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Cell : 9595 359 435, Ph No: 02172372010 Email: ayisrj@yahoo.in Website: www.isrj.org

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PREDICTION OF CROP YIELD USING WEATHER AND CLIMATE PARAMETERS FOR SUGAR CANE YIELD IN INDIA

M. Naveen Kumar[1] and M. Balakrishnan[2]
[1]Research Scholar, Research and Development Centre,Bharathiar University, Coimbatore .
[2]Senior Scientist, National Academy of Agricultural Research Management (NAARM), ICAR, Rajendra Nagar, Hyderabad.

ABSTRACT

In India, sugarcane is the key raw material for the production of sugar. Most of the sugarcane produced in India is a 10-12 month crop planted during January to March. Besides, 18 to 20 months crop is also practiced in northern Maharashtra, parts of Telangana, Tamil Nadu, Andhra Pradesh and Karnataka. Sugarcane yield in Telangana was considerably low (nearly half) compared to that of Maharashtra. The higher yield was observed in the northern districts of Telangana. The maximum yield (about 50 t/ha) was observed in Maharastra State., whereas the lowest yield (about 30t/ha) is recorded in Nizamabad district in Telangana State. The sugarcane yields ranged between 35 to 45 t/ha in the central part of the State. In Maharashtra, higher yields (about 80 to 90 t/ha) were observed in southern districts. In contrary of Telangana cane yields decreased gradually towards the northern districts of Maharashtra. Sugarcane is being cultivated throughout the country except for certain hilly tracts in Kashmir, Himachal Pradesh, etc,. The sugarcane growing areas may be broadly classified into two agro-climatic regions i.e., subtropical and tropical. The major sugarcane producing states in the sub-tropical areas include Uttar Pradesh (UP), Uttaranchal, Bihar, Punjab, and Haryana. In tropical areas of India, sugarcane is grown primarily in Telangana(TS), Maharashtra(MS), Andhra Pradesh (AP), Tamil Nadu (TN), and Gujarat(GJ).

The climatic suitability of Andhra Pradesh, India, for sugarcane crop has been talked about and the harvest climate connections for sugarcane at Anakapalle arranged in upper east Andhra Pradesh have been contemplated. The climate parameters amid the tillering period were found to have significant impact on the yield. A second-degree various relapse mathematical statement including most extreme and least temperatures and relative dampness in the third month of the product period

has been created which could be valuable for get ready yield standpoint articulations. A suitable statistical model has been developed for forecasting the yield of the sugarcane in Coimbatore district (1981-2004) using the yield data and fortnightly weather variable viz. average daily maximum and minimum temperature, relative humidity in the morning and evening and total fortnightly rainfall. The forecast model was developed using generated weather variables as regressors in model. The generated weather variables were developed using weighted accumulation of fortnightly data on weather variable, weights being the correlation coefficient of the weather variables, in respective fortnights with yield. The data for a period of (1981-2001) was used to develop the forecast model. The validation of the model was done using the data from (2002-2004).

KEYWORDS: *Generated weather variables; Weighted accumulation; Regressors; Fortnightly data; Correlation coefficient; Forecast model.*

INTRODUCTION

India, with the second largest area (about 5 million ha) under sugarcane cultivation in the world, produces largest quantity of sugar and sugarcane. Telangana and Maharashtra are the major sugarcane growing States and contribute maximum sugar production. From 1980 till 2006, irrigation coverage increased from 80% to 93 % of the total sugarcane cultivated land. Thus about 7 to10 % sugarcane crops remain under the mercy of quantum and distribution of rainfall causing considerable variation of sugarcane production. In India, area under sugarcane is highest in Telangana where sugarcane is mostly grown (about 2 million ha) under irrigated condition. On the other hand Maharashtra is one of the water scare States in India having more than 80% area as ground water irrigation for sugarcane production.

In more recent years, Gujarat, Madhya Pradesh and Rajasthan have significant expansion in arable area under irrigation. In Gujarat, the gross irrigated area has gone up by more than 25 percent, as the ratio moved up from 27 percent of gross sown area in 1989-90 to 33 percent in 1996-97. Likewise, the gains in irrigation in Madhya Pradesh and Rajasthan are 75 and 51 percent respectively. However, these states are still rain dependant, with just 25-30 percent of the gross sown area being irrigated. Maharashtra, on the other hand, has reported insignificant success in bringing more land under irrigation in the eight years between 1989-90 and 1996-97. The gross irrigated area has declined, from 15.8 percent in 1989-90 to 14.5 percent in 1996-97 as a percentage of sown area.

With the growing recognition of the possibility of climate change and clear evidence of observed changes in climate especially disasters such as drought, flood, heat and cold wave during 20th century, an increasing emphasis on food security and its regional impacts has come to forefront of the scientific community. In recent times, the crop simulation models have been used extensively to study the impact of climate change on agricultural production and food security. The results obtained by the models can be used to make appropriate management decisions and to provide farmers and others with alternative options for their farming system. Monsoon regions feed about 70% percent of the world's population. The weather and climate variability in these regions often lead to natural hazards, such as flooding, droughts, heat waves, and blizzards, which exert strong impacts on both the society and the human lives. Therefore, the monsoon research has traditionally held a very high priority for the weather and climate international scientific communities. It is also an urgent task for the scientific community to gain a deeper understanding of the monsoon variability to meet the rising demand of a better weather forecast and climate prediction.

Sugarcane is grown as a commercial crop throughout India except for western Rajasthan, western Gujarat and some northeastern states. Uttar Pradesh produces 44% of the total. Other major sugarcane-producing states are Maharashtra, Tamil Nadu, Karnataka and Andhra Pradesh. The crop calendar for sugarcane spans the entire year in most of the country. It is planted during November-February, and is harvested after one year. The lack of significant association with monsoon rainfall seems to reflect the fact that more than 85% of area under sugarcane is fully irrigated.

Wheat, sugarcane and banana are among the major crops in the country that are grown on mostly irrigated area. Comparatively less irrigated area is sown under cotton, groundnut, coarse cereals and pulses. These crops would suffer most from a late or weak start to the rainy season, and are susceptible to extended breaks in monsoon rains. If the southwest monsoon withdraws from the region earlier than expected, late-planted crops may be hurt from lack of moisture during grain filling. Conversely, a late withdrawal resulting in late-season rains can be detrimental to maturing crops, especially cotton. Strong monsoon circulation can bring flooding, especially along the Ganges and Indus Rivers.

Sugarcane yield in Telangana was considerably low (nearly half) compared to that of Maharashtra. The higher yield was observed in the northern districts of Telangana. The maximum yield (about 50 t/ha) was observed in Maharastra State., whereas the lowest yield (about 30t/ha) is recorded in Nizamabad district in Telangana State. The sugarcane yields ranged between 35 to 45 t/ha in the central part of the State. In Maharashtra, higher yields (about 80 to 90 t/ha) were observed in southern districts. In contrary of Telangana cane yields decreased gradually towards the northern districts of Maharashtra. Maximum yields (90-100 t/ha) were reported in of Niphad, Pune, and Solapur districts and lowest yield s in northern districts of Nagpur and Parbhani. Sugarcane yields ranged between 79-90 t/ha in the central part of Maharashtra. Sugarcane growth as well as yield was significantly influenced by spatial variation of climatic parameters at all growth stages. Extremely high and low temperatures in Telangana have caused significant cane yield reduction compared to that in Maharashtra where crop has experienced less number of heat and cold waves. Lower minimum temperatures at germination and maturity stages compared to the optimum required have impacted sugarcane yields in Telangana.

The role of climatic parameters in contributing to higher/lower yield of sugarcane in the States of Uttar Pradesh (U.P.) and Maharashtra has been assessed. The spatial variation of mean sugarcane yield in relation to mean meteorological parameters at each of the growth phases of sugarcane has also been studied. The study revealed that the variation of meteorological parameters at each of the growth stages from that of the optimum requirement are considerably higher in U.P. compared to that of Maharashtra. It is observed that the spatial variation of mean meteorological parameters played a crucial role in the variation of sugarcane yield in these two major sugarcane growing States.

The tropical sugarcane region consists of sugarcane agro climatic zone 4 (peninsular zone) and 5(Coastal zone) which includes the states of Telangana, Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka, Gujarat, Madhya Pradesh, Goa, Pondicherry and Kerala.

Sugarcane is one of the important commercial crops in India. Sugarcane occupies about 3% of the total cultivated area and it is one of the most important non food grain crops which contributes to about 7.5% gross value of the agricultural production in the country. In India, sugar industry is the second largest agro-based industry, playing an important role. Sugar factories are considered as growth centers in rural areas. India produces 18 million tonnes of sugar annually through more than 453 sugar mills. The exploding population growth and increased per capita sugar consumption warrants increased sugar production with the available area. Proper forecast of such important commercial crops is necessary for future planning and policy making. In the year 2006, in its first advance estimate, the Ministry of Agriculture assessed 283.4 million tonnes of sugarcane crop that was successively revised upward to 355.5 million tonnes. These incorrect forecasts formed the basis of a ban on sugar exports and as a result there was a loss of export business when sugar price was high in the international market. Accurate early warning of crop failures can go a long way in mitigating the undesirable effects like price rise and agrarian distress through public policy. Since sugarcane productivity forecast could help in estimating the production and making decisions regarding export and import policies, distribution, price policies and for exercising measures for storage and marketing, an attempt has been made to develop suitable pre-harvest forecasting model for Coimbatore district of Tamilnadu state.

Individual effects on weather factors on rice yield were studied by Jain et al. (1980) and Agrawal et al. (1986). Agrawal et al. (1983) studied the joint effect of weather variables on rice yield. In the above models generated weather variables were used. Weather indices and principal components of weather variables were used in the models developed by Agrawal et al. (1980). Composite models, combining biometrical characters and weather variables were developed by Mehta et al. (2000). Yield forecast models were developed for wheat and rice using weather variables and agricultural inputs on agro-climatic zone basis by Agrawal et al. (2001).Four different approaches, two on original weather variables and two on generated weather variables were used by Khistaria et al. (2004) and Varmola et al. (2004). By coupling technology trend with weather variables, models were developed by Mallick et al. (2007). The present study provides yield forecast models for sugarcane production of Coimbatore district using weather variables.

Sub-tropical sugarcane region: Around 55 percent of total cane area in the country is in the sub-tropics. U.P, Bihar, Haryana and Punjab comes under this region. The sugarcane yields are substantially higher in the tropical states such as Telangana, Andhra Pradesh, Karnataka, and Tamil Nadu as compared to the sub-tropical regions. The southern states, over a period of time, have increased the productivity through appropriate adoption of new varieties replacing the traditional ones. The cane yield of southern states is also higher when compared with northern states where sugarcane is known to grow over a wide range of environmental conditions and therefore is exposed more too both biotic (insect pests, diseases, and weeds) and a biotic (drought, salinity, alkalinity, water logging and extreme temperatures) stresses.

Crop distribution: Sugarcane growing countries of the world are lying between the latitude 36.70 north and 31.00 south of the equator extending from tropical to sub-tropical zones. In India sugarcane is cultivated all over the country from latitude 80 N to 330 N, except cold hilly areas like Kashmir valley, Himachal Pradesh and Arunachal Pradesh.

Climatic requirement

Temperature for different critical stages of sugarcane: The different critical stages are germination, tillering, early growth, active growth and elongation. Optimum temperature for sprouting (germination) of stem cuttings is 32° to 38°c. It slows down below 25°, reaches plateau between 30°-34°. Temperatures above 38° reduce the rate of photosynthesis and increase respiration. For ripening, however, relatively low temperatures in the range of 12° to 14° are desirable.

The sugarcane productivity and juice quality are profoundly influenced by weather conditions prevailing during the various crop-growth sub-periods. Sugar recovery is highest when the weather is dry with low humidity; bright sunshine hours, cooler nights with wide diurnal variations and very little rainfall during ripening period. These conditions favour high sugar accumulation. The climatic conditions like very high temperature or very low temperature deteriorate the juice quality and thus affecting the sugar quality. Favourable climate like warm and humid climate favour the insect pests and diseases, which cause much damage to the quality and yield of its juice and finally sucrose contents. The average area of sugarcane cultivation increased from 2.4 million ha in the early-sixties to about 4.3 million ha at present.

CLIMATE CHANGE MAY HIT SUGARCANE CROP:

Climate change may hit the sugar industry in the state with sugarcane crop yields being reduced by up to 30% in the future with long-term socio-economic implications for many farmers. This was revealed after a four-year study conducted by the World Bank in Maharashtra, Andhra Pradesh and Orissa that predicted drops in agricultural yields. Sugarcane output during SY2003-04 was also adversely impacted by pest attacks on sugarcane grown in Maharashtra, Karnataka and some pockets of UP and Uttaranchal. As a result, sugarcane production declined 3.3% during SY2003 and 18.6% during SY2004. During SY2005, sugarcane output increased 1.2% to 237.09 metric tons (MT), mainly because of higher output in Maharashtra which offset declines in Telangana and Karnataka.

AREA, PRODUCTION AND YIELD OF SUGARCANE IN MAJOR GROWING STATES

In Tropical zone Maharashtra is the major sugarcane growing state covering about 9.4 lakh ha area with production of 61.32 Million ton, whereas the productivity of Tamil Nadu is highest in tropical zones. Uttar Pradesh is the highest sugarcane producing State in sub tropical zone having area about 22.77 Lakh ha with the production of 135.64 Million Ton cane whereas Haryana has highest productivity of sugarcane in Sub tropical zone.

ARCHITECTURE OF CROP PREDICTION

The architecture of crop prediction which includes an input module which is responsible for taking input from farmer. In that the farmer has to provide area of land, region, economic status and city. The farmer is also responsible for interacting with predicted results. After selecting the city parameter based on altitude, longitude and latitude automatic climatic data will be reflected from crop knowledge base. The feature selection module is responsible for subset selection of attribute from crop knowledge base for robust learning. The crop knowledge base is consist of farm knowledge such as region-id, region name, soil-type, water ph, rainfall, humidity, sunlight, land information, environmental parameter, city, pesticides information, crop knowledge such crop type, seed type. The knowledge-base also includes the samples of crop with corresponding farm knowledge, environmental parameter, and pesticides information. After subset selection of attribute, the data goes to classification and association rule for grouping similar contents. Then prediction rules will be applied to output of clustering to get results in terms of crop, pesticide and cost.

MATERIALS AND METHODS

The yield figures of sugarcane for a period of (1981-2004) collected from season and crop report, issued by the state government of Tamil Nadu has been used for the present study. The daily data on weather parameters such as Temperature (max. & min.), Relative humidity (morn. & even.), Amount of rainfall for 23 years period has been collected from weather station located at Sugarcane Breeding Institute, Coimbatore.

DATA AND VARIABLES USED IN THE STUDY

Fortnightly average data on weather variables have been used for the study namely, X1 – Max. Temp (^{0} C), X2 – Min. temp (^{0} C), X3 – Rel. hum. Mor. (%), X4 –Rel. hum. Eve. (%), X5 – Rainfall (mm). The forecast models were developed using the partial crop season data. i.e. the data on weather variables during the active vegetative phase has been used for our study. The data from the period of (1981-2001) has been used in developing the forecast model and the remaining three years data from (2002-2004) has been used for the validation of the models.

2.2 Yield forecast model

The yield forecast model is given by

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{1} a_{ij} Z_{ij} + \sum_{i \neq i'=1}^{p} \sum_{j=0}^{1} a_{ii'j} Z_{ii'j} + cT + e, \qquad (1)$$

where $Z_{ij} = \sum_{w=1}^{m} r_{iw}^{j} X_{iw}$ and $Z_{ii'j} = \sum_{w=1}^{m} r^{j}_{ii'w} X_{iw} X_{i'w}$.

Here Y is the sugarcane yield (tonnes/hec)

X_{iw} is the value of the i-th weather variable in the w-th fortnight.

$r_{iw}/r_{ii'w}$ is correlation coefficient of Y with i-th weather variable/product of i-th and i'-th weather variable in w-th fortnight.

'm' is the fortnight of forecast

'p' is the number of weather variables = 5

$i = i'$= 1,2,…..5 correspond respectively to maximum and minimum temperatures, relative humidity at 7hr , 14hr and rainfall.

a ,b and c are constants

'T' is year number included to correct for the long term upward or downward trend in yield

And 'e' is the error term.

For each weather variable, two variables were generated- one as simple accumulation of weather variable and the other one as weighted accumulation of fortnightly data on weather variable, weights being the correlation coefficients of the weather variables, in respective fortnights with yield. Similarly, for joint effect of weather variables, fortnightly interaction variables were generated using fortnightly products of weather variables taking 2 at a time. Stepwise regression was used to select significant generated variables Zij and Zii'j . Further analysis was carried out including significant generated variables only. In order to study the consistency of forecast, predicted yield values of subsequent years (not included in the forecast equation) were worked out. Yields of subsequent years were forecasted two months before harvest. For forecasting, observed weather was used up to the time of forecast and normal values of weather variables for the remaining period up to harvest.

RESULTS AND DISCUSSION:

The results of ANOVA are presented in table 1. The results of F-test show that the regression equation is highly significant.

Table 1: The results of ANOVA for the regression equation

Model	Sum of Squares	df	Mean Square	F - value	Sig.
Regression	1638.3	10	163.83	6.393**	0.005
Residual	230.65	9	25.63		
Total	1868.95	19			

**- Significant at 1% level

The results of t-test show that the generated weather variables Z20 and Z40 are significant at 5% level. And further the generated variables Z25, Z131 are significant at 1% level.

The results of t-test along with the values of partial regression coefficients are presented in Table 2

Table 2: The results of t-test and partial regression coefficients

Variables	Unstandardized Coefficients		t	Sig.
	B	Std. Error		
(Constant)	-627.984	230.282	-2.73	0.023
Z10	0.493	0.259	1.90	0.089
Z20	1.673	0.628	2.66*	0.026
Z40	0.125	0.049	2.55*	0.031
Z50	2.005	1.016	1.97	0.080
Z150	0.015	0.018	0.84	0.425
Z250	-0.100	0.024	-4.08**	0.003
Z350	-0.001	0.003	-0.50	0.629
Z450	-0.002	0.003	-0.62	0.553
Z131	0.062	0.013	4.73**	0.001
Z141	-0.009	0.008	-1.15	0.279

* - Significant at 5% level
**- Significant at 1% level

Yield Forecast Model

The yield forecast equation has been developed using the significant generated weather variables based on equation1. The final yield forecast function using important weather variables along with its R 2 value has been presented below.

$$Y = -627.984 + 0.493\,Z_{10} + 1.673\,Z_{20} + 0.125\,Z_{40} + 2.005\,Z_{50} + 0.015\,Z_{150} - 0.100\,Z_{250} - 0.001\,Z_{340} - 0.002\,Z_{450} + 0.062\,Z_{131} - 0.009\,Z_{141}. \qquad (2)$$

$$R^2 = 0.877$$

R 2 value which is measure of goodness of fit indicates that generated weather variables are able to explain 87% of variation in the sugarcane yield. The performance of the sugarcane yield forecast equation has been tested by comparing the simulated values (which were not included in the forecast equation) with the observed values for a period of three years from (2002-2004) which are presented in table 3. The simulated values of sugarcane yield were 5.59 % lower than the actual yield values for the year 2002. For the year 2003, the simulated values were 3.47 % higher than the actual values. While comparing the results of 2004, it has been noticed that the deviations are little higher in comparison with the previous years. The results of table 3 indicate that the results of forecasted yield are satisfactory. These results reflect that the performance of the yield forecast model is acceptable.

Table 3: Performance of the sugarcane yield model

Year	Observed Yield (tonnes/hec)	Simulated Yield (tonnes/hec)	% of deviation (±)
2002	113	106.67	-5.59
2003	102	105.67	3.47
2004	116	95.62	-17.50

A comparison between the actual and predicted values of sugarcane yield, which were used in developing the forecast model, is presented in table 4. The results show that the percentage of deviations from the actual yield are within 5 percent range. Figure 1 gives a graphical representation of actual and predicted values of sugarcane production during the period of 1981-2001.

Table 4: Comparison actual and predicted values of sugarcane yield of Coimbatore district, from 1981-2001

Year	Actual values	Predicted values	% of deviation (±)
	(tonnes/hectare)		
1981	113	114.7	1.49
1982	98	98.3	0.27
1983	90	85.9	-4.59
1984	99	101.9	2.91
1985	110	111.7	1.55
1986	106	107.6	1.47
1987	100	105.1	5.1
1988	102	101.3	-0.72
1989	103	107.1	3.95
1991	110	107.2	-2.53
1992	124	117.5	-5.25
1993	122	113.8	-6.74
1994	118	120.1	1.81
1995	117	120.2	2.72
1996	119	115.3	-3.13
1997	101	102	0.95
1998	89	90	1.08
1999	102	100.8	-1.16
2000	106	107	0.92
2001	112	113.8	1.61

Sugarcane yield in U.P. was considerably low (nearly half) compared to that of Maharashtra. The higher yield was observed in the northern districts of U.P. The maximum yield (about 50 t/ha) was observed in Muzaffarnagar, whereas the lowest yield (about 30t/ha) was recorded in southern districts viz., Aligarh, Jhansi and Lucknow. The sugarcane yields ranged between 35 to 45 t/ha in the central part of the State. In Maharashtra, higher yields (about 80 to 90 t/ha) were observed in southern districts. In contrary of U.P. cane yields decreased gradually towards the northern districts of Maharashtra. Maximum yields (90-100 t/ha) were reported in of Niphad, Pune, and Solapur districts and lowest yields in northern districts of Nagpur and Parbhani. Sugarcane yields ranged between 79-90 t/ha in the central part of Maharashtra.

Sugarcane being an irrigated crop, its growth is not much affected due to soil water stress as expected during dry spell and variation of rainfall during SW and NE monsoon seasons. However, rainfall has influenced the yield indirectly which is reflected in Climate Changes. During active growth stage rainfall varied between 200 to 400 mm in U.P. Rainfall varied between 400 to 600 mm from rain shadow western Maharashtra to eastern region and 600 to 800 mm with increasing trend from south western to north eastern region of U.P. Sugarcane is the most important sugar crop contributing more than 75% to the world's sugar production. With increasing human population in the world, sugar demand has also gone up, and by the end of first decade of 21st century its requirement is projected to be around 1.50 million tones.

Farmer Adaptations

Farmers may adapt to both short and long-term changes in climate conditions, when choosing crops and production technologies. In addition, exit and entry into farming may die under die rent climate conditions. Because the ejects of climate variation on yield are estimated in our yield model using the yields realized under varying year-to-year climate conditions, we accommodate any within year adjustments that farmers make in advance of a growing season based on anticipated temperature or rainfall, along with any adaptations made during a growing season, as actual temperature and rainfall levels are observed.

The number of farmers cultivating sugarcane has increased as per the Government records. With yield of around 65,000 kilogram (kg) per hectare, and minimum support price of 79.5 per quintal for SY2006, sugarcane can be the most profitable crop, wherever irrigation is available. In India, the sugarcane acreage under irrigation facilities is as high as 92%. The attraction of farmers towards sugarcane cultivation can be demonstrated by the fact that the area under sugarcane cultivation has increased consistently.

SUMMARY AND CONCLUSION

Using the forecast model, pre-harvest estimates of sugarcane yield for Coimbatore district could be computed successfully very much in advance before the actual harvest. As the data used for developing this model is of high degree of accuracy, its reliability is also high. Further, this model will produce more accurate results depending on the accuracy of input data provided. The district government authorities also can make use of the forecast model developed using weather indices, in this study, for obtaining accurate pre-harvest estimates of sugarcane crop. Till the final production of crops becomes known, decisions have to be made on the basis of informed predictions or scientific forecasts. The main beneficiaries are farmers (decide their procurement prices), traders, exporters and importers (for planning their logistics, inventories and contracts). The processing companies can also plan in advance about the capacity, manpower and marketing strategy.

Sugarcane growth as well as yield was significantly influenced by spatial variation of climatic parameters at all growth stages. Extremely high and low temperatures in U.P. have caused significant cane yield reduction compared to that in Maharashtra where crop has experienced less number of heat and cold waves. Lower minimum temperatures at germination and maturity stages compared to the optimum required have impacted sugarcane yields in U.P. Rainfall at different sugarcane growth stages across Maharashtra and U.P. played a contrasting role as they contributed significantly to higher yields in U.P. whereas higher rainfall amounts adversely affect cane growth and yields in Maharashtra.

Relative air humidity at different cane growth stages was also strongly correlated with yields.

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M. Naveen Kumar
Research Scholar, Research and Development Centre,Bharathiar University, Coimbatore .