IJARIIT

INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X

Impact factor: 4.295

(Volume 4, Issue 2)

Available online at: www.ijariit.com

A data mining perspective of the dual effect of rainfall and temperature on cotton crop yield prediction

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ABSTRACT

This paper presents the final investigation within the north Gujarat region of qualitative and quantitative investigations carried out for the processing and analysis of geographic land-usage data in an agricultural context. The geographic data was made up of crop and cotton crop land use profile. These were linked to previously recording climatic data from fixed weather stations in north Gujarat. In this study, the profiles for the stochastic average monthly temperature and rainfall for north Gujarat selected area were used to determine their simultaneous effects on crop production. The temperature and rainfall were sampled for a selected decade of crop production for the years from 2006 to 2015. The evaluation was carried out using graphical, correlational and data-mining-regression techniques to detect the patterns of crop production in response to the climatic effect across the agricultural region. Data mining classification algorithms within the WEKA software package were used with the location as the classifier to make comparisons between predicted and actual cotton yields. The predicted patterns suggested that crop production is affected by the climate variability especially at certain stages of plant growth.

Keywords: *Data mining, Cotton crop, Yield prediction, Temperature, Rainfall.*

1. INTRODUCTION

Although crop production has been linked to several factors such as seasonal temperature, temperature variations, radiation, evaporation, soil moisture and crop management practices [18], this work investigated the effect of rainfall in conjunction with temperature variability on crop production. The aim of this work is to determine the relationship between climate variables such as rainfall and temperature taken together on the actual crop production in the northern agricultural region of Gujarat. The research was carried out to verify the agricultural land usage at these locations as well as to provide the agricultural industries an insight into cotton crop decision making. Therefore, this work is site-specific and has a grid-cell spatial significance. In addition, the research is carried out to possibly predict the crop production at certain locations within the agricultural region, given the prevalent rainfall and temperature conditions. According to Olesin and Bindi (2002), the factors of rainfall, radiation, temperature and temperature variation all affect yield to some degree with increased temperature variability especially increasing the crop yield variability [10]. The cotton crop yield is especially conducive to monsoon and winter when taken in conjunction with other management factors such as rainfall, sowing time, stage of plant growth, fertilization and harvesting over the growing season of cotton from the first week of June to November in the northern agricultural region of Gujarat.

Spatial scales are important where scale related results are specific to the related group or agency. For example, the national scale may be used by governments to determine their economic strategy from food reserves [4], while results from smaller scale relationships, being used to detect food shortages and associated mitigation possibilities [8], and for seasonal forecasting by farmers at the farm level [6]. This study will investigate the correlations between these factors on a spatial scale that is somewhere between the farm level (small) and the whole agricultural region level (large). This intermediate level is the region level (medium) and the temperature and rainfall readings are aggregated upwards from the fine resolution of 1000m of a GIS grid cell. Focus and scope being the two purposes, as well as to highlight the relationships between temperature variability, rainfall and cotton yield variability, 10 specific production years from 2006 to 2015 were selected.

2. RELATED WORK

The effect of observed seasonal climatic conditions such as rainfall and temperature variability on crop yield prediction has been undertaken by Trnka et al. through an empirical crop model [10]. Interactions between input variables such as temperature variability and output variables such as crop yield have been shown to be important and have affected the yields statistically [10]. In particular, the relevance of changing temperatures was emphasized at critical phonological growth stages of a crop [19]. There are two approaches for developing models and these are the process-based crop models (CM) for the establishment of non-linear relationships between weather variables and crop yield and general circular models (GCM) of the coupling of the ocean and the atmosphere. The use of general circular models for prediction at a seasonal lead-time suffers from the problem of simulation of too many low-intensity temperature instances within each grid cell [2]. Other problems with these models include the coarse granularity of the spatial resolution and the less than accurate simulation of the local current climate [9]. As short-term weather forecasting rather than long-term climate forecasting is important [1], this study is, therefore, more suited to the crop models approach. Furthermore, there are two approaches to investigating the impact of climate change on crop production which includes the crop suitability approach and the production function approach [9]. The crop suitability approach, also known as the agro-ecological zoning (AEZ) approach, uses climate to determine crop suitability at an agricultural location using simulated rather than measured crop yields [7]. On the other hand, the production function approach uses either an empirical or experimental production function to measure the relationship between crop production and climate change [12]. The complexity of any crop model can be based on the level of detail of the analysis [16], or they can be less detailed with only estimations of moisture content [17]. Other approaches have been the use of normalized difference vegetative index (NDVI) for grouping homogeneous regions to establish the scale [3]. There have also been approaches to crop modeling using the derivation of a probability distribution function (PDF) for the assessment of quantifying the risks and benefits of making weather-based decisions [13]. Although according to Sivakumar (2006), notwithstanding that considerable improvements in understanding and predicting climate variability have been made, the need to further develop understanding and refine tools is ever increasing [11], especially because the atmosphere is intrinsically a chaotic system as well as due to the phenomenon of climate change [14].

3. MATERIALS AND METHODS

The study area randomly selected are the Banaskantha and Sabarkantha District under the northern agricultural region of Gujarat. The ArcGIS, ERMapper and GeoMedia software packages were used to create the study area and the land usage profiles. In addition, all the datasets were fitted specifically to the extraction region of the selected study area. The climate data included both rainfall and temperature. Historical temperature and rainfall data existed only at specified sparsely located weather stations within the study area. To overcome the limitation of a sparse dataset associated with the weather stations, a process of interpolation was carried out using an *R* script resulting in temperature and rainfall data points at each 100ha cell of the study area grid for the 12 months for the years 2006 to 2015. The temperature and rainfall profiles were fitted onto the high-resolution grid surface. This was done for maximum temperature, minimum temperature, temperature variation and rainfall for the growing season months of June to November. The monthly climate data was scaled to match the annual production data using an *R* script where the final aggregated data was sorted in regional order. This dataset was then analyzed for the cotton crop yield in relation to the rainfall and temperature variants across the talukas.

4. EXPERIMENTAL RESULTS AND ANALYSIS

There were a number of aspects of the data handling and the analyses. They included the pre-processing and metrics, the analysis of the rainfall, temperature and the individual cotton crop yields as part of the macroscopic phase. In addition, there was the Data Mining (DM) analysis of the individual cotton crop yields which formed the microscopic phase.

Pre-processing and Metrics

The study area within the north Gujarat agricultural zone included several talukas. The normalization of the differently sized area was calculated in order to determine the crop yields in tonnes/hectare. The rainfall, maximum, minimum and variation in temperature for the years 2006 to 2015 and the months from June to November were averaged for each taluka using an *R* script individually. These were then collated with the cotton crop yield data for the same 10 year period in MS Excel for each of the talukas to produce one aggregated file in preparation for the DM analyses in WEKA.

The visual inspection of the graphs required a uniform method of evaluation. This was in the form of a baseline metric of classifying the talukas into rainfall categories of high yield (HY) of over 45,000 tonnes per region and low yield (LY) of less than 45,000 tonnes per region per annum. Accordingly, the HY region is Kankaraj, Diyodar, Bhabhar, Vijapur, Kadi, Becharaji, Visnagar, and Mahesana. The LY region was Palanpur, Amirghadh, Danta, Vadgaam, Deesa, Dhanera, Dantiwada, Vaav, Tharad, Unjha, Vadnagar, Kheralu, Satlasana.

Analysis of Climate Variables

The first stage in the analysis was the general visual inspection of the data which was part of the exploratory data mining (EDM) process for the rainfall and temperature for the crop growing season in months of June through November for the 21 crop yielding talukas in the agricultural region of north Gujarat.

The rainfall patterns were similar for both the High Yield and Low Yield region except that the Low Yield region experienced a marginally higher rainfall. For example, the High Yield region of Diyodar received a lower rainfall in 2007 as opposed to the LY region of Vaav which received a higher rainfall in 2010. In addition, the steep rise in rainfalls in July and August and sharp declines in September were very pronounced for 2007, 2009, 2013 and 2015. The rainfall patterns in 2007, 2009, 2013 and 2015 were prominent especially with the high rainfall in the year of 2013 whereas rainfall was low in August and high in September. However, the trend was similar and in that, both the High Yield and Low Yield region matched each other more closely. For example, the High Yield region of Diyodar received a rainfall of 278.00 mm as opposed to the Low Yield region of Unjha which also received a high rainfall of 330.3 mm in July 2006.

The highest maximum temperature occurred in the HY region of Kankaraj (45°C) and at the LY region of Tharad (44°C) in June 2011. The lowest maximum temperature was at Diyodar (7.2°C) and at Kankaraj (7°C) in November 2009. The highest mean maximum temperature for the 10 years in High Yield region was 45°C in June 2010 and lowest mean maximum temperature was 7°C in November 2009. However, the trend was similar in that the highest maximum temperature was recorded at the LY region of Vaav (34.30°C) in June 2010 and at the HY region of Kankaraj (34.0°C).

The preceding rainfall and temperature visual inspections were followed by an examination of the cotton yield across all the region in the study area for the decade from 2006-2015. This process marked the beginning of an exploratory data mining of the cotton yield.

Analysis of the Cotton Crop Yield

The EDM was the analysis of annual cotton crop yields over the decade for years 2006 to 2015 across all the region in the study area of the agricultural region. This was a two-stage process where the cotton yields were taken both individually and in conjunction with rainfall and temperature variables. The individual cotton yields for the HY and LY region are shown in Fig. 1 and Fig. 2 respectively. The cotton yields for 2006 were the highest for most of the HY region especially for the Diyodar for the year 2006, with low yields at some of the HY region such as Mahesana for the year 2007. This corresponded well with the rainfall for those two years. Conversely, the cotton yields for the LY region revealed that the region of Vadnagar performed well in 2008, 2011, 2012 and 2015 with the region of Deesa producing a low yield in 2009 and high in 2008.

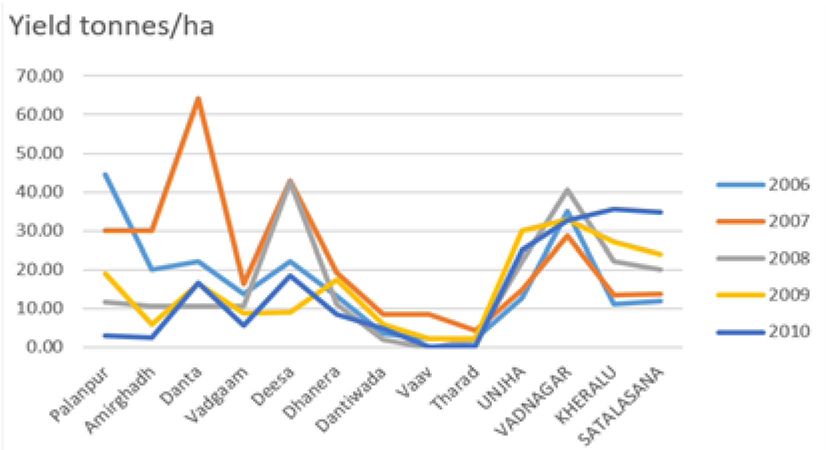

Figure 1 Cotton Yield for the year 2006-2010 LY region

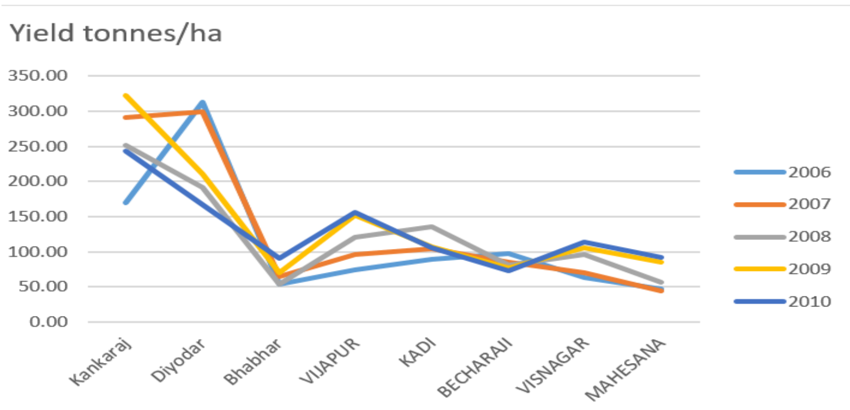

Figure 1 Cotton Yield for the year 2006-2010 HY region

The second stage of the EDM of the cotton yield was the examination of the combined effect of rainfall and temperature on the cotton yield. The dataset includes snapshots for the attributes for rainfall, temperature (maximum, minimum, variation) and the annual cotton yield for the months of June to September

For the purposes of clarification, a mean seasonal rainfall below 625 mm was rated as dry, 626 mm to 920 mm as average and over 920 mm as wet. Mean seasonal temperatures below 26.50 degrees were rated as low, 26.51 to 26.90 degrees as medium and over 26.91 degrees as high. Cotton yields below 54.22 tonnes/hectare were rated as low, 54.23 to 62.22 tonnes/hectare as a medium, and 62.23 tonnes/hectare as high and over 70 tonnes/hectare as very high. These observations are summarized in Table I.

Table 1 General Cotton Yield Response to Mean Annual Rainfall and Average Temperature

Year	Mean Rainfall	Rainfall rating	Mean Temp	Temp Rating	Mean Annual Yield	Yield Rating
2006	890.55	Avg.	26.78	Med	53.33	Low
2007	863.05	Avg.	26.18	Low	64.24	High
2008	506.50	Dry	26.58	Med	56.76	Med
2009	481.15	Dry	27.10	High	63.38	High
2010	1070.30	Wet	27.10	High	58.48	Med
2011	897.70	Avg.	26.33	Low	64.52	High
2012	774.00	Avg.	26.53	Med	64.05	High
2013	1084.50	Wet	26.35	Low	57.72	Med
2014	536.15	Dry	26.78	Med	35.82	Low
2015	901.20	Avg.	27.35	High	63.90	High

Cotton, a semi-xerophyte, is grown in tropical & sub-tropical conditions. Accordingly, one could expect hot and moist climate as ideal for good cotton yield. A minimum temperature of 15 degrees is required for better germination at field conditions. The optimum temperature for vegetative growth is 21-27 degree & it can tolerate temperature up to the extent of 43 degrees Celsius but temperature below 21 degrees Celsius is detrimental to the crop. Warm days and cool nights with large diurnal variations during the period of fruiting are conducive to good boll & fiber development. However, it was uncovered that the yield could still be high with similar temperatures, provided that the rainfall was very high for the year 2011.

The average rainfall and the medium temperature, as was marked for the years 2007, 2011 and 2012. Generally, the cotton yield was high when the rainfall was average, and the temperature was medium to low. Under these conditions, the Low Yield regions produce higher yields. High temperature up to 43 degrees Celsius after the flowering and boll development is also good for the high cotton yield. The conclusions from these observations were as a result of visual correlations constructed from the data.

In order to augment the correlation analyses, a facility for prediction through the use of regression was necessary. Consequently, DM was explicitly chosen for this purpose to reveal potentially hidden patterns and relationships that would otherwise be obfuscated by the multiplicity as well as the opposing nature of the variables.

Data Mining Analysis

The next step in the individual scrutiny of the exercise was the use of regression to determine if the relationship established through simple observed correlation could be supported by a mechanism of predicting the cotton crop yield through the variation in temperature across the growing months from June through November. This was carried out using the classification technique of DM in the Waikato Environment for Knowledge Analysis (WEKA) software. The aggregated data for average monthly rainfall, maximum, minimum and variation in temperature together with the cotton crop yields for the 21 talukas were used for this activity. In addition, an average of all the region was added for the mean crop yield and temperature variables. The region was sorted into High Yield and Low Yield groups. The aggregated cotton crop yield and the average monthly maximum temperatures and rainfall dataset were split up into a training set and a test set.

The training set included the data for the years 2006, 2009 and 2014 and the test set was made up of the data for years 2007, 2008, 2010, 2011, 2012, 2013 and 2015. The choice of the years for the test set was based on obtaining a mix of predictions for the dry, wet and productive years. The exploratory part of the DM activity was to use the training set to determine the best-fit algorithm using a simple model of crop yield as a function of the location class and the average maximum monthly temperatures for the growing season months as the attributes. A test of all of the classification algorithms that used regression for predicting continuous values in response to input values was made to determine correlation results and root mean square errors (RMSE). The correlation and RMSE results were omitted here for brevity. The algorithm with the best performance in these criteria turned out to be GP with a correlation of 0.9726 and an RMSE for the training set of 1.0689 as well as an RMSE of 1.0925 for the cross-validation run and RMSE of 1.2168 for the test set. Consequently, the results for using the GP algorithm were used for the analyses and split into two tables of actual and predicted cotton crop yields, one for the years 2007 and 2013 and another for the years 2010 and 2011 as in Table II and Table III respectively. The region in both tables was grouped into High Yield and Low Yield region, where the High Yield region are denoted by yellow shading.

With reference to Table II, there were both underestimated and overestimated predictions for the region for the high yield year of 2007. The High Yield region Bhabhar had positive prediction errors. On the other hand, only one Low Yield region of Danta had positive prediction errors for the year 2007. For grade scale, good predictions were considered to have a percentage error of less than 3.70%, with average predictions a percentage error of 3.71-5.80% and weak predictions a percentage error of over 5.81-8.10%. Accordingly, in 2007, the High Yield talukas like Kankaraj (2.92%), Bhabhar (0.01%), Mahesana (1.05%), Vijapur (2.30%), Kadi (2.56%), Becharaji (1.09%) and Visnagar (1.75%) except Diyodar (3.86%) had good predictions. Conversely, the Low Yield talukas performed worse than the High Yield taluka with good predictions for the region of Danta (0.01%), Deesa (2.35%) and Vadnagar (2.80%). The Palanpur (3.75%), Amirghadh (3.75%), Dhanera (4.92%), Unjha (4.31%), Kheralu (4.46%) and Satalasana (4.43%) talukas had average predictions. Only the talukas like Vadgaam (5.23%), Dantiwada (6.08%), Vaav (6.08%) and Tharad (6.55%) had weak predictions. Overall both High Yield and Low Yield together had an average prediction with a prediction error of 3.35%.

Table 2 Cotton Yield WEKA GP Result

	High Yield Year 2007			High Rainfall Year 2013		
Region (Taluka)	Actual Yield Ton/ha	Pred. Yield Ton/ha	% Error	Actual Yield Ton/ha	Pred. Yield Ton/ha	% Error
Palanpur	29.97	47.13	3.75	9.85	31.03	4.62
Amirghadh	29.97	47.14	3.75	14.58	33.59	4.15
Danta	64.21	64.25	0.01	27.58	40.29	2.77
Vadgaam	16.40	40.35	5.23	19.04	35.49	3.59
Deesa	42.81	53.56	2.35	18.71	34.92	3.54
Dhanera	19.26	41.79	4.92	6.57	28.66	4.82
Dantiwada	8.56	36.43	6.08	3.94	27.94	5.24
Kankaraj	291.10	277.69	2.92	284.02	267.46	3.61
Diyodar	299.66	281.97	3.86	183.86	217.49	7.34
Bhabhar	64.21	64.25	0.01	26.27	38.38	2.64
Vaav	8.56	36.42	6.08	1.31	25.51	5.28
Tharad	4.28	34.28	6.55	3.28	26.42	5.05
Mahesana	44.78	49.61	1.05	114.87	88.06	5.85
Vijapur	95.47	74.95	2.30	118.40	89.74	6.25
Kadi	103.86	79.14	2.56	69.66	65.10	1.00
Becharaji	84.43	69.42	1.09	46.82	53.65	1.49
Visnagar	70.40	62.39	1.75	83.12	70.98	2.65
Unjha	14.95	34.70	4.31	46.52	54.28	1.69
Vadnagar	28.70	41.54	2.80	53.82	57.07	0.71
Kheralu	13.54	33.96	4.46	51.87	55.78	0.85
Satalasana	13.86	34.14	4.43	27.93	44.87	3.70

The prediction results for the wet year 2013 were slightly better for Low Yield region. Overall there was a less weak prediction for the year 2013 for both the HY and LY region. But, overall both High Yield and Low Yield together had an average prediction with a prediction error of 3.66%. Generally, the prediction errors relative to the combined effect of rainfall and temperature were better in 2007 than in 2013.The DM results using the GP algorithm for the years 2010 and 2011 were shown in Table III.

Table 3 Cotton Yield WEKA GP Result						
	High Yield Year 2010			High Rain Year 2011		
Region (Taluka)	Actual Yield Ton/ha	Pred. Yield Ton/ha	% Error	Actual Yield Ton/ha	Pred. Yield Ton/ha	% Error
Palanpur	3.12	24.14	4.59	2.78	26.91	5.27
Amirghadh	2.50	22.84	4.44	11.88	31.24	4.22
Danta	16.66	28.95	2.68	2.23	27.00	5.41
Vadgaam	5.72	26.12	4.45	1.95	26.84	5.43
Deesa	18.54	34.58	3.50	24.14	36.20	2.63
Dhanera	8.47	30.46	4.80	11.60	28.05	3.59
Dantiwada	4.86	25.70	4.55	3.71	26.72	5.02
Kankaraj	243.72	247.73	0.88	315.63	285.70	6.53
Diyodar	166.65	178.63	2.61	213.51	233.19	4.29
Bhabhar	90.27	72.03	3.98	9.28	19.50	2.23
Vaav	0.14	28.91	6.28	0.00	13.88	3.03
Tharad	0.35	29.41	6.34	0.28	15.79	3.39
Mahesana	91.62	89.41	0.48	87.24	80.62	1.44
Vijapur	156.55	152.23	0.94	188.90	162.80	5.69
Kadi	104.91	117.45	2.74	130.16	103.94	5.72
Becharaji	72.27	71.21	0.23	63.39	71.30	1.73
Visnagar	113.54	115.03	0.33	119.11	102.54	3.62
Unjha	25.06	44.63	4.27	40.65	56.36	3.43
Vadnagar	32.64	51.70	4.16	46.53	66.34	4.32
Kheralu	35.55	54.40	4.11	47.11	65.93	4.11
Satalasana	34.85	49.95	3.29	34.90	56.52	4.72

In 2010, all the talukas of high yield and low yield like Kankaraj (0.88%), Diyodar (2.61%), Mahesana (0.48%), Vijapur (0.94%), Kadi (2.74%), Becharaji (0.23%), Visnagar (0.33%), Danta (2.68%), Deesa (3.50%) and Satalasana (3.29%) had good predictions whilst Bhabhar (3.98%), Palanpur (4.59%), Amirghadh (4.44%), Vadgaam (4.45%), Dhanera (4.80%), Dantiwada (4.55%), Unjha (4.27%), Vadnagar (4.16%) and Kheralu (4.11%) except Vaav (6.28%) and Tharad (6.34%) had average predictions. Overall both HY and LY together had a good prediction of 3.32% for 2010 than 2007.

The prediction results for the wet year 2011 were slightly poor. Most of the region had average prediction errors except Deesa (2.63%), Dhanera (3.59%), Bhabhar (2.23%), Vaav (3.03%), Tharad (3.39%), Mahesana (1.44%), Becharaji (1.73%), Visnagar (3.62%), Unjha (3.43%). There were more weak predictions for 2011. Generally, the prediction errors relative to the combined effect of rainfall and temperature were better in 2010 than in 2007.

5. DISCUSSION

In establishing a relationship between stochastic average monthly rainfall, temperature, and cotton crop yield, a number of considerations had to be made such as the multi-faceted nature of the temperature variables; the overall temperature; location specificity; the climatic and geographic resolution; the effect of stochastic and scaled measurements.

Notwithstanding these effects and interactions, a pre-cursory relationship using a simple crop model was used and the average monthly rainfall and temperature variables used as predictors of the cotton crop yield. The results from the two-stage analysis showed that there was some correlation between stochastic average monthly climate and cotton yield. Data mining classification algorithms were utilized in order to supplement the simple correlations that were established between rainfall, temperature and crop yield with a facility for prediction. The results showed that the crop yield prediction improved from an average prediction (4.09%)

in 2011 to a good prediction (3.32%, 3.35%, 3.66%) in 2010, 2007 and 2013, and from these three in 2010 the prediction was (3.32%) with least error. The trend shown was that the HY region performed better than the LY region in 2010 and worse in 2011.

Excessive morning rain can render the cotton plant sterile. The flowers fill with water, which disrupts pollination, and the plant does not get fertilized. Unfertilized blossoms fall to the ground. Saturated soil from rainy weather also causes the plant to not produce adequate cotton bolls. Spring rainfall can lower the soil temperature to below 14-16 degree Celsius and delay or stunt cotton seed germination. So, a marginal reduction in temperature resulted in a major failure to the cotton crop yield. Nevertheless, there was a considerable amount of error in the predicted cotton yields which created ambiguous outcomes.

6. CONCLUSION

The cotton yield predictions across the years 2007 (3.35%), 2010 (3.32%), 2011 (4.09%) 2013 (3.66%) were significant wherein they showed an improvement in 2010. This seemed to indicate that the accuracy of the predictions improved as the actual yields dropped. In addition, the LY region had better crop yields as well as better predictions overall due to the slightly suitable temperatures and rainfall prevalent in them. This amounted to a complex relationship between temperature and the cotton crop yield prediction where the crop yield could be expected to be better at higher temperatures and worse at lower temperatures also with the rainfall. The cotton crop grown in a sunny and humid climate needs more water per day, but not in a cloudy and cooler climate. Here factors are the humidity and the wind speed. When it is dry, the crop water needs are higher than when it is humid. In windy climates, the cotton crop will use more water than in calm climates.

The onset of monsoon affected germination and initial growth, whereas, abnormal temperatures affected crop physiology and quality of produce. The combined effect of rainfall and temperature was on the relative humidity that created a conducive atmosphere for insect and pest attacks on crops. Therefore, it is concluded that erratic monsoon or delayed monsoon hampers the yield due to changes in other weather parameters.

7. ABBREVIATIONS AND ACRONYMS

AEZ	agro-ecological zoning
CM	crop models
DM	data mining
EDM	exploratory data mining
GP	gaussian progression
GCM	general circular models
HY	high yield
LY	low yield
NDVI	normalized difference vegetative index
PDF	probability distribution function
RMSE	root mean square errors
WEKA	Waikato Environment for Knowledge Analysis

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