

Managing impact of extreme weather events in sugarcane in different agro-climatic zones of Uttar Pradesh

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सार – गन्ना उत्तर प्रदेश की नकदी फसल है, यहां के कृषकों की आर्थिक स्थिति बहुत हद तक गन्ने के उत्पादन पर निर्भर करती है। यद्यपि इस राज्य की औसत पैदावार 39.5 टन/ हेक्टेयर (1950-51) से बढ़कर 59.2 टन/ हेक्टेयर हो गई है, यह आकलन मौसमी परिस्थितियों के उतार-चढ़ाव से संबंधित है जबकि भारत में चीनी उत्पादक अन्य प्रमुख क्षेत्रों की औसत उपज 70 टन/ हेक्टेयर है। उपर्युक्त अध्ययन के परिणाम यह दर्शाते हैं कि राज्य के संपूर्ण कृषि जलवायविक क्षेत्रों के वार्षिक न्यूनतम तापमान (0.03 डिग्री Cyr^{-1}) में औसतन वृद्धि की प्रवृत्ति है। नौ कृषि जलवायविक क्षेत्रों में से चार क्षेत्रों नामतः दक्षिण पश्चिमी क्षेत्र मध्य मैदानी क्षेत्र पश्चिमी मैदानी क्षेत्र और पूर्वी मैदानी क्षेत्र में वार्षिक वर्षा में कमी की प्रवृत्ति देखी गई है। यद्यपि विन्ध्यान क्षेत्र, मध्य पश्चिमी क्षेत्र एवं भ्रमर तथा तराई के क्षेत्र में वर्षा में वृद्धि की प्रवृत्ति देखी गई है। गन्ने की पैदावार और मौसमी प्राचलों के बीच संबंधों की अच्छी व्याख्या करने के लिए इस शोध में यह भी बताया गया है कि गन्ने के अंकुरण, गुड़ाई, पूर्ण विकास और कटाई की अवस्थाओं में अधिकतम, न्यूनतम तापमान तथा नमी का महत्वपूर्ण योगदान होता है। खराब मौसम को ध्यान में रखकर विचारने पर हम पाते हैं कि 25 डिग्री सेल्सियस से नीचे का तापमान और 35 डिग्री सेल्सियस से 40 डिग्री सेल्सियस से ऊपर का तापमान विकास को धीमा कर देता है और अंततः पैदावार कम कर देता है। यह भी देखा गया है कि अत्यधिक तापमान और वर्षा से गन्ने की पैदावार के प्रभावित होने की संभावना रहती है परन्तु काफी संख्या में ऐसी भी घटनाएं मिलती हैं जिसमें पैदावार के उतार-चढ़ाव में अत्यधिक तापमान एवं वर्षा की प्रत्यक्ष कारण नहीं होते हैं। इसलिए इस शोध पत्र में उत्पादकता को अनवरत बनाए रखने के लिए किस्मों की अंगीकारी अनुक्रिया में सुधारों, कृषकों को मूल्यों पर आधारित मौसम से संबंधित परामर्शी सेवाएं प्रदान करके प्रचण्ड मौसमी परिघटनाओं से जुड़ी जोखिम प्रबंधन और फसल बीमा ऐजन्सियों की अनुशंसा की जाती है।

ABSTRACT. Sugarcane is a cash crop in Uttar Pradesh; economic condition of the farmers is highly dependent on sugarcane production. However, average yield of the state has gone up from 39.5 t/ha (1950-51) to 59.2 t/ha (2009-10), was observed associated with fluctuating weather conditions, whereas other major sugar producing area in India have average yield of 70 t/ha. The result of the above study showed that there was an average rising trend in the annual minimum temperature (0.03° Cyr^{-1}) over all the agro-climatic zones of the state. Out of nine agro-climatic zones, four zones namely South Western Zone, Central Plain Zone, Western Plain Zone and Eastern Plain zone, which were marked by decreasing annual rainfall trend. However, Vindhyan Zone, Mid Western Zone and Bhabhar and Tarai Zone show rising trend. To explain better relation between cane yield and weather parameters this study also show that maximum, minimum temperature and moisture plays the most important role during germination, tillering, grand growth and ripening phases of the sugarcane. Considering extreme weather, we found that temperature below 25 °C, above 35 °C and 40 °C are slowing down the growth and finally reducing the final yield. It is also noticed that temperature and rainfall extremes had high possibility of governing sugarcane yields but there were also quite a number of instances wherein the extremes couldn't be reasoned directly for the yield fluctuations. Therefore, to sustain the productivity, this study recommends the improvements of the adoptive responses of varieties, management of the risk associated with extreme weather events by providing weather linked value-added advisory services to the farmers and crop insurance agencies.

Key words – Extreme weather, Climate variability, Sugarcane, Management.

1. Introduction

Sugarcane is one of the most important cash crops of the country and plays a pivotal role in the country's agricultural and industrial economy. Sugar industry is the second largest agro-based processing industry after

textiles in the country. Sugarcane crop occupies merely 2.5 per cent of India's gross cropped area and accounted for about 6 per cent of the total value of agricultural output during 2013-14 (Price policy for Sugarcane, 2013). About 6.0 million farmers are engaged in its cultivation and employment is provided to millions in this industry,

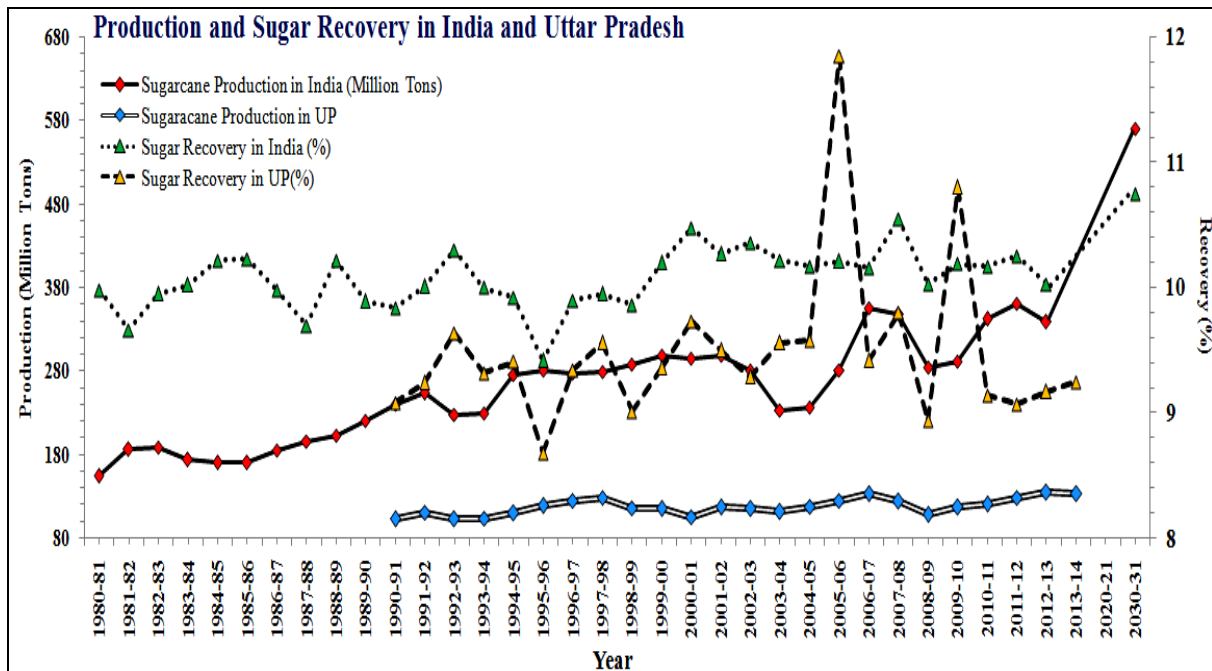


Fig. 1. State-of-the-art of sugarcane production and per cent recovery in India and Uttar Pradesh (Source : Cooperative Sugar, 2014)

export and territory sectors related to sugarcane. In terms of area (5.0 million ha) and production (~340 million tonnes) of sugarcane, India ranks second after Brazil among important sugarcane producing countries of the world. However in terms of productivity, India ranks tenth. Uttar Pradesh (U. P.) has distinguished itself as a 'sugarcane state' on account of its largest share of sugarcane area (~2.2 million ha, 47%, 1st in India) and production (135 million tonnes, 40%, first in India) and therefore sugarcane cultivation becomes the largest contributor to the economy and industrial development of the state (Samui *et al.*, 2014; IISR, 2011; Sugar Policy, 2013; DSD, 2013). There is still substantial scope to increase both productivity and sugar recovery of sugarcane crop in Uttar Pradesh to meet the 2030 demand (Fig. 1) *i.e.*, sugar recovery of 10.75, productivity of 100-110 t/ha and sugarcane production up to 520 million tonnes of (IISR, 2011).

It is known that worldwide agricultural production is governed by the combination of climate, soil tilth, technology, genetic resources, and farm management decisions such as tillage, manure and fertilizer applications, and crop variety selection. The best available science exploring the cause and effect relation of climate change and crop physiology underscore the fact that the effects of climate variability will be quite adverse for an up keep of sustainable global productivity (Aggarwal *et al.*, 2009; Aggarwal & Singh, 2010; Wani *et al.*, 2010;

Chandrashekar, 2010; Lobell and Gourdj, 2012; Pathak *et al.*, 2014). Keeping in the backdrop, the above discussion regarding impact of climate variability and change on crop productivity, it becomes obvious that sugarcane cropping will too experience the adversities (Mall and Singh, 2000; Mall and Gupta, 2002; Singh *et al.*, 2010; Srivastava and Rai, 2012; Samui *et al.*, 2014; Bhaskaran and Nair, 2014). India being the developing country, it is recently projected that it may have to suffer on an average 10-25 per cent of decline in agricultural productivity by 2080 due to average temperatures crossing the crop tolerance levels (Mahato, 2014).

The newer findings indicate that warming is more pronounced than expected. The impact would be particularly severe in the tropical areas, which mainly consist of developing countries, including India (Sathaye *et al.*, 2006; Mall *et al.*, 2011; Mall, 2013; Bhatt *et al.*, 2015). Increasing temperature trends of the order of 0.60 °C during last 112 years (IMD 2012) and increase in heavy rainfall events and decrease in low and medium rainfall events (Goswami *et al.*, 2006) over India have been observed. Changes in rainfall and temperatures have also been reported by De *et al.* (2005), Arora *et al.* (2005), Guhathakurta and Rajeevan (2008), Dash *et al.* (2009), Tyagi and Goswami (2009), MoEF (2010), Kothawale *et al.* (2010), Kothawale *et al.* (2012), Lobell *et al.* (2012) and Jain and Kumar (2012).

For India as a whole, the significant decreasing trend in the frequency of cold days and increasing trend (close to 5% significant level) in frequency of hot days have been found (Dash and Mamgain, 2011). However Indian monsoon does not show any significant trend except a slight decrease of 0.4 mm /year (From 1871-2009) (Mall *et al.*, 2007; MoEF, 2010). A study (Kumar *et al.*, 2006) conducted for whole of the country emphasized on the observation that night temperatures have been found increasing at a faster rate than that of day whereas it also projected that both the extremes of maximum and minimum temperature are to increase in future. Nevertheless, some studies have been found to show some clear trends for precipitation parameter for example, Central and North India have been reported to witness the decrease in the frequency of heavy rainfall events whereas the peninsular east and north east India have been reported to experience an increase for the same (Rajeevan *et al.*, 2008; Guhathakurta *et al.*, 2011; Duhan and Pandey, 2013). Central India is also reported to have witnessed almost no clear trend in rainfall in monsoon season but has experienced both increasing and decreasing trend in extreme rainfall (≥ 70 mm) for a period of 1901 to 2010 (Dubey and Krishnakumar, 2014). A study (Chand *et al.*, 2011) pertaining to Bundelkhand zone of Uttar Pradesh (Jhansi district) carried out 34 years of rainfall analysis reporting that most of the rainfall in the region was received in South West Monsoon and that since 2000 onwards the zone had frequently been confronted with increasing frequency of droughts. It is recently reconfirmed that the frequency and intensity of the rainfall events has highly uncertain distribution on spatio-temporal scale (Pai *et al.*, 2015).

According to IPCC (2013) as compared to 1986 - 2005, the global mean surface temperatures are projected to *likely* to experience an increase of 0.3 °C (minimum of RCP2.6) to 4.8 °C (maximum of RCP 8.5) for 2081-2100. For temperature extremes it is *very likely* projected that heat waves will occur with greater frequency and greater duration with occasional cold winter extremes. Aberrations in water cycle projected by IPCC (2013) highlight the fact that monsoon retreat would be delayed there by lengthening the monsoon season regionally along with more intense and more frequent extreme events by the end of the century. Other than IPCC's global outlook towards the trend in climate extremes, many regional studies (Piao *et al.*, 2010; Chen *et al.*, 2012; Laborte *et al.*, 2012; Pathak, *et al.*, 2014; Barlow *et al.*, 2015 and Rezaei *et al.*, 2015; Talukder *et al.*, 2014) aimed at impact of extreme weather events on the global crop productivity have been conducted.

Climate projections developed for India for the 2050s, indicate an increase in average temperature by 2-4 °C, decrease in the number of rainy days by more than

15 days in western and central India and an increase by 5-10 days near foothills of Himalayas and in northeast India. Estimations for frequency of flooding for various regions in the 2030s show a variation between 10% and over 30% of the magnitudes in the 1970s (MoEF, 2010). A recent study by Unnikrishnan *et al.* (2015) shows that the Indian Ocean has shown acceleration over the past two decades in a similar manner reported at global scale in the SPM, showing a global mean sea-level rise of 1.7 mm yr⁻¹ between 1901 and 2010 and of 3.2 mm yr⁻¹ between 1993 and 2010.

In Indian scenario, crop productivity tends to face the similar vagaries of the weather in particular the extreme events jeopardizing the socio-economic demand, therefore we need to make better policy and planning disaster risk reduction in future (Mall *et al.*, 2006; Geethalakshmi *et al.*, 2011). Unlike different crops grown in India, which are marked by their defined biotic and abiotic optimums, sugarcane productivity too depends on different weather optimums. For example, temperature range of 25 - 35 °C stands as optimum for good sugarcane yield and recovery with a total water requirement of ~2000mm (IISR, 2011; Samui *et al.*, 2014). Therefore, higher or lower temperature and precipitation conditions with others could be held responsible for the fluctuations in the crop yield.

Therefore as discussed above and also known that sugarcane is a cash crop in U.P., economic condition of the farmers is highly dependent on sugarcane production. However, average yield of the state has gone up from 39.5 t/ha (1950-51) to 59.2 t/ha (2009-10), was observed associated with fluctuating weather condition, whereas other major sugar producing area in India have average yield of 70 t/ha. The production of the crop is sensitive to fluctuations to climatic variability. Though there are plenty of studies in India and there are some for Uttar Pradesh too studying the impact of weather parameters on crop productivity, in specific for extreme events, yet there is hardly any study on Agro-Climatic Zones wise of the state. Hence, following is an attempt to explore the zone wise impact of weather extremes on sugarcane with a special reference towards the management of weather constraints and determining strategies for increasing/sustainable production in the region through better agronomic management.

2. Data and methodology

2.1. Study site

Uttar Pradesh is located in Indo-Gangetic Plains of India and falls between 23°50' - 30°45' N and 77°04' - 84°38' E. It covers an area of 2.94 lakh km². It is divided

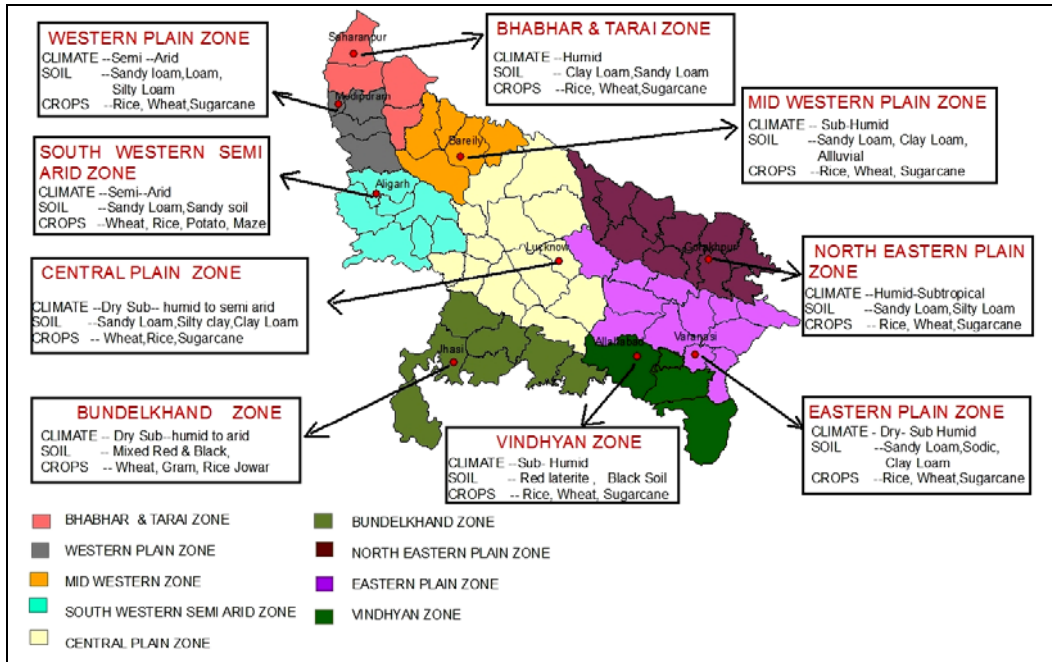


Fig. 2. Climate and soil type in different agro-climatic zone of Uttar Pradesh

TABLE 1

General description of the nine agro-climatic zones of Uttar Pradesh

Agro-climatic Zones*	Average temperature (°C)		Magnitude of change in temperature/decade (°C)		Average annual rainfall (mm)	Magnitude of change in rainfall/decade (mm)	Average productivity (t/ha)
	Maximum temperature	Minimum temperature	Maximum temperature	Minimum temperature			
South-western Semi-arid Zone (SWZ)	31.8	18.5	0.25	0.20	713	-4.91	51.0
Vindhyan Zone (VZ)	32.6	19.5	0.12	0.23	936	4.62	41.1
Mid Western Plain Zone (MWZ)	30.4	18.1	0.15	0.45	1045	3.43	52.1
North Eastern Plain Zone (NEZ)	31.2	18.1	-0.17	0.19	1287	0.6	51.9
Bundelkhand Zone (BKZ)	32.2	18.1	-0.01	0.34	861	0.12	38.7
Central Plain Zone (CPZ)	31.4	18.2	-0.17	0.13	900	-1.94	45.5
Western Plain Zone (WPZ)	29.9	18.2	0.45	0.39	781	-2.25	58.7
Bhabar & Tarai Zone (BTZ)	27.0	14.3	0.08	0.25	1415	17.97	57.2
Eastern Plain Zone (EPZ)	31.7	19.5	0.04	0.10	910	-2.70	41.3

*Perspective and Strategic Plan (2009-2027), Department of Land Development and Water Resources, Government of U. P.

into nine agro-climatic zones namely, Bhabhar & Tarai (BTZ), Western Plain (WPZ), Mid-Western Plain (MWZ), South-Western Plain (SWZ), Central Plain (CPZ), Bundelkhand (BKZ), North-Eastern Plain (NEZ), Eastern Plain (EPZ) and Vindhyan region (VZ) and accordingly

nine stations have been selected representing each zone of the state for the present study. Locations of these stations with latitude and longitudes and information related to weather parameters, soil type and major climatic classification are shown in Table 1 and Fig. 2.

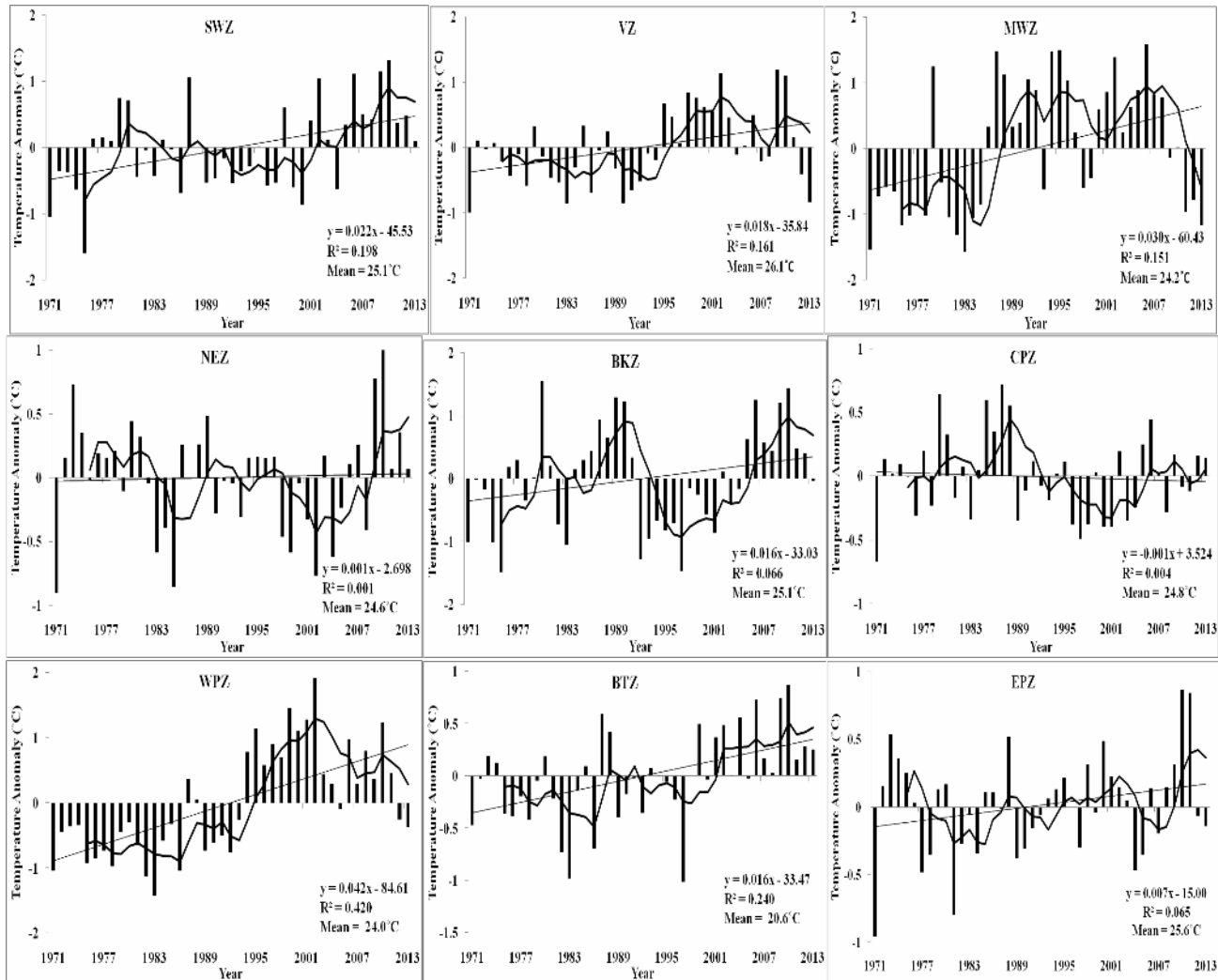


Fig. 3. Annual mean temperature anomalies over nine agro-climatic zones of Uttar Pradesh

2.2. Data and analysis

The observed daily long-term maximum temperature, minimum temperature and rainfall data from 1971-2013 were collected from the Indian Meteorological Department, New Delhi as well as from various state Agriculture Universities and State level Governmental Organizations. Sugarcane yield data were obtained from the Krishi Bhawan, Lucknow, Uttar Pradesh and from the Government of India's national portal for information through Department of Agriculture & Cooperation (DACNET) (<http://eands.dacnet.nic.in/>).

Long term daily data were converted to monthly data and Mann Kendall Test at 0.05% significance level have been applied to detect the trend in the weather data. Data for total sugarcane yield of the nine agro-climatic zones were correlated with the weather parameters of each

representative zone for each of the growth stage with that of the annual sugarcane yield and accordingly the correlation coefficient (Pearson) values were computed. This study is founded on the assumption that only temperature and rainfall are influencing the sugarcane yields while the rest of the meteorological parameters are kept as constant. This section is followed by phase wise assessment of the ranges tripping over the crop optimums under the influence of Temperature and Rainfall extremes.

3. Results and discussion

3.1. Climate and sugarcane yield variability

The analysis for mean temperature and rainfall resulted into an overall increasing trend for all the various Agro-climatic zones of Uttar Pradesh. Though these trends were meagerly positive at 5% significant level. We

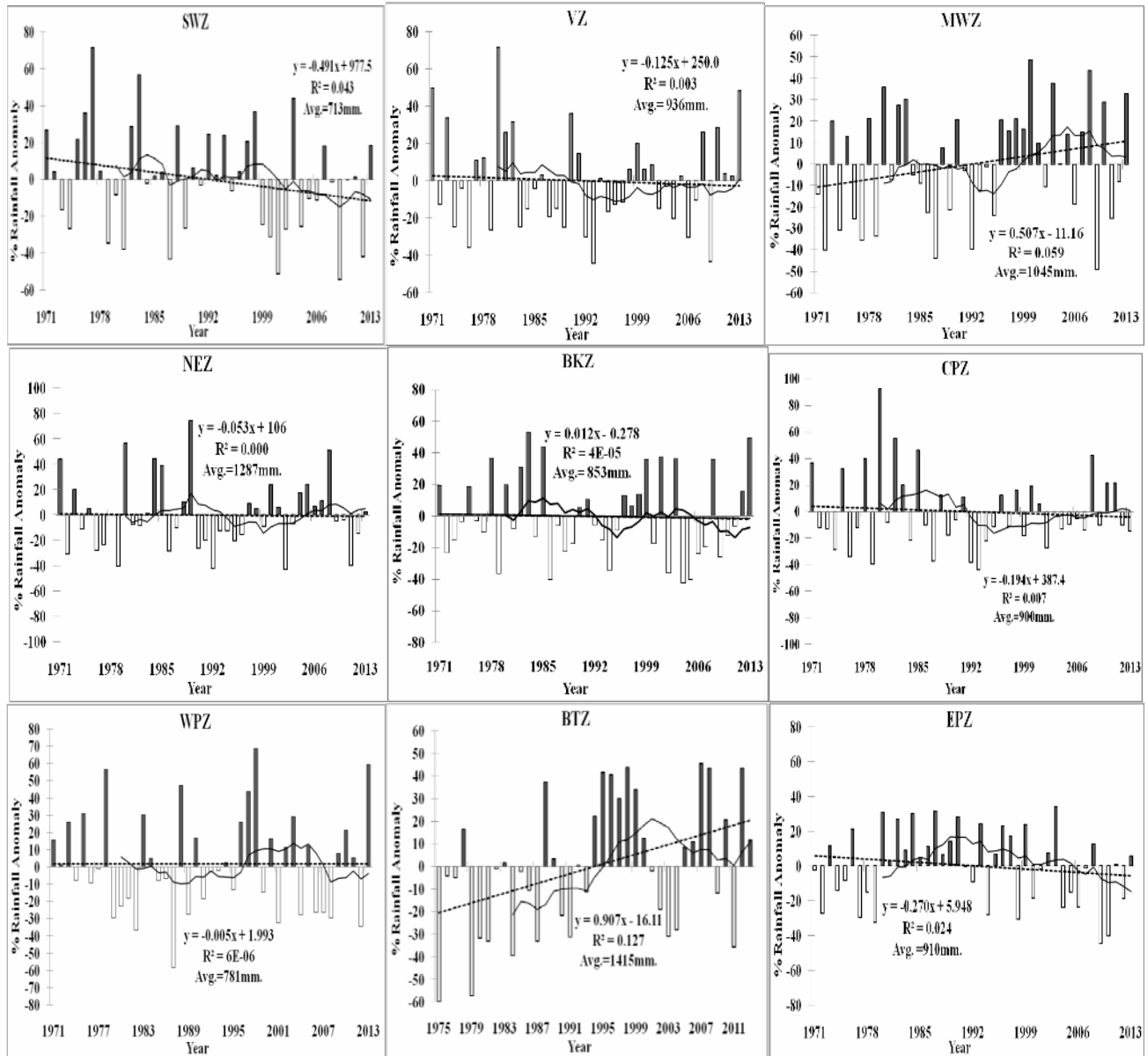


Fig. 4. Annual rainfall anomalies over nine agro-climatic zones of Uttar Pradesh

found zone wise increasing trends of mean temperature varied from each other in WPZ, MWZ, SWZ, VZ, BKZ, and EPZ and were 0.04, 0.03, 0.02, 0.02, 0.02 and 0.01 °C yr⁻¹ respectively. However CPZ shows decline trend (-0.02 °C yr⁻¹) in mean temp., and especially there was consistent decline in the maximum temperature (Fig. 3). Decreasing trend in rainfall observed in SWZ and EPZ, however increasing trend of rainfall has been observed in MWZ and BTZ (Fig. 4).

Different zones of Uttar Pradesh show overall increasing trend in the sugarcane yield with approximate trend of 0.5 t/ha yr⁻¹. Highest average yield of

approximately 58.68 t/ha was found in WPZ and BTZ and lowest yield of 38.74 t/ha was found in BKZ. In a study it is found that 32-39% of global crop variability is due to climate variability though climate variability cannot be considered a sole controlling factor for the same (Ray *et al.*, 2015).

3.2. Sensitivity of sugarcane yield to maximum & minimum temperature

We analyzed cane yield for two consecutive years in different zones to study the climate variability and its impacts, as variety, management practices etc. cannot be

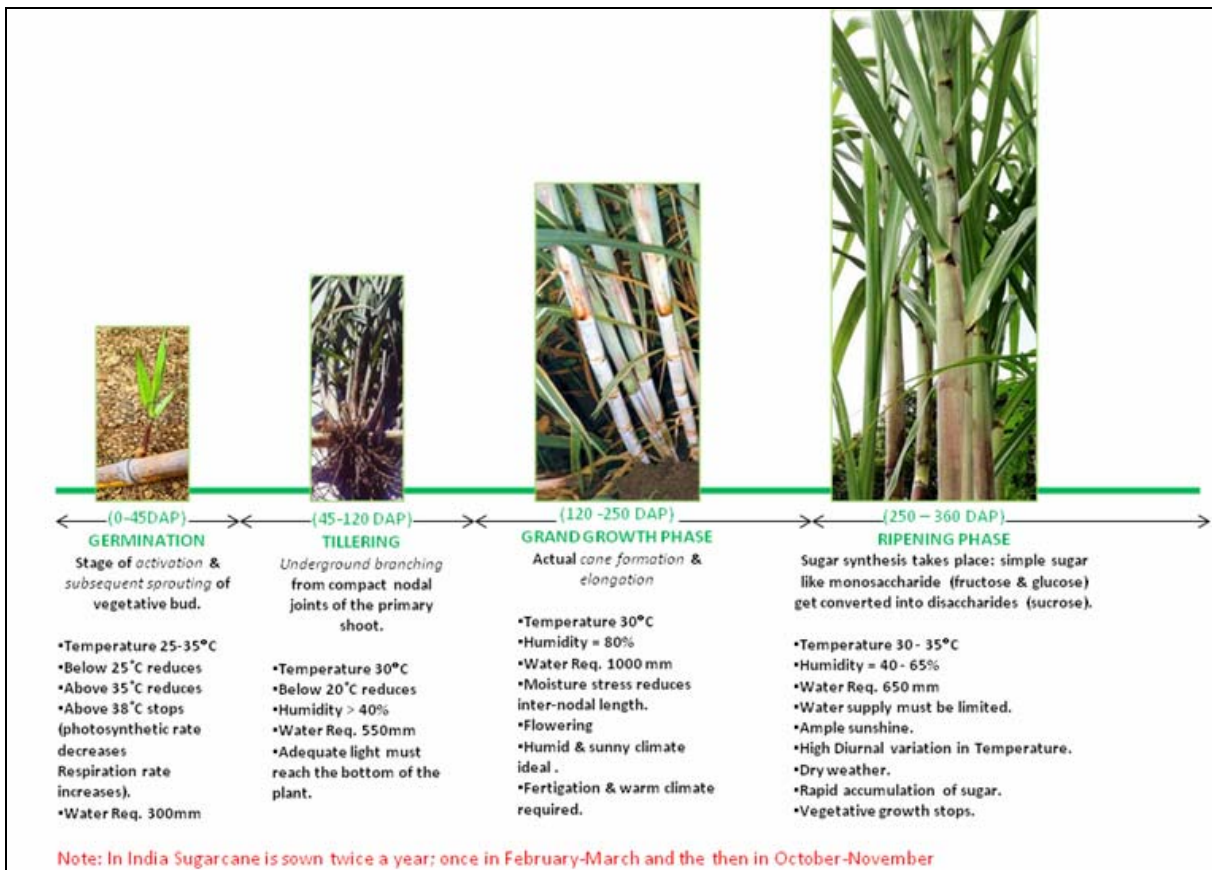


Fig. 5. Various phenological stages of sugarcane crop in India

changed drastically during two consecutive years. Sugarcane productivity show increasing trend in SWZ, with the magnitude of 0.7 t/ha yr^{-1} . The average sugarcane yield was 51.1 t/ha . In the year 1987 the yield (43.0 t/ha) was very low (-15.7% as compared to normal yield in the SWZ) as maximum temperature was high and the minimum temperature was low. This year there was drastic rainfall deficiency as this year was declared as the severe drought and was an El Nino year too, which might be held being the cause of decline in the yield. Very next year during 1988, the yield shows a large jump to 53.26 t/ha *i.e.*, about 23.8% increases compare to 1987, because both the maximum and minimum temperature was around optimum temperature accompanied by a good rainfall compared to the previous year. This year was also declared as the La-Nina year. Again analyzing two consecutive year 2003 and 2004, we found that cane yield in 2004 was about 11% less as compared to 2003. During 2004 rainfall was deficient ($\sim 25\%$) as compared to normal rainfall. In 2007, the yield declined to 6.8% compared to the year 2006, as there was decline in temperature maximum and minimum throughout the year. Again in

2009, there was decline in the yield due to deficiency in the rainfall.

Sugarcane productivity in VZ also shows effects of climate variability. In 1991 cane yield rose up to 57.3 t/ha as compared to 1990's 27.2 t/ha , because during 1991 maximum and minimum temperature was fluctuating around optimum temperature of sugarcane. Again in 1992, there was decline in the maximum and minimum temperature and rainfall lead to the reduction in the yield. From 2000 to 2003 there was drastic decline in the yield as there was warming conditions in these years as increase in the maximum temperature and decrease in the minimum temperature. Year 2002 was the El-Nino year, observed the very less rainfall and was declared as the drought year, which is possible reason for the decline in yields. In 2005, again there was drastic decline in the yield (33.1 t/ha) due to the sharp decline in the minimum temperature as compared to the previous year and heavy rainfall during the year. From 2008 to 2009 the yield declined nearly up to 20.8% as in implication of decline in maximum and minimum temperatures as well as rainfall.

Observations for 2010 for increase minimum temperature and rainfall could be taken as cause behind the rise in the yield (58.34 t/ha).

In MWZ, the average yield of sugarcane was 52.10 t/ha. Comparing the year 2002 and 2003, the yield drastically declined in 2002, the temperature maximum and minimum was high but the rainfall was very less as this year declared as severe drought. In the consecutive year, 2003, though there was a following decline in the yield, there was decline in the minimum and maximum temperature with severe rainfall. The high yield (62.6 t/ha) in 2004 could possibly be reasoned by adoption of good variety and management practices as the weather parameters showed normal trend near to optimum. In 2008, the yield fell by 3.1%, which may be due to severe rainfall leading to water logging. Whereas in 2009, low rainfall accompanied by good distribution during the year seemed to allowed rise in the yield.

In NEZ, the average cane yield was 51.88 t/ha. Comparing the year 2011 and 2012, the yield was drastically declined in 2011, the temperature maximum and minimum was normal but the rainfall (779 mm) was less and declared as drought. In the consecutive year, 2012 yield increases due to optimum temperature and good amount of rainfall (1108 mm). BKZ shows interesting figure as in 2004 high can yield (60.2 t/ha) followed by next year declined up to 22.5 t/ha however rainfall was high in 2005 as compared to 2004 but were marked by consecutive rise and fall in the yield mainly because of large difference between the two years' minimum temperature.

3.3. Different growth stages of sugarcane

To explain better relation between cane yield and weather parameters at different growth stages, the effect of each of weather parameters on cane yield was studied by working out the correlation at different stages of the crop (Fig. 5) and the computed correlation coefficient (Pearson) values are enlisted in the Table 2.

3.3.1. Germination phase

The germination period lasts for about 40 days from the date of planting. The base temperature for the germination is 12 °C. In sugarcane, activation and sprouting of vegetative bud occurs in this phase. Generally the optimum temperature for germination is 20 °C to 32 °C (Biswas, 1988; Samui *et al.*, 2003). The optimum temperature requirement during this stage is about 26.8 °C (Raheja, 1959). However in the state, at this stage sugarcane experienced maximum temperature in the range of 27-33 °C, with a average maximum temperature of

30.6 °C. Therefore that is affecting the germination and in final cane yield of sugarcane in the different region of U.P. where maximum temperature was higher than optimum.

If we see across different zones *i.e.*, SWZ, VZ, MWZ, WPZ and BTZ show positive correlation with the sugarcane yield and maximum temperature. Highest correlation coefficient (0.38, not significant) was found in MWZ. If we consider the spatial variation in the weather parameter in the state we observed that during germination stage, maximum temperature varied between 30 to 32 °C showing increasing trend from EPZ to CPZ in the state. Maximum temperature was less by 2 °C in the EPZ compared to the CPZ. The minimum temperature and cane yield show positive correlation in all the stations with the maximum coefficient value of 0.60 (significant at 5% level) in MWZ, except in BKZ and EPZ which show negative correlation marginally (Table 2).

3.3.2. Tillering phase

Tillering starts after around 40 days from the date of planting and lasts up to 100 to 120 days. In this growth phase minimum temperature plays important role towards yield. The crop experiences afternoon humidity about 33%, an average minimum temperature of 23.5 °C and total rainfall around 23.5 mm. In this phase, underground branching from compact nodal joints of the primary shoot occurs. Tillering provides the crop with appropriate number of stalks required for good yield. At the tillering phase the optimum temperature should be 25 °C to 30 °C. Below 20 °C the tillering retards and affecting final cane yields. In SWZ, MWZ, BKZ, WPZ and EPZ, the maximum temperature in this phase show positive correlation with yield (Table 2), whereas negative correlation were found in VZ, WPZ, CPZ and BTZ. The positive correlation with minimum temperature was found in VZ, MWZ, NEZ, WPZ, BTZ and EPZ, whereas negative correlation was found in SWZ and BKZ and in CPZ no correlation was found. Overall mean temperature show positive correlation in SWZ, MWZ, WPZ, BTZ and EPZ, whereas in rest of the districts, the yield is negatively correlated. Rainfall show positive correlation in VZ, MWZ, CPZ and EPZ only and in rest of districts the yield is negatively correlated.

Increasing trend of maximum temperature was observed from northern zone to southern zone of the state. Normally no correlation or negative correlation found between cane yield and maximum temperature in this growth stage. Rainfall shows increasing trend from southern zone to northern zone. An adequate supply of soil moisture is essential for good growth in this stage (Fig. 5). Crop generally experiences moisture stress during

TABLE 2

Relation between the weather parameters and the sugarcane yield at different phenological phases of the crop over nine agro-climatic zones of Uttar Pradesh

Zones	Variables	Germination	Tillering	Grand Growth	Ripening
SWZ	Temperature Maximum	0.21	0.20	0.06	0.04
	Temperature Minimum	0.14	- 0.08	-0.16	0.09
	Temperature Mean	0.20	0.09	-0.04	0.06
	Rainfall	-0.04	- 0.03	-0.04	-0.29
VZ	Temperature Maximum	0.26	-0.11	0.12	-0.17
	Temperature Minimum	0.32	0.09	0.43	0.11
	Temperature Mean	0.31	-0.02	0.33	-0.02
	Rainfall	-0.15	-0.37	0.037	-0.16
MWZ	Temperature Maximum	0.38	0.43	0.12	0.18
	Temperature Minimum	0.61*	0.54*	0.58*	0.55*
	Temperature Mean	0.53*	0.52*	0.36	0.44
	Rainfall	0.07	0.08	-0.14	0.15
NEZ	Temperature Maximum	0.02	-0.23	-0.12	-0.05
	Temperature Minimum	0.29	0.03	0.09	0.33
	Temperature Mean	0.14	-0.18	-0.03	0.14
	Rain	-0.09	-0.14	-0.28	0.18
BKZ	Temperature Maximum	-0.04	0.14	0.22	0.04
	Temperature Minimum	-0.44	-0.35	0.07	-0.37
	Temperature Mean	-0.29	-0.16	0.21	-0.27
	Rainfall	0.04	-0.15	0.19	-0.02
CPZ	Temperature Maximum	-0.13	-0.26	-0.17	-0.38
	Temperature Minimum	0.53*	0.00	0.21	0.19
	Temperature Mean	0.15	-0.19	-0.06	-0.16
	Rainfall	-0.09	0.16	-0.27	0.09
WPZ	Temperature Maximum	0.38	0.44	0.44	0.31
	Temperature Minimum	0.45	0.29	0.61*	0.52*
	Temperature Mean	0.45	0.40	0.58*	0.50*
	Rainfall	-0.08	-0.00	0.01	0.16
BTZ	Temperature Maximum	0.14	-0.00	0.09	-0.01
	Temperature Minimum	0.33	0.12	0.49*	0.51*
	Temperature Mean	0.21	0.06	0.21	0.30
	Rainfall	-0.06	-0.13	0.40	0.18
EPZ	Temperature Maximum	-0.04	0.19	-0.18	-0.14
	Temperature Minimum	0.01	0.18	0.32	-0.14
	Temperature Mean	-0.03	0.26	0.09	-0.21
	Rainfall	-0.04	0.02	0.08	-0.00

*Significant at 5% level

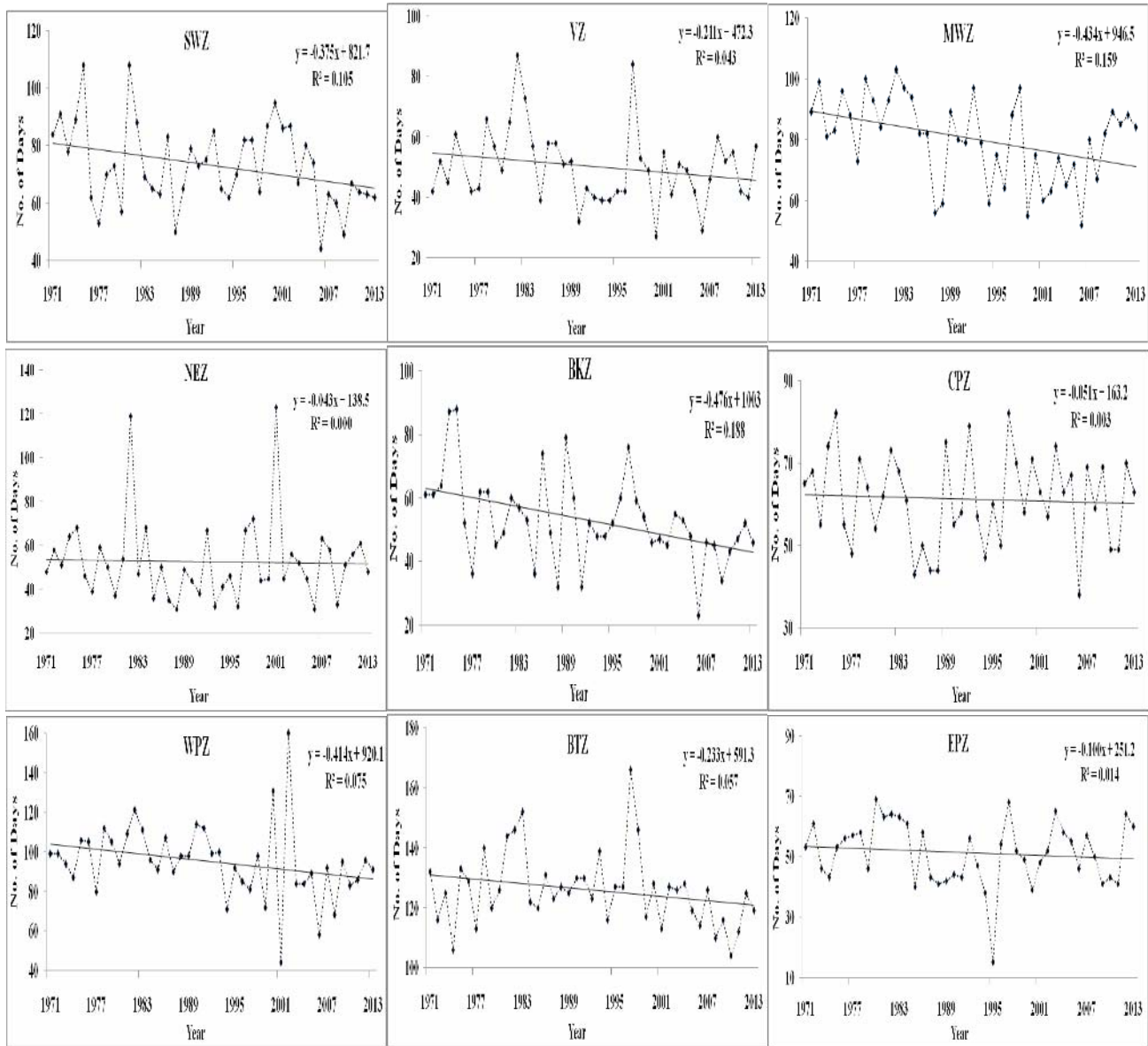


Fig. 6. Number of days < 25 °C estimated for the nine agro-climatic zones of Uttar Pradesh

this stage as it is coincided with summer months and therefore affects growth and yield. During this stage sugarcane received very less rainfall (10-20 mm) as compared to its requirement of 550 mm. Therefore, a small increase in rainfall in this phase enhances the growth and higher final cane yield.

3.3.3. Grand growth phase

This phase starts from 120 after the day of planting and lasts up to 250 to 270 days. This is the most important phase of the crop wherein the actual cane formation and

elongation and thus yield buildup takes place. The optimum temperature in this period is around 30 °C. The spatial variation of maximum temperature ranged between 31-44 °C at this stage. Minimum temperature ranged between 23 to 28 °C. The rainfall during this stage ranges between 400-1000 mm showing increasing trends from SWZ to NEZ of the state. Zone wise SWZ, VZ, MWZ, BKZ and WPZ cane yield show positive correlation with maximum temperature with highest value of 0.44 and WPZ. NEZ, CPZ, BTZ and EPZ show negative correlation. Temperature minimum show positive correlation with yield in all the districts except in SWZ

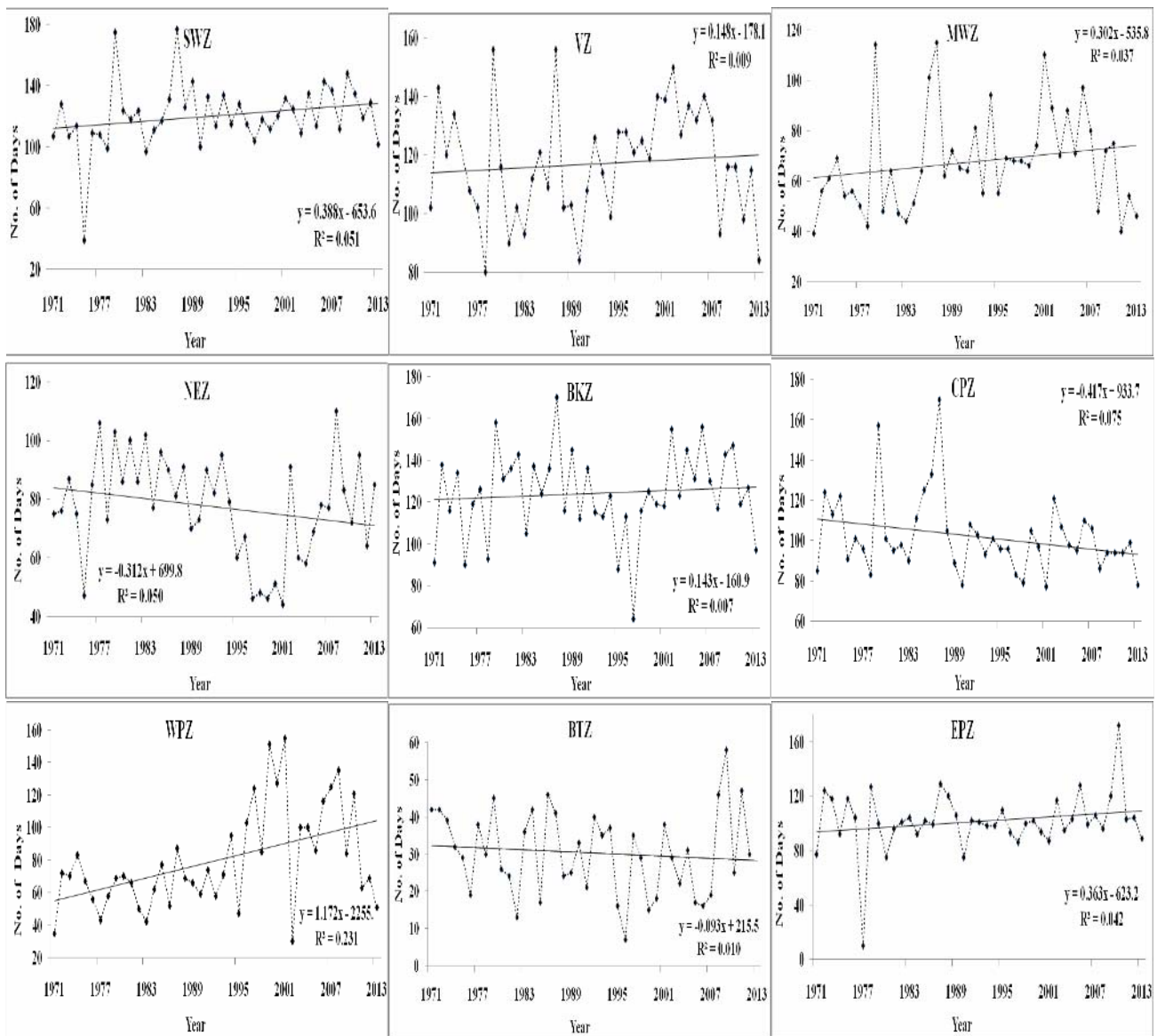


Fig. 7. Number of days >35 °C estimated for the nine agro-climatic zones of Uttar Pradesh

with highest positive value of 0.61 and in WPZ negative correlation of about -0.16. Overall mean temperature show positive correlation in VZ, MWZ, BKZ, WPZ, BTZ and EPZ and in rest of the districts it is negatively correlated.

3.3.4. Ripening phase

This phase lasts for about 250 to 360 days after planting. Sugar synthesis and rapid accumulation of sugar takes place during this phase and vegetative growth is reduced. Maximum temperature shows positive correlation in SWZ, MWZ and BKZ whereas the yield declined in VZ, NEZ and CPZ. Minimum temperature

favoured the yield in all the districts except in BKZ where the yield was negatively correlated. Overall mean temperature show positive correlation in SWZ, MWZ, BKZ and WPZ. VZ, NEZ, CPZ and EPZ show negative correlation, whereas BTZ does not show any relation. Rainfall favored the yield in MWZ, NEZ, CPZ, WPZ and BTZ whereas the yield declined in SWZ, VZ, BKZ and EPZ.

3.4. Extreme weather and its effects

As discussed above temperature and rainfall play an important role in the growth and productivity of the crop.

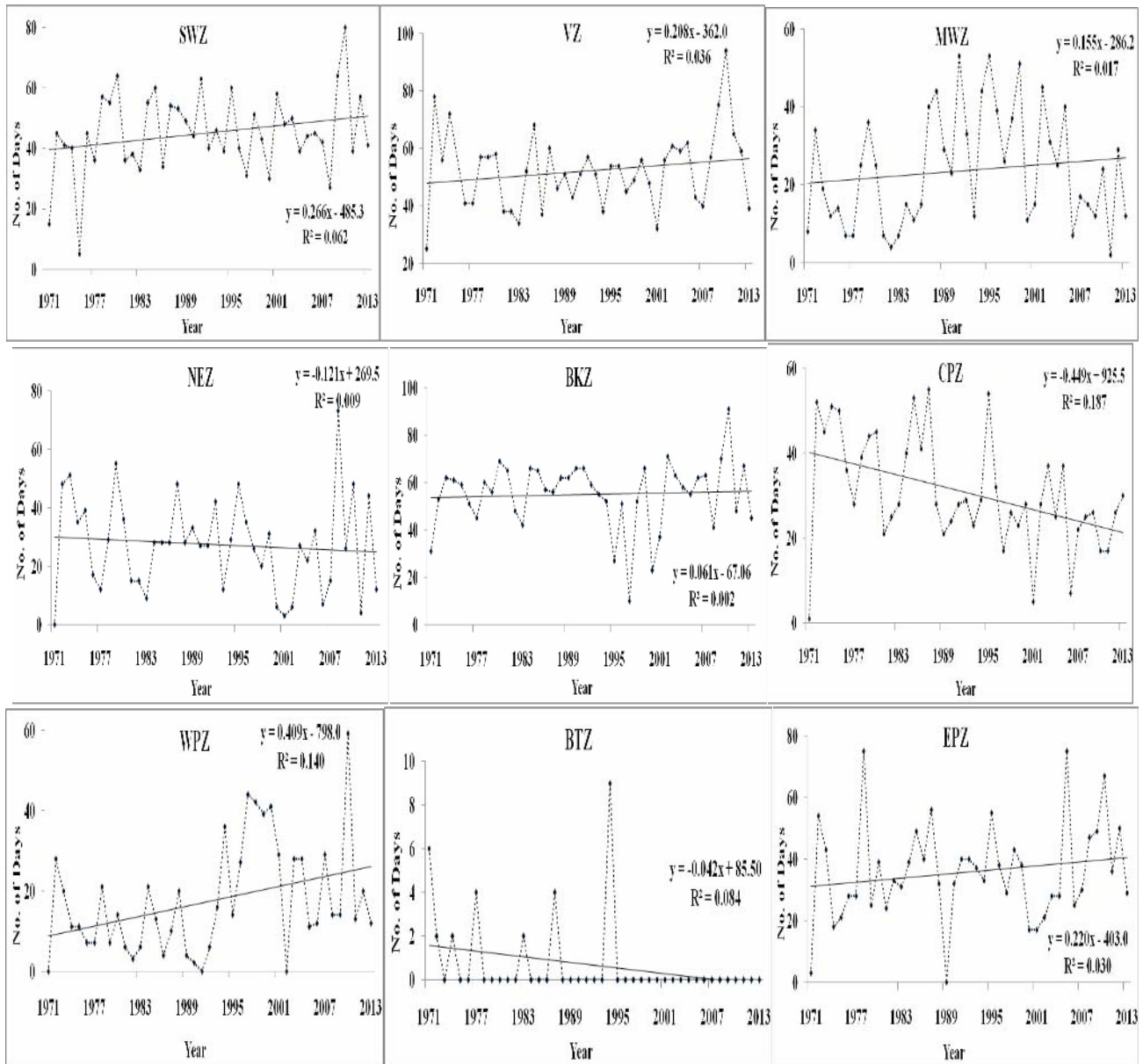


Fig. 8. Number of days $>40^{\circ}\text{C}$ estimated for the nine agro-climatic zones of Uttar Pradesh

During different phases certain optimum and threshold temperature is required, beyond which crop may have severe effect on the growth, yield and recovery of sugar. Temperature below 25°C and above 35°C may slow down the growth. Fig. 6 shows the number of days less than 25°C across the different Agro-climatic zones of U.P. during the crop season. Fig. 7 shows the number of days greater than 35°C across the different agro-climatic zones of U.P. during the crop season. Fig. 8 shows the number of days greater than 40°C across the different agro-climatic zones of U.P. during the crop season. Fig. 9 shows the number of rainy days across the different agro-

climatic zones of U.P. during the crop season. Whereas $>40^{\circ}\text{C}$ shows the number of days during which heat waves developed as per the criteria given by Indian Meteorological department, New Delhi. Number of rainy days (≥ 2.5 mm a day) were also estimated as per the criterion of IMD. In all the zones, the number of days $<25^{\circ}\text{C}$ shows declining trend. Low temperature below 20°C to 12°C may reduce the rate of vegetative growth and sucrose content in cane (Fageria *et al.*, 2010). Number of days $>35^{\circ}\text{C}$ show declining trend in NEZ, CPZ and BTZ whereas, in rest of zones increasing trend was observed. Temperature above 38°C increases the rate of

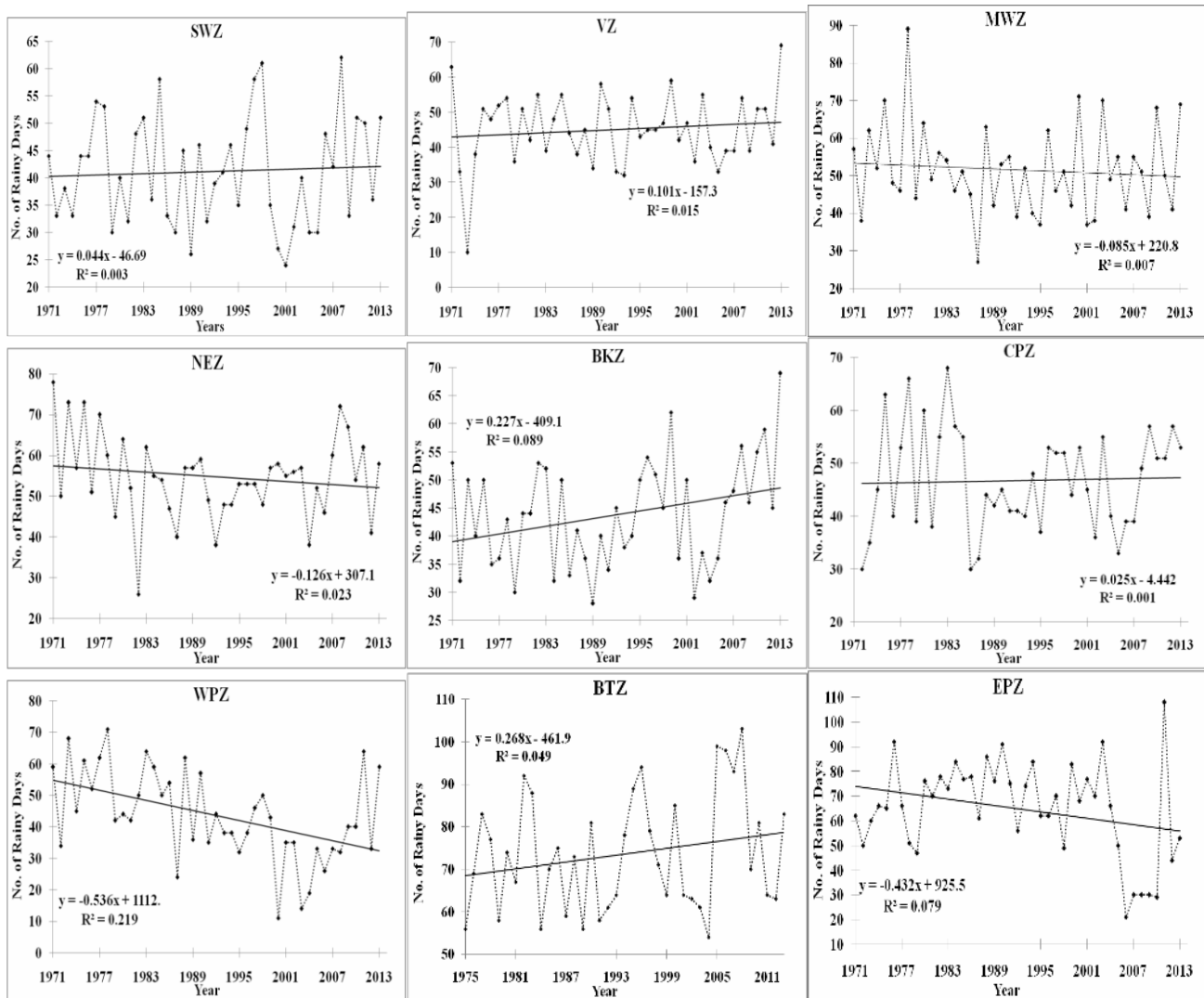


Fig. 9. Number of rainy days estimated for the nine agro-climatic zones of Uttar Pradesh

respiration and reduces the rate of photosynthesis (DSD, 2013). Temperature $>40^{\circ}\text{C}$ shows increasing trend in zones SWZ, VZ, MWZ, BKZ, WPZ and EPZ. High temperature occurring for few hours could drastically reduce the production (Rao *et al.*, 2015; Teixeira, 2013) and may enhance the risk of pest infection on the crop and may influence the accumulation of sucrose content and may reverse sucrose into fructose and glucose. Increased photorespiration due to high temperature may reduce the sugar accumulation (Gawander, 2007; Srivastava and Rai, 2012).

Considering each of the nine agro-climatic zones into which the state has been divided it is observed that EPZ, BTZ, WPZ and MWZ all are facing large fluctuations when compared with their respective zonal

mean for annual rainy days. Such fluctuations underscore the fact that the study period pertaining to these zones suffered good number of rainfall extremes as compared to the other zones.

An in depth study of total rainy days in the span of 42 years revealed that extremes with >50 mm/day count were significantly high for EPZ, BTZ, WPZ and MWZ respectively. The impact of high rainfall events on sugarcane cropping system can generate a state of poor root respiration, loss of nutrients, crop lodging due to excessive branching and leaching of sucrose. An excess moist or water logged condition may upset (Mali *et al.*, 2014) the ripening stage of sugarcane crop leading to low sugar recovery as this phenological stage demands dry climatic conditions for good productivity.

3.4.1. Germination phase

In SWZ, number of days less than 25 °C was found to be maximum in the year 1971 and 1982 and that year cane yield was very low. In VZ, year 1973 have the maximum number of days less than 25 °C affected final yield which was about 29.2 t/ha. MWZ, have maximum count in the year 1978 (yield 34.0 t/ha). In BKZ the maximum number of days less than 25 °C was found in 1979 resulted yield was 23.8 t/ha. Whereas, CPZ the maximum number of days less than 25 °C was in the year 1984 (yield 36.6 t/ha). Temperature less than 25 °C may affect the sprouting of the stem cutting of the cane.

In SWZ, number of days greater than 35 °C were maximum in the 2008, whereas in VZ, the maximum counts was in 2009-affected cane yield, which was around 43.7 t/ha. Temperature might affect germination stage and it reduces and stops above 38 °C. Temperature greater than 40 °C is considered to be heat waves according to the Indian Meteorological Department, New Delhi. In VZ, many years the temperature was above 40 °C whereas maximum count was found in VZ in the year 2010 which prevailed for about 13 days affected the final yield. BKZ the maximum count was found in the year 2010 (yield 37.6 t/ha). The temperature in this range generally ceases the development of the crop.

3.4.2. Tillering phase

VZ observed maximum number of days less than 25 °C in the year 1973 with the count of 29 days affected final yield, which was around 29.2 t/ha. If the temperature goes below 25 °C, then the primary shoot formation from the nodal joints below ground may get hampered. In all the zones, number of days having temperature > 35 °C were in the range of 80 to 90 except in the BTZ district the count was below 50, that is affecting negatively to cane yields. Temperature above 40 °C, were found in all the stations in the range of 50 to 70 days. But NEZ and WPZ observed the range below 40 days whereas BTZ observed days less than 6. Temperature above 40 °C forms the heat waves, which may destroy the tiller formation, and attacks of pests are very frequent. As far as the first two phenological phases, namely germination and tillering, of the crop are concerned both phases do not require much water thus even with less rainfall a modest amount of irrigation supply meets the physiological needs of vegetative growth.

3.4.3. Grand growth phase

This phase is generally dependent on the amount of rainfall and humidity so temperature might not influence

much. Optimum temperature for this phase is around 30 °C. VZ and BKZ have experienced maximum number of days less than 25 °C, due to that generally we get less sugarcane production in these regions, whereas number of days in other stations ranges between 1 to 5 days. VZ experienced more days greater than 35 °C in the year 1979 and 1987 resulted in yield about 14.7 and 20.7 t/ha respectively (Fig. 7). BKZ have experienced more days in 1979, 1982, 1987, and 1989 and in 2002. CPZ, WPZ and EPZ observed in the year 1973, 1997 and 2010 respectively. BTZ did not experienced much days but highest count of 16 days was observed in the year 1987. Temperature greater than 40 °C was found maximum in SWZ with the count of 18 in the year 2001 and BKZ experienced 32 days in the year 1992. WPZ experienced 37 days in 1995 whereas EPZ experienced 22 days in the year 1978 and 2005 (Fig. 8). Influence on yield is dependent on moisture stress, which might reduce the inter-nodal length and influence the flowering. Actual cane formation and elongation occurs in this phase. It requires humid and sunny climate.

Among the four phases it is the Grand Growth Phase (GGP) that requires maximum amount of water (approx. 1000 mm). The phase lasts from 120 to 250 days after planting *i.e.*, generally from last week of June to first week November. The period consists of both the parts of monsoon and post-monsoon seasons experienced in Indian sub-continent.

A comparative study of total rainfall recorded per year per span of GGP suggests that across the various zones in the state rainfall varied between ~131 mm (WPZ in 1987) and ~1735 mm (BTZ in 1995) being confined roughly within 300-1300mm. A simultaneous analysis for annual rainy days for 1987 and 1995 for WPZ and BTZ were found to be 24 and 89 respectively (Fig. 9). A specific look at the respective sugarcane productivity counts for these above two agro-climatic zones reflects clear implications of less and more number of rainy days considering independence from other factors. The sugarcane productivity for WPZ was estimated to be lower (5.772 tonnes) whereas, for BTZ the same was higher (11.283 tonnes) than that of their 42 years' of respective averages. Apart from these two years of the two zones discussed there are many years for each of the nine agro-climatic zones who have witnessed quite low an amount of rainfall failing to meet the water requirement at the GGP phase of the crop when not accompanied by irrigational supply.

3.4.4. Ripening phase

The optimum temperature for this phase is 30 to 35 °C. In this phase there must be a diurnal variation in

the temperature. Temperature less than 25 °C counts were found in every station. But maximum counts were observed in BTZ. Temperature observed was more than 35 °C in VZ, BKZ, and EPZ only. Temperature more than 40 °C in this phase were not observed in any of the stations. Higher temperature may enhance the photorespiration, which reduces the accumulation of sugar. Also the sucrose may convert into fructose and glucose.

This phenological phase of sugarcane crop is the last phase lasting from the 250 to 360 days after planting. The expanse of the phase lasts from 1st week of November to the February of the next year *i.e.*, it covers both the post-monsoon and winter seasons. A comparative account of total rainfall recorded per year for every Ripening phase suggests that across the various zones of the state rainfall varied between 0mm (at one such occurrence in all the zones) to ~206 mm (in 1982 in BTZ). Rainfall of this phase for various zones was mainly confined within a limit of ~85 mm. with some instances of zones experiencing a phase specific rainfall up to 120 to 150 mm. for VZ, MWZ, BKZ and WPZ. The rainy day analysis for 1982 in BTZ stands at a count of 92. In 1982 sugarcane productivity in BTZ fell by 8.6 t/ha from the average yield of 58.5 t/ha of this zone. As this phase of crop growth demands less humid and drier conditions as compared to GGP to undergo sufficient monosaccharide formation, the fall in the 1982 productivity might have been due less rain fall and that too being not accompanied by sufficient irrigation supplement. Besides, in 1994 the zone had experienced highest sugarcane productivity reaching up to a count of 70.6 t/ha wherein, the year was marked by only a 62.7 mm of rainfall in the respective phase span and only a 78 rainy day count. This contradiction between the sugarcane yields of 1982 and 1994 might be due the soil moisture that might have been sustained from the just preceding GGP rainfall, *i.e.*, ~752 mm and ~1302 mm. Though the rainfall in the ripening phase of 1994 was less but higher soil moisture secured from higher rainfall during the same year's GGP lifted up the yield but already low rainfall of 1982 followed by in generally higher count (~205 mm.) of the same in ripening phase couldn't actually fulfill the standard of water requirement of 650 mm. Thus it not necessary that a higher rainy day count always amounts to a good deal of rainfall as could be assessed from the above discussion.

Despite all these climatic vagaries, it may be the proper supplement of water through irrigation fulfilling the need for the optimum water requirement and other management practices that the overall trend of sugarcane productivity across the whole state stood positive (~0.5 t/h/year).

4. Conclusion

The result of the above study showed that there was an average rising trend in the annual minimum temperature (0.03 °Cyr⁻¹) over all the agro-climatic zones of the state. These results for minimum temperature are in concordance with the findings of Rao *et al.* (2014) wherein, they reported prevalence of increasing minimum temperature across India. Out of nine agro-climatic zones, four zones namely SWZ, CPZ, WPZ and EPZ, which are marked by decreasing annual rainfall trend. NEZ and BKZ show no clear trend as far as annual rainfall is concerned. Among VZ, MWZ and BTZ, BTZ show very significant (0.05% level) rise of 1.8 mm yr⁻¹. Therefore it is difficult, as far as the scope of the study is concerned, to report a clear estimated trend for the state as a whole. There had been many instances wherein temperature and rainfall extremes had high possibility of governing sugarcane yields but there were also quite a number of instances wherein the extremes couldn't be reasoned directly for the yield fluctuations.

Thus, sugar recovery in this scenario of temperature and rainfall trends for the various agro-climatic zones of UP raises concerns about its efficiency level. As in this study, it was found that Western UP is marked by overall rise in minimum temperature trends. BTZ occupying the extreme west of the state is characterized by exceptionally high rainfall trend. So both the minimum temperature and rainfall conditions might be held responsible for the recent (2011-12) government records of Sugarcane Development in the 12th Five year Plan of western UP for lower sugar recovery (8.55%) when compared with the same for the eastern UP (9.45%).

Apart from temperature and rainfall, there are several other biotic, abiotic management related factors, not considered in the study that might have affected the final yield counts of sugarcane. Thus the answers for such instances which were as such difficult to be answered solely with the analysis of temperature and rainfall parameters may lie with the considerations for the factors not included here. Though there are promises with the advancement of accurate and frequent weather forecasts and pest control measures for the better agricultural produce yet if it is not a distant goal then of course it is a goal yet to be achieved. Presently, IMD is issuing National Agro Met Advisory Bulletin that is improving day by day in coherence with different Agro Met Forecast Units (AMFUs) across the country, which needs to improve by including new knowledge/technologies/communication etc. Mean while, there is an urgent requirement of some resilient, effective and economic management strategies to with stand the present and near future climate adversities.

Following are some management related suggestions to be explored for their possible implementation:

- Genetic improvements in crops to develop resistance against climatic extremes.
- Developing new and modifying existing crop calendars for the crops not yet explored for their phenological responses and for the crops that have been replaced by newer varieties.
- Development of indigenous regional crop weather models to give better projections for regional level by downscaling climate change scenarios to study crop sensitivity to plausible climate scenarios.
- Adopting adaptive and mitigative measures to reduce the adverse impacts of weather extremes affecting crop productivity and that in turn affects the livelihood and national economy.
- In case of emergency there should be a toolbox of contingency plans for each of the strategies to fall back on when the first plans fail.
- Adequate weather information and advisories under particular extreme weather events to the farmer as well as other stakeholders of agronomic products must be accessible both in time and quality, then farmers/stakeholders will be better able to make management decisions to existing and expected weather to reduce the risk.
- Sugarcane is vulnerable to a number of pest attacks mainly Red Rot, Smut, Top borer and Pyrilla, therefore modules for better cultivation and integrated disease as well as for insect-pests management is necessary to ensure sustained good yield.
- As per the targets proposed by the Government of Uttar Pradesh in the 12th Five-year Plan for Sugarcane Development, the state will have to achieve 70 t/ha and 10% counts for average yield and sugar recovery respectively. For accomplishing such Government targets the scientific advancements in agro-metrological research alone will not suffice. The scientific advancements must be supplemented with Government aid to the farmers and other stakeholders of sugarcane. The targets of 12th Five year Plan in this respect are promising but an inclusion of better and subsidized transportation facilities for the harvested cane and not only the cane seeds to the nearest mills could be highly beneficial for both the growers and state economy at large.

Now we can finally conclude that there are several promising opportunities to manage agricultural risks, which depend on climate information, and these are yet to be fully exploited because of gaps in existing climate information services due to quality of data, knowledge and application of technologies.

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