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Comparative analysis of FTSM for predicting agricultural crop yield

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Abstract
For the agriculture based country like India, crop production is of immense importance. The good production is not enough as post production it requires a lot of planning like storage, management, distribution etc. If farmers and agro business based companies get some approximately advanced information regarding the future production then it will be of great help. In this paper a comparative study is conducted for fuzzy time series models for production forecasting of rice using twenty years data of agriculture farms of GBPUA&T, Pantnagar, India. These models are strictly examined on the basis of errors. The study will provide a base for the small area production forecast.

Keywords: Crop production, error estimation, fuzzy logical relations (FLR), fuzzy sets (FS), fuzzy time series model (FTSM), time invariant series (TIS)

1. Introduction

FS theory is an interesting tool in which mathematical abstraction and idealization are combined. When Zadeh [15] introduced the concept of FS, Mamdani [5] used this concept and applied to approximate reasoning. Wu [13] provided a study based on FLR equations. Duboi and Parde [4] in his study used possibility distributions and Fuzzy Sets. Song and Chissom [9-11] in his famous, the most used and applied model to predict University enrolments. This study became a landmark in forecasting models. Chen [2] used arithmetic operations for defuzzification and presented a simplified method. Chen and Mao-Juin [3] discussed in details the forecasting methods with the help of fuzzy concepts. Yu [14] proposed a refined FTSM for forecasting. Ravi, Vadlamani and Prasad [8] applied the concepts of FS to financial services analysis based on opinion mining. Bose and Mali [1] presented a method for modelling high order FTS by using data partitioning and rule selection techniques. Rana [6] presented a study for FTS models for forecasting rice production. Vovan [12] studied and proposed an improved FTS forecasting model using data variations. The nested interval based FTS model by Rana [7] was tested for fish production forecasting in India In the present paper author studied the development and application of the time invariant FTSM to predict the rice production which is a non-linear process and contains the data which is in general contains vagueness and imprecision.

2. Fuzzy Time Series

Definition 2.1 Define a FS A as

$$A = \sum \frac{f_A(u_i)}{u_i}, i = 1,2, \dots . n \quad (1)$$

Definition 2.1 Let $F(t) = \{f_i(t), i = 1.2 \dots .\}$ is called FTS defined on $U(t), (t = 0,1,2, \dots .)$
Definition 2.2 If $F(t)$ is resulted by either $F(t-1)$ only or by $F(t-2)$ or $F(t-3)$ or….. $F(t-m), m > 0$ then fuzzy relational equation can be expressed as

$$F(t) = F(t-1)^\circ R(t, t-1) \text{ can be expressed as} \quad (2)$$

And is called first order model of $F(t)$ is

$F(t) = F(t-1) \cup F(t-2) \cup F(t-3) \cup \dots \dots F(t-m) {}^\circ R_0(t, t-m)$ (3)

Definition2.3 $F(t)$ is resulted by $F(t-1)$, $F(t-2)$,$F(t-3)$….. $F(t-m), m > 0$ simultaneously. This fuzzy relational equation (4) is called m^{th} order model.

$$F(t) = F(t-1) * F(t-2) * F(t-3) * \dots \dots F(t-m) {}^\circ R_a(t, t-m) \quad (4)$$

Definition 2.4 If $R(t_1, t_1-1) = R(t_2, t_2-1)$, or $R_0(t_1, t_1-m) = R_0(t_2, t_2-m)$ or $R_a(t_1, t_1-m) = R_a(t_2, t_2-m)$, then $F(t)$ is time invariant FTS otherwise time variant FTS.

3. First Order Fuzzy Relations in Time Invariant Model

Let fuzzy relation $R_{ij}(t, t-1)$ is as $f_j(t) = f_j(t-1) {}^\circ R_{ij}(t, t-m)$ (5)

Which is equivalent to IF ….THEN rule as "IF $f_j(t-1)$ THEN $f_j(t)$ ",

$$R_i(t, t-1) \cup_{ij} R_{ij}(t, t-1) \quad (6)$$

$$R_{ij}(t, t-1) = f_i(t-1) {}^\circ f_j(t-1) \quad (7)$$

Here the operator “ ° ” is called Mamdami type max min operator and R_{ij} is first order relation.

4. FTS Algorithm

FTSM have following steps-

Step 1 Define U
Step 2 Divide U in equal sub intervals.
Step 3 Define FS
Step 4 Fuzzification
Step 5 Get FLR
Step 6 Get fuzzified output
Step 7 Defuzzification

5. Computation Process Steps

Step 1. $U = [3200 - 4600]$

Step 2. Divide U in equal sub intervals $u_1, u_2, u_3, \dots, u_7$ as
u_1 = [3200, 3400], u_2= [3400, 3600], u_3= [3600, 3800],
u_4 = [3800, 4000], u_5 = [4000, 4200], u_6 = [4200, 4400],
u_7 = [4400, 4600]

Step 3. Define FS $A_1, A_2, A_3, \dots, A_7$ for word variable “Production”

A_1: poor A_2: below average A_3: average A_4: good A_5: very good A_6: excellent A_7: bumper

FS $A_1, A_2, A_3, \dots, A_7$ with membership values are as

A_1: $[\frac{1}{u_1}, \frac{.5}{u_2}, \frac{0}{u_3}, \frac{0}{u_4}, \frac{0}{u_5}, \frac{0}{u_6}, \frac{0}{u_7}]$, A_2 : $\left[\frac{.5}{u_1}, \frac{1}{u_2}, \frac{.5}{u_3}, \frac{0}{u_4}, \frac{0}{u_5}, \frac{0}{u_6}, \frac{0}{u_7}\right]$, A_3 : $[\frac{0}{u_1}, \frac{.5}{u_2}, \frac{1}{u_3}, \frac{.5}{u_4}, \frac{0}{u_5}, \frac{0}{u_6}, \frac{0}{u_7}]$, A_4 : $\left[\frac{0}{u_1}, \frac{0}{u_2}, \frac{.5}{u_3}, \frac{1}{u_4}, \frac{.5}{u_5}, \frac{0}{u_6}, \frac{0}{u_7}\right]$,
A_5 : $\left[\frac{0}{u_1}, \frac{0}{u_2}, \frac{0}{u_3}, \frac{.5}{u_4}, \frac{1}{u_5}, \frac{.5}{u_6}, \frac{0}{u_7}\right]$, A_6 : $[\frac{0}{u_1}, \frac{0}{u_2}, \frac{0}{u_3}, \frac{0}{u_4}, \frac{.5}{u_5}, \frac{1}{u_6}, \frac{.5}{u_7}]$, A_7 : $[\frac{0}{u_1}, \frac{0}{u_2}, \frac{0}{u_3}, \frac{0}{u_4}, \frac{0}{u_5}, \frac{.5}{u_6}, \frac{1}{u_7}]$

Step 4**.** After fuzzification results are in table 1

Table 1: Rice yield data fuzzification

Year	Yield kg/hect	A_1	A_2	A_3	A_4	A_5	A_6	A_7	Fuzzified Yield
81-82	3552	.5	1	.8	.3	0	0	0	A_2
82-83	4177	0	0	0	.5	1	.9	.4	a_5
83-84	3372	1	.8	.3	0	0	0	0	A_1
84-85	3455	.8	1	.5	0	0	0	0	A_2
85-86	3702	0	.5	1	.5	0	0	0	A_3
86-87	3670	.2	.7	1	.5	0	0	0	A_3
87-88	3865	0	.2	.7	1	.5	0	0	A_4
88-89	3592	.5	1	.9	.4	0	0	0	A_2
89-90	3222	1	.5	0	0	0	0	0	A_1
90-91	3750	0	.5	1	.8	.3	0	0	A_3
91-92	3851	0	.3	.8	1	.5	0	0	A_4
92-93	3231	1	.5	0	0	0	0	0	A_1
93-94	4170	0	0	0	.5	1	.9	.4	A_5
94-95	4554	0	0	0	0	0	.5	1	A_7
95-96	3872	0	.2	.7	1	.6	.1	0	A_4
96-97	4439	0	0	0	0	.4	.9	1	A_7
97-98	4266	0	0	0	.2	.7	1	.5	A_6
98-99	3219	1	.5	0	0	0	0	0	A_1
99-00	4305	0	0	0	0	.5	1	.7	A_6
00-01	3928								

Step 5. The FLR have obtained from the above table are placed in table 2 as

Table 2: FLR of the historical rice production

$A_1 \rightarrow A_2$	$A_1 \rightarrow A_3$	$A_1 \rightarrow A_5$	$A_1 \rightarrow A_6$	$A_2 \rightarrow A_1$
$A_2 \rightarrow A_3$	$A_2 \rightarrow A_5$	$A_3 \rightarrow A_3$	$A_3 \rightarrow A_4$	$A_3 \rightarrow A_4$
$A_4 \rightarrow A_1$	$A_4 \rightarrow A_2$	$A_4 \rightarrow A_7$	$A_5 \rightarrow A_1$	$A_5 \rightarrow A_7$
$A_6 \rightarrow A_1$	$A_7 \rightarrow A_4$	$A_7 \rightarrow A_6$		

Further the FLR groups are

Table 3: FLR groups

1	$A_1 \rightarrow A_2$	$A_1 \rightarrow A_3$	$A_1 \rightarrow A_5$	$A_3 \rightarrow A_6$
2	$A_2 \rightarrow A_1$	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_5$	
3	$A_3 \rightarrow A_3$	$A_3 \rightarrow A_4$		
4	$A_4 \rightarrow A_1$	$A_4 \rightarrow A_2$	$A_4 \rightarrow A_7$	
5	$A_5 \rightarrow A_1$	$A_5 \rightarrow A_7$		
6	$A_6 \rightarrow A_1$			
7	$A_7 \rightarrow A_4$	$A_7 \rightarrow A_6$		

Using $R = \cup_{i=1}^{15} R_i$; where R is fuzzy time invariant relation.
Calculate relations $R_i, (i = 1,2, \ldots)$ by "IF...THEN" rule
If $[A]_{px1}$ and $[B]_{px1}$ are matrices and R_i is obtained as $C_{ij} = Min.(i, j = 1,2 \ldots, p)$ where $C = A^T \times B$

Thus computing all the FLR $R_1, R_2, \ldots, R_{15}$ and using $R = R_1 \cup R_2 \cup \ldots \cup R_{15}$, $R = \begin{bmatrix} .5 & 1 & 1 & .5 & 1 & 1 & .5 \\ 1 & .5 & 1 & .5 & 1 & .5 & .5 \\ .5 & .5 & 1 & 1 & .5 & .5 & .5 \\ 1 & 1 & .5 & .5 & .5 & .5 & 1 \\ 1 & .5 & .5 & .5 & .5 & .5 & 1 \\ 1 & .5 & .5 & 1 & .5 & .5 & .5 \\ .5 & .5 & .5 & 1 & .5 & 1 & .5 \end{bmatrix}$

Step 6. Fuzzy prediction Computation is done by two models.

Step 7. Defuzzified output is in table 4.

6. Predicted Yield

The predicted yield by two models is in table 4 and graphically shown in figure 1.

Table 4: Rice production forecast

Year	Actual yield kg/ha	Chen's arithmetic model	Song and Chissom's model
81-82	4177	3700	3700
82-83	3372	3900	3300
83-84	3455	3900	3600
84-85	3702	3700	3700
85-86	3670	3800	3800
86-87	3865	3800	3800
87-88	3592	3767	4000
88-89	3222	3700	3700
89-90	3750	3900	3900
90-91	3851	3800	3622
91-92	3231	3767	3758
92-93	4170	3900	3900
93-94	4554	3900	4500
94-95	3872	4100	4000
95-96	4439	3767	4000
96-97	4266	4100	3700
97-98	3219	3600	3600
98-99	4305	3900	3900
99-00	3928	3600	3600
00-01	3978	3767	4000
Forecasting Error		8.3%	6.9%
Mean Square Error		139500	102250

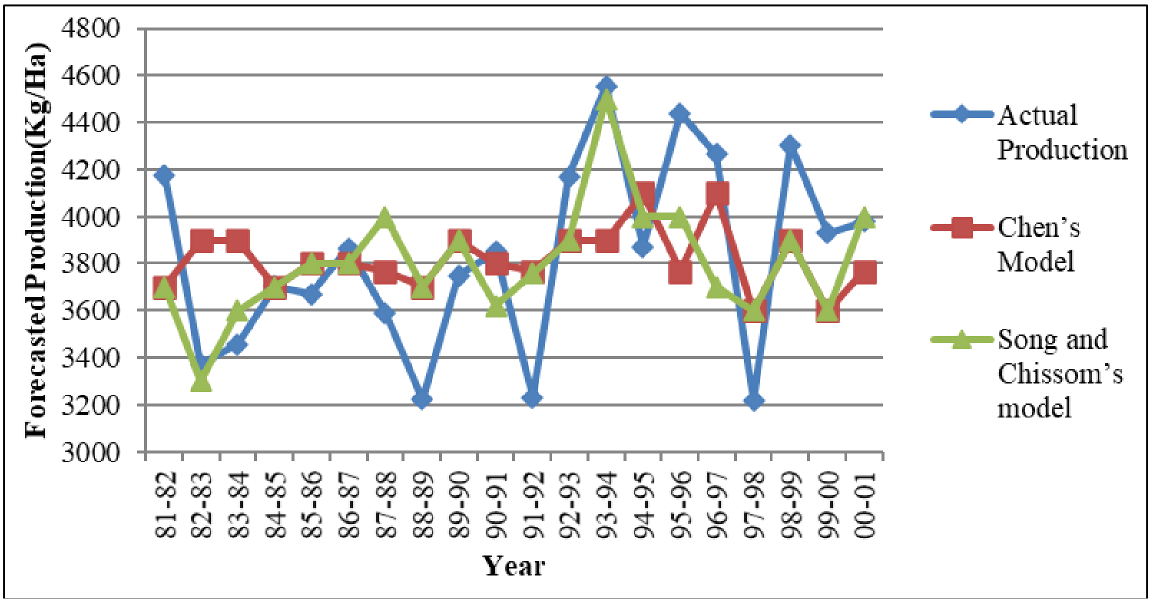

Fig 1: Comparison of forecasting of rice production

7. Conclusion

The results obtained by two FTSM are showing differences as the forecasting error is 8.3%, 6.9% for Chen's, Song and Chissom's models respectively. Also in terms of mean square errors the two models are showing MSE 139500, 102250 respectively. These results exhibits that Song and Chissom's model have an edge over the Chen's model. The present study provides an advantage in maintaining a better management and making future policies for agro based industries and farmers also. On the basis of the study carried out by the author it can be suggested that soft computing techniques such as FTS is a handy tool for such type of forecasting resulting in real life application benefiting the society.

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