8	.2	A_5
01-02	3000	0	0	0	0	.6	1	.3	A_6

Table 2 Fuzzy logical relationship groups

1. $A_1 \rightarrow A_3$
2. $A_3 \rightarrow A_5$ $A_3 \rightarrow A_5$ $A_3 \rightarrow A_6$
3.$A_4 \rightarrow A_4$ $A_4 \rightarrow A_5$ $A_4 \rightarrow A_5$
4.$A_5 \rightarrow A_3$ $A_5 \rightarrow A_4$ $A_5 \rightarrow A_5$ $A_5 \rightarrow A_5$ $A_5 \rightarrow A_6$ $A_5 \rightarrow A_7$ $A_5 \rightarrow A_7$ 5.$A_6 \rightarrow A_4$
$A_6 \rightarrow A_7$
6.$A_7 \rightarrow A_1$ $A_7 \rightarrow A_3$ $A_7 \rightarrow A_5$

Table 3 Fuzzy logical relationship groups without repetition

1. $A_1 \rightarrow A_3$
2. $A_3 \rightarrow A_5$ $A_3 \rightarrow A_6$
3. $A_4 \rightarrow A_4$ $A_4 \rightarrow A_5$
4. $A_5 \rightarrow A_3$ $A_5 \rightarrow A_4$ $A_5 \rightarrow A_5$ $A_5 \rightarrow A_6$ $A_5 \rightarrow A_7$
5. $A_6 \rightarrow A_4$ $A_6 \rightarrow A_7$
6. $A_7 \rightarrow A_1$ $A_7 \rightarrow A_3$ $A_7 \rightarrow A_5$

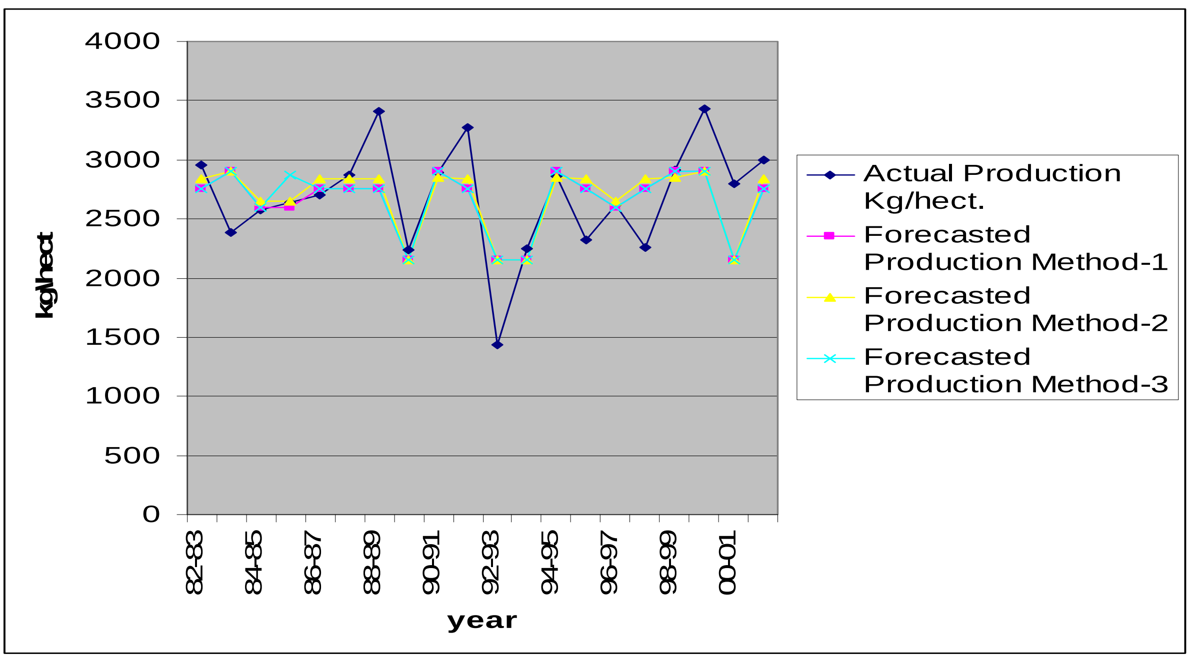
Table 4: fuzzy output of wheat forecasting

Year	$\mathbf{A_1}$	$\mathbf{A_2}$	$\mathbf{A_3}$	$\mathbf{A_4}$	$\mathbf{A_5}$	$\mathbf{A_6}$	$\mathbf{A_7}$
82-83	.5	.5	1	1	1	1	1
83-84	.5	.5	.8	1	.8	.8	1
84-85	0	.5	.5	1	1	.8	.5
85-86	.3	.5	.8	1	1	.8	.8
86-87	.5	.5	1	1	1	1	1
87-88	.5	.5	1	1	1	1	1
88-89	.5	.5	1	1	1	1	1
89-90	1	.5	1	.5	1	.5	.5
90-91	0	.5	.5	.8	1	1	.5
91-92	.5	.5	1	1	1	1	1
92-93	1	.5	1	.8	1	.5	.8
93-94	0	.5	1	.5	.5	.5	.5
94-95	0	.5	.5	.8	1	1	.5
95-96	.5	.5	1	1	1	1	1
96-97	0	.5	.5	1	1	.8	.5
97-98	.5	.5	1	1	1	1	1
98-99	0	.5	.5	.8	1	1	.5
99-00	.8	.5	.8	1	.8	.5	1
00-01	1	.5	1	.5	1	.5	.5
01-02	.2	.5	1	1	1	1	1

Table 5: Wheat production forecast

Year	Actual Production Kg/hect.	Forecasted Production Model-1	Forecasted Production Model-2	Forecasted Production Model-3
82-83	2957	2750	2836	2750
83-84	2382	2900	2900	2900
84-85	2572	2600	2650	2600
85-86	2642	2600	2650	2867
86-87	2700	2750	2836	2750
87-88	2872	2750	2836	2750
88-89	3407	2750	2836	2750
89-90	2238	2150	2150	2150
90-91	2895	2900	2850	2900
91-92	3273	2750	2836	2750
92-93	1431	2150	2150	2150
93-94	2248	2150	2150	2150
94-95	2857	2900	2850	2900
95-96	2318	2750	2836	2750
96-97	2617	2600	2650	2600
97-98	2254	2750	2836	2750
98-99	2910	2900	2850	2900
99-00	3434	2900	2900	2900
00-01	2795	2150	2150	2150
01-02	3000	2750	2836	2750

Figure1:-Fuzzy time series forecasting of wheat production



Model 2

The fuzzy logical relations obtained for the case of wheat production are placed in table 2 and using the weighted mean type defuzzification discussed in step 6 for the case of wheat production the forecasted vales for the wheat production are placed in Table 5.

Model 3

The fuzzy output of the time series forecasting by Model 3 for the wheat production are given in Table 4 and applying the defuzzification method as discussed in step 7 to the fuzzy output in Table 4, we get the crisp forecast and is presented in table 5.

In case of Wheat production, all the three models provide similar forecast. The forecasted values from model-1 and model-3 are in close agreement with each other, where as the models-2 exhibits some variation with the two models and which can be visualized in Fig. 1. The testing of these three models shows that all the three models under study provide forecast with an average error of about 11%. The Mean Square Error (MSE) for model-1, model-2 and model-3 are 138458, 135105 and 140901 respectively

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