# Yield Gap Analysis of Sugarcane in different Agro-climatic Zones of Uttar Pradesh using DSSAT-CANEGRO Model

**K.K. Singh* R.S. Singh** Anila H. Bhengra** and Priyanka Singh**
*India Meteorological Department, New Delhi-111003
**Department of Geophysics, BHU, Varanasi-221 005
Email: rsingh_61@yahoo.co.in; kksingh2022@gmail.com

***ABSTRACT***

*In the present study, yield potentials of sugarcane crop utilizing normal weather data have been presented for all the eight agro-climatic zones/districts of Uttar Pradesh state of India using the calibrated as well as evaluated DSSAT - CANEGRO v 4.6 simulation model. The potential yield of sugarcane stalk fresh mass ranged from 81.7 to 96.6 t ha$^{-1}$ whereas the observed yields ranged from 40.1 to 62.8 t ha$^{-1}$ giving yield gaps ranging from 22.8 to 56.5 t ha$^{-1}$ (27–59%) of potential yield over the eight selected representative sites/districts in each agro-climatic zone of Uttar Pradesh. For Western Plain Zone (WPZ), the total yield gaps were minimum and ranged from 10.2 to 29.9 t ha$^{-1}$ (13–34%) in various districts within the same zone followed in Mid Western Plain Zone (MWPZ), whereas sowing yield gap and management yield gap in Western Plain Zone (WPZ) varied from 7.9 to 31.5 t ha$^{-1}$ (9-34%) and from 7.6 to 25.0 t ha$^{-1}$ (12-38%), respectively. In general, maximum yield gaps found in Bundelkhand Zone (BZ) followed in Vindhyan Zone (VZ) and South Western Semi Arid Zone (SWSAZ) and partially high also in Central Plain Zone (CPZ) & Eastern Plain Zone (EPZ) where farmers do not have assured irrigation facility. It is suggested that location-specific integrated approaches would be needed to bridge the yield gap of the sugarcane crop grown in the target regions. Various other constraints limiting the crop yields in these regions have been highlighted. Findings also reveal that DSSAT-CANEGRO simulation model is an effective tool for decision support system & advisory services.*

***Keywords:*** *Sugarcane, Yield potentials, Yield gaps and DSSAT-CANEGRO model.*

## 1. Introduction

Sugarcane (*Saccharum officinarum*) is basically a tropical crop but it is cultivated in the tropics as well as in subtropics too on the Earth. India is second largest producer of sugarcane in the world after Brazil. Total sugarcane production in India is about 355.5 million tonnes during the year 2006-07. Uttar Pradesh is the largest producer of cane among all the states in India contributing about 48% of the area and 40% of the production but its productivity is low (about 59.6 t ha$^{-1}$) against the national average (about

70.3 t ha$^{-1}$) productivity (Deokate, 2013). Further, the productivity of sugarcane crop must be increased substantially over the coming decades to keep pace with energy demand driven by population & income growth (Niti Aayog 2015 and van Ittersum et al., 2013). Assessment of potential yield and the yield gap between potential and actual yield is essential before any investment for improving crop production for a location is made. Potential yield is determined by solar radiation, temperature, photoperiod, atmospheric concentration of carbon dioxide, and genotype characteristics assuming water, nutrients, pests, diseases and pollutants are not limiting crop growth. This is also called water non-limiting potential yield (van Ittersum et al., 2013). Under rainfed situation where the water supply for crop production is not fully under the control of the grower, water-limiting yield may be considered as the maximum attainable yield for yield gap analysis assuming other factors are not limiting crop production. However, there may be season-to-season variability in potential yield caused by weather variability, particularly rainfall. Once the yield gap between water-limiting yield and actual yield is determined, then the relative contributions of other major constraints and limitations causing yield gap can be assessed in order to focus on the priority research or crop management needs to bridge the yield gap (Samui et al., 2014; Singh et al., 2015; Mall et al., 2016 and Singh et al., 2016).

Crop simulation models have been used to estimate yield potentials (Grassini et al., 2011; Laborte et al., 2012; Aggarwal and Kalra, 1994). These simulation models are mathematical representations of our current understanding of biophysical crop processes (phenology, carbon assimilation, assimilate partitioning) and of crop responses to environmental factors (van Ittersum and Donatelli, 2003). Chand et al., 2011 had carried out a study pertaining to Bundelkhand zone of Uttar Pradesh (Jhansi district) and reported 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).

Like 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 about 2000 mm (IISR, 2011; Samui et al., 2014). Therefore, higher or lower temperature and precipitation conditions with other factors could be held responsible for the fluctuations in the sugarcane yield.

Sugarcane being a cash crop in Uttar Pradesh, economic condition of the farmers is highly dependent on sugarcane production. Before any improvements to crop management practices are suggested, it is useful to know the potential yield of the crop in the region of interest, and the gap between the potential yield and the actual yield obtained by the growers. This analysis helps to know the major factors causing the difference between the actual and the attainable yield for a given site. Hence, current study is an attempt to explore the zone wise different yield potentials and yield gap and to identify appropriate management options to reduce yield gap for maximizing cane yield.

## 2. Material and Methods

Sugarcane is a long duration crop (10-12 months duration) and it is grown in the world from latitude 36.7 °N to 31.0 °S and from sea level to 1000 m altitude (www.agritech.tnau.ac.in/extent_system/sugar/botany&climate.html**).** The crop can be grown in diverse climatic and soil conditions in different parts of the India. Significant weather and climatic variability along with their extremes play major role in sugarcane cultivation in different agro-climatic zones in Uttar Pradesh and neighboring states. Sugarcane being cultivated as a commercial crop by farmers in the state of Uttar Pradesh, there is a long term trend of increase (Deokate, 2013) in the area cultivated and production of sugarcane. However, as the crop encounters different season and environmental conditions during its life cycle, its productivity as well as maturation is directly affected by all these weather conditions and affects the economic condition of the farmers which is highly dependent on sugarcane production in Uttar Pradesh and adjoining sugarcane producing states.

### 2.1 General characteristics of study area

Uttar Pradesh is located in northern part of India and falls between 23˚52’ - 31˚ 28’ N and 77˚04’ - 84˚39’ E. It covers an area of 2.94 lakh km$^2$. The major sugarcane growing districts, namely Saharanpur, Shamli, Muzaffarnagar, Meerut, Ghaziabad, Hapur Bulandshahr, Baghpat, Bareilly, Shambhal, Amroha, Moradabad, Rampur, Badaun. Shahjahanpur, Pilibhit, Lakhimpur kheri, Hardoi, Sitapur, Gonda, Basti, Balarampur & Kushinagar (Chaurasiya et al., 2017) are mostly confined to northwest & northern part of the state also known as *tarai* areas popular for sugarcane cultivation in the Uttar Pradesh.

### 2.2 Climate, soil & crop types in the study area

The climate of Uttar Pradesh state of India is predominantly subtropical with dry sub-humid type and in general congenial for agriculture, but weather conditions change significantly with location and seasons. Depending on the elevation, the average temperatures vary from

**Table 1. General characteristics of representative station selected for each agro-climatic zone (ACZ) of Uttar Pradesh during the period from 1980-81 to 2014-15 (R** means Rainy months July to September and **PR** means Post Rainy months October to December.)

| | Representative Station & Agro-climatic Zone (ACZ) | Lat. | Long. | Alt. (m) | Max temp range ($^0$C) | | Min temp range ($^0$C) | | Rainfall (mm) | | Major soil texture type | Reported Cane yield (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | R | PR | R | PR | R | PR | | |
| 1. | Muzaffarnagar (WPZ) | 29.5 °N | 77.7 °E | 248 | 33.6 | 33.2 | 24.0 | 10.9 | 757 | 38 | Sandy loam | 61.8 |
| 2. | Shahjahanpur (MWPZ) | 28.0 °N | 80.0 °E | 153 | 33.9 | 27.5 | 25.2 | 12.9 | 851 | 45 | Sandy loam | 54.3 |
| 3. | Agra (SWSAZ) | 27.3 °N | 78.0 °E | 177 | 35.9 | 29.0 | 26.1 | 13.4 | 560 | 32 | Sandy loam | 46.9 |
| 4. | Lucknow | 27.0 °N | 81.0 °E | 113 | 34.7 | 28.6 | 25.6 | 13.7 | 859 | 69 | Sandy loam | 49.0 |
| 5. | Basti (NEPZ) | 26.8 °N | 82.7 °E | 88 | 34.4 | 29.0 | 25.9 | 15.2 | 1030 | 53 | Silt loam | 52.1 |
| 6. | Faizabad (EPZ) | 26.8 °N | 82.1 °E | 101 | 34.3 | 28.7 | 25.2 | 13.8 | 889 | 68 | Silt loam | 51.1 |
| 7. | Allahabad (VZ) | 25.8 °N | 82.0 °E | 96 | 35.0 | 29.2 | 26.6 | 15.3 | 810 | 50 | Sandy loam | 44.2 |
| 8. | Jhansi (BZ) | 25.8 °N | 79.0 °E | 245 | 35.2 | 29.7 | 25.0 | 14.3 | 803 | 44 | Sandy loam | 40.1 |

12.5–17.5 °C during peak winter month of January to 27.5–32.5 °C during peak summer months of May and June. The normal annual rainfall of the state is about 950 mm and it ranges from about 700 mm to 1750 mm during the last 40 years. The *tarai* (i.e.foot hill) receives heavy rainfall while in south part rainfall decreases. Rainfall in the State ranges from 1000 to 2000 mm in the east to 600 to 1000 mm in the west. About 90% of the rainfall occurs during the southwest Monsoon, lasting from about June to September. The normal winter rainfall ranging between 30 to 50 mm contributing small quantities towards the overall precipitation of the state is received during December to February that is more in North-West part of the Uttar Pradesh. As such the most of the rainfall concentrated during this

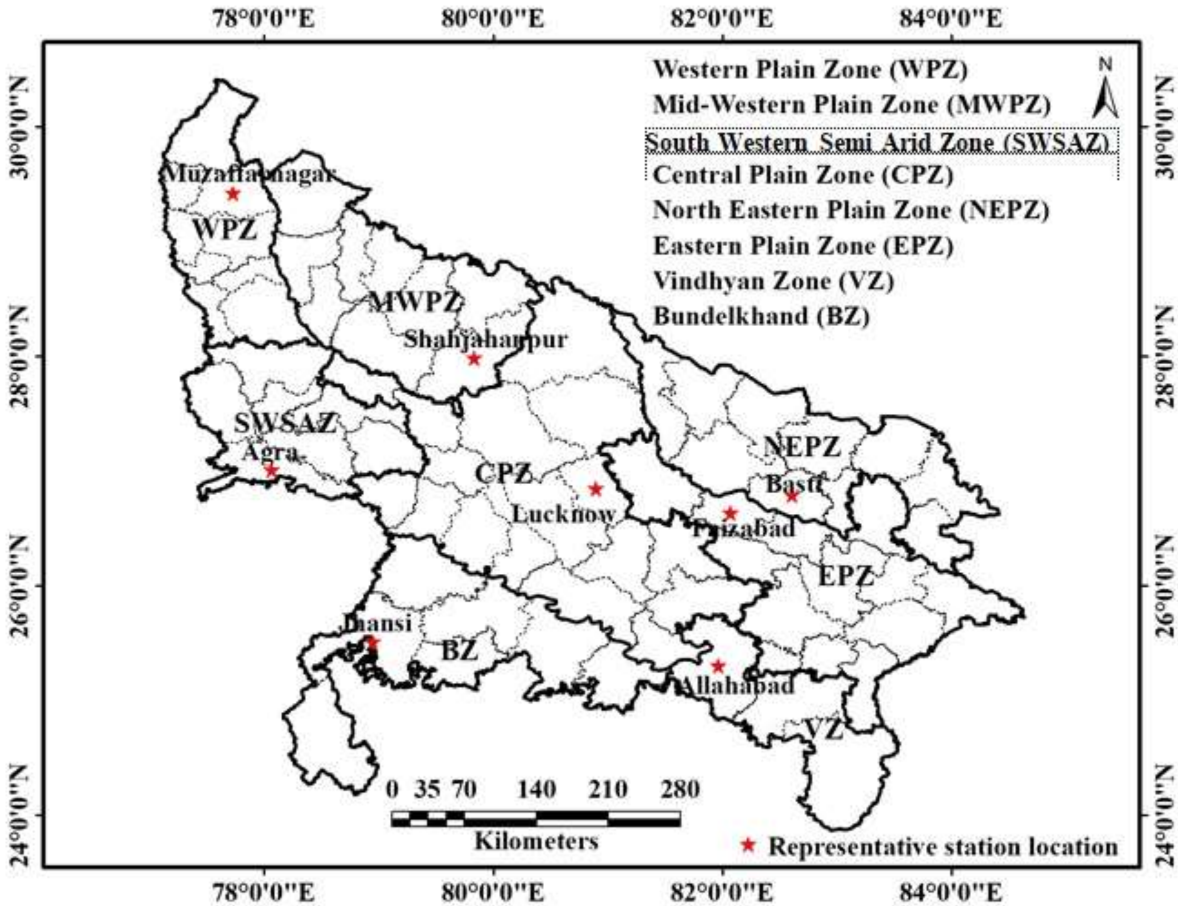


**Figure 1: Different agro–climatic zones in Uttar Pradesh (India) with district boundary and location of representative station**

four-month period from June to September, floods are a recurring problem and cause heavy damage to the crops, particularly in the eastern part of the state, where the Himalayan-origin rivers flow with a very low north-south gradient. Periodic failure of monsoons results in drought conditions and adversely affects the crop productivity in some or other parts of the state (Singh et al., 2012; Singh, 2012).

Soils in the region falling under different Agro-climatic zones are mostly alluvium-derived (recent to old) soils. The dominant soil landscapes, representing the northern plains, constitute gently to very gently sloping lands. In some area the soil is highly calcareous. The soils in general are neutral in reaction and have moderate clay and low organic carbon content.

Rice, maize, pigeon pea, moong bean crops are common in rainy (*kharif)* season. In post-rainy (*rabi*) season wheat, bengal gram, pea, mustard, rapeseed, lentil and sesame are grown. The important cash crops of the region are sugarcane, potato, chillies, turmeric, coriander, tomato, onion and other vegetable crops with supplemental irrigation. Rice–wheat cropping system is the predominant but Sugarcane – wheat cropping system covers about 30 per cent area in the western Uttar Pradesh (Singh et al., 2009).

**2.3 Agro-climatic zones (ACZ)**

An “Agro-climatic zone”, ACZ is a land unit in terms of major climates, suitable for a certain range of crops and cultivars. Accordingly, the Uttar Pradesh is divided into eight agro-climatic zones as per NARP classification of ICAR (Ghosh, 1991) namely, Western Plain Zone (WPZ), Mid-Western Plain Zone (MWPZ), South-Western Semi Arid Plain Zone (SWSAZ), Central Plain Zone (CPZ), North-Eastern Plain Zone (NEPZ), Eastern Plain Zone (EPZ), Vindhyan Zone (VZ), and Bundelkhand Zone (BZ) and accordingly eight stations having long-term daily weather & crop production data namely Muzaffarnagar, Shahjahanpur , Agra, Lucknow, Basti, Faizabad, Allahabad and Jhansi, respectively, have been selected representing each of the above 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 agro-climatic classification are shown in Table 1 & Fig 1.

**2.4 Model used as tool for simulating yield potentials and yield gap Analysis**

Crop growth modeling is an important tool to address various issues related to crop potential yield & maturity in relation to weather, soil, crop parameters and management. The Decision support System for Agro-technology Transfer (DSSAT) is developed by International Benchmark Sites Network for Agro-technology Transfer (IBSNAT) (Tsuji et. al., 1994) which contains crop simulation models, weather, soil and crops coefficients database; and strategy evaluation programs integrated with a user friendly interface on computers. Therefore, CANEGRO model which is embedded with DSSAT model version 4.6 and also calibrated as well as validated for Uttar Pradesh region (Bhengra et. al., 2016) is used in the present study to simulate the sugarcane productivity to address the yield gap related issues in Uttar Pradesh. Yield gap analysis of different districts / agro-climatic zone was carried out by defining potential yield ($Y_p$), attainable yield ($Y_a$) and actual yield ($Y_f$) reported at district level. Various types of yield gap & their computation are described below as well as presented in Table 2.

In the present study detailed yield gap analysis has been carried out for sugarcane crop with respect to one representative district from each of all eight agro-climatic zones of Uttar Pradesh using DSSAT CANEGRO model. The potential and attainable yields were simulated using daily series of normal weather through DSSAT CANEGRO model. Yield potentials and gap analysis were carried out for four sugarcane varieties early maturing COJ 64 & COSe 95422, medium duration variety CoS 8436 and mid-late duration CoS 767. Dates of planting for all type

**Table 2. Yield metrics and yield gap compilation in sugarcane**

| Measures | Definition and limiting factors | Data used |
|---|---|---|
| Actual yield ($Y_f$) | District reported yield comprising of all cultivars and conditions practiced by farmers in the district. **Limiting:** Moisture, Genetics, Crop management etc. | State Department of Agriculture (Regional statistics) |
| Attainable yield under irrigated condition ($Y_a$) | Average yield simulated for selected cultivars under optimal management condition, a measure of benefit of proper crop management **Limiting:** Crop Management, Genetics | Yield simulated with validated CANEGRO model (Bhengra et al., 2016) |
| Potential yield ($Y_p$) | Average yield simulated for selected cultivars under non-limiting condition during study period | Yield simulated with validated CANEGRO model (Bhengra et al., 2016) |
| Sowing yield gap (SYG) | Difference between potential yields and attainable yield due to delayed planting ($Y_p$ – $Y_a$). | Time series of potential yields and attainable yields. |
| Management yield Gap (MYG) | Difference between attainable yield and actual yield ($Y_a$ – $Y_f$) | Time series of attainable yields and actual yields. (Fischer et al., 2009; van Ittersum et al., 2013) |
| Total yield gap (TYG) | Difference between potential yields and actual yields ($Y_p$ – $Y_f$) | Time series of potential yields and actual yields. |

maturing varieties were taken starting from 15 February at every fortnight interval up to 15 April. Optimum planting time was estimated based on the maximum of potential / attainable yield simulated. Following three types of yield gap analysis were carried out in this study.

### 2.4.1 Total yield gap (TYG) analysis

For total yield gap analysis DSSAT-CANEGRO model under potential yield condition was run with respect to long-term normal daily series of weather for most of the districts including the representative district of each agro climatic zones in the state. Average of simulated potential district yield for four dominating varieties was worked out at agro climatic zone level to get the representative yield value at ACZ level. Simulated potential yield and observed district yield was further compared for total yield gap analysis.

### 2.4.2 Management yield gap (MYG) analysis

Actual observed yield and attainable yield was compared for management yield gap analysis. Attainable yield was simulated in DSSAT-CANEGRO model utilizing normal weather

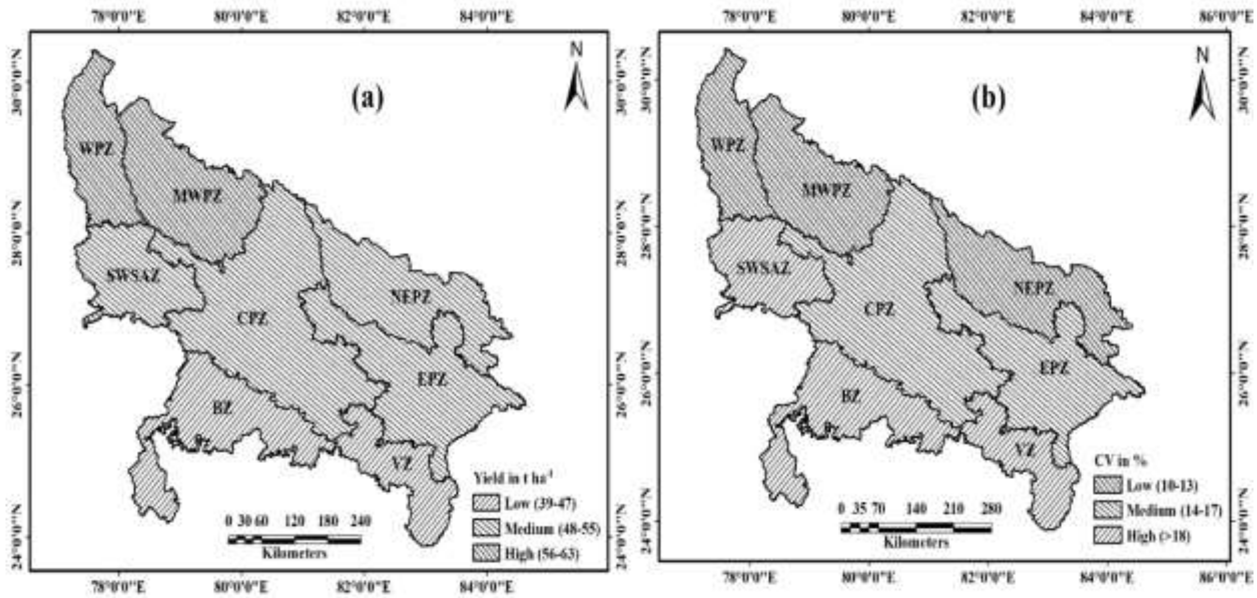


**Figure 2(a&b): Categorization of mean reported (actual) yield and it's co-efficient of variation (CV) over different agro – climatic zones of Uttar Pradesh (1980-81 to 2014-15)**

with the irrigation practices carried out at farmer's field; the data of irrigation application were collected from literatures and field experiments. Average of simulated attainable and observed district yield for different variety was calculated at agro climatic zone level to get the representative yield value at ACZ level. Simulated attainable yield and the observed district yield was further compared for management yield gap analysis

### 2.4.3 Sowing yield gap (SYG) analysis

**S**owing yield gap was calculated as difference between the simulated potential yield and the simulated attainable yield. Difference between the potential yields and the attainable yield mainly due to delayed planting of sugarcane was analysed as sowing yield gap to visualise the impact of changed weather exposure on productivity of the sugarcane crop under the available resources or management practices.

## 3.0 Results & Discussion

### 3.1 District reported yield ($Y_f$) and its coefficient of variation (CV)

Sugarcane observed yields (i.e. district reported yield) as well as simulated potential and attainable yields have been spatially analyzed. Mean reported yield of the state are found varying from 38 to 70 t ha$^{-1}$. Spatial variability of sugarcane productivity are depicted in Figure 2a & b, which shows that the high productivity zone of the state are concentrated in Western plain zone (WPZ), Mid western plain zone (MWPZ) and to some extent in the North eastern plain zone (NEPZ) also with the mean reported yield of about 52 to 63 t ha$^{-1}$and standard deviation (SD) of 5.9 to 9.4 t ha$^{-1}$and coefficient

**Table 3. Mean potential, attainable and observed yields with various yield gaps over different agro climatic zone of Uttar Pradesh. (Simulated with 30 year normal weather data & crop statistics used from 1980-81 to 2014-15)**

| | Simulated Yield (t $ha^{-1}$) | | Reported Yield (t $ha^{-1}$) | | | Yield Gap (t $ha^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|
| Representative District & ACZ | Potential | Attainable | Actual | SD | CV (%) | Sowing | Management | Total |
| **Muzaffarnagar (WPZ)** | 85.6 | 77.7 | 62.8 | 9.4 | 15 | 7.9 (9) | 14.9 (19) | 22.8 (27) |
| **Shahjahanpur (MWPZ)** | 81.7 | 61.9 | 54.3 | 5.9 | 11 | 19.8 (24) | 7.6 (12) | 27.4 (34) |
| **Agra (SWSAZ)** | 93.0 | 61.6 | 46.9 | 8.0 | 17 | 31.4 (34) | 14.8 (24) | 46.2 (50) |
| **Lucknow (CPZ)** | 89.0 | 65.7 | 48.9 | 7.5 | 15 | 23.3 (26) | 16.8 (26) | 40.1 (45) |
| **Basti (NEPZ)** | 89.0 | 69.1 | 52.1 | 6.3 | 12 | 19.9 (22) | 17.0 (25) | 36.9 (42) |
| **Faizabad (EPZ)** | 84.8 | 67.5 | 51.1 | 6.6 | 13 | 17.4 (21) | 16.4 (24) | 33.7 (40) |
| **Allahabad (VZ)** | 91.3 | 60.1 | 44.2 | 12.2 | 28 | 31.2 (34) | 15.9 (27) | 47.1 (52) |
| **Jhansi (BZ)** | 96.6 | 65.1 | 40.1 | 8.7 | 22 | 31.5 (33) | 25.0 (38) | 56.5 (59) |
| **Entire U.P.** | 87.2 | 65.9 | 50.7 | 2.1 | 4.1 | 21.3 (24) | 15.2 (23) | 36.5 (42) |

**Note:** Figure in parenthesis indicates the per cent change of potential/attainable yield.

of variation (CV) of 11-15%. Whereas the medium productivity zones are mainly concentrated over the part of Eastern plain zone (EPZ), Central plain zone (CPZ) and South west semi arid zone (SWSAZ) with the mean values of 46.9 to 51.1 t $ha^{-1}$as well as SD and CV are 6.6 to 8.0 t $ha^{-1}$and 13 to 17%, respectively. The low productivity was found in Bundelkhand zone (BZ), Vindhyan zone (VZ) and partially in Central plain zone (CPZ) with a mean value of 40.1 to 44.2 t $ha^{-1}$with SD and CV are 8.7 to 12.7 t $ha^{-1}$and 22 to 28%, respectively. Since the sugarcane stalk yield and sucrose content is controlled by solar and thermal regimes under irrigated condition and water availability under potential climate zone. Spatial differences were mainly found due to assured irrigation facility and better management practices over the high productivity zone and rainfed situation in the low productivity zone of BZ and nearby zones of south western semi arid plain zone (SWSAZ). Besides these, VZ, and some parts of CPZ & EPZ are also identified for low productivity in the state. This low productivity are mainly due to relatively poor irrigation facility and poor management practices in the regions.

It can be further summarize that out of various districts grouped into eight agro-climatic zones in the state, the WPZ, MWPZ and to some

**Table 4. Categorization of districts into Low, Moderate and High potential of sugarcane cultivation based on the simulated yield**

| S.no | Category of sugarcane yield | Simulated potential yield | Name of the Districts | Simulated attainable yield | Name of the Districts |
|---|---|---|---|---|---|
| 1. | Low yield area | 75-84 t $ha^{-1}$ | Baghpat, Saharanpur, Bijnor, Moradabad, Rampur, Pilibhit*, Shahjahanpur, Hardoi* and Bahraich* | 55-60 t $ha^{-1}$ | Rampur, Hamirpur & Mahoba |
| 2 | Moderate yield area | 85-90 t/ha | Bulandshahr, Meerut, Muzaffarnagar, Bareilly, Badaun, Aligarh, Mathura, Etawah Farrukhabad, Fatehpur, Lakhimpur Kheri*, Lucknow, Rae-Barely, Sitapur, Balarampur*, Basti*, Deoria*, Gonda*, Kushinagar*, St. Kabirnagar*, Shrawasti*, Siddharth Nagar*, Ambedkar Nagar*, Azamgarh, Ballia, Barabanki, Faizabad, Gorakhpur*, Mau, Varanasi, Mirzapur & Hamirpur | 61-65 t/ha | Bareilly, Bijnor, Moradabad, Pilibhit*, Shahjahanpur, Agra, Mainpuri, Mathura, Etawah, Fatehpur, Hardoi*, Pratapgarh, Bahraich*, Shrawasti, Azamgarh, Mau, Varanasi, Allahabad, Mirzapur & Banda |
| 3. | High yield area | >90 t/ha | Agra, Etah, Mainpuri,, Auraiya, Kanpur, Pratapgarh, Maharajganj*, Sultanpur, Allahabad, Banda, Jhansi, Mahoba | >65 t/ha | Baghpat, Bulandshahr, Meerut, Saharanpur, Muzaffarnagar, Badaun, Aligarh, Etah, Auraiya, Farrukhabad, Kanpur, Lakhimpur Kheri*, Lucknow, Raebarely, Sitapur*, Balarampur*, Basti*, Deoria*, Gonda*, Kushinagar*, Maharajganj*, St. Kabir Nagar*, Shrawasti*, Ambedkar Nagar, Ballia, Barabanki, Faizabad, Gorakhpur*, Sultanpur & Jhansi |

**Note:-** *District located in *tarai* region and also traditionally known for sugarcane cultivation in Uttar Pradesh.

extent NEPZ having high sugarcane productivity zone (56-63 t $ha^{-1}$) with low coefficient of variation (10-13%). The BZ, VZ and SWSAZ fall under low productivity (39-47 t $ha^{-1}$) zone with high (>18%) coefficient of variation (CV). The rest of the two agro-climatic zones (CPZ & EPZ) were having medium productivity (48-55 t $ha^{-1}$) with medium value of CV i.e. 14-17%. Hence, normally, high productivity agro-climatic zone(s) were coinciding with the low coefficient of variation (CV) zone(s) in the state of Uttar Pradesh.

### 3.2 Distribution of different simulated yield potentials over Uttar Pradesh

The potential yield simulated district wise by the calibrated DSSAT-CANEGRO model was found to be the highest (96.6 t $ha^{-1}$) yield in Jhansi district of bundelkhand zone and it was about 2.4 times higher than actual district reported yield (40.1 t $ha^{-1}$). However, the attainable yield was highest (81.1 t $ha^{-1}$) in Bulandsahar district of western plain zone and lowest (55.6 t $ha^{-1}$) yield in Hamirpur district of bundelkhand zone. The analyses showed variation over the eight agro climatic zones of Uttar Pradesh (Table 3), which is mainly due to climate and management practices of the crop. Study was conducted to identify the appropriate or optimum planting date (period) sowing windows for sugarcane cultivation in order to reap the maximum agro-climatic benefits and also to categorize the districts of Uttar Pradesh in three types (high, medium & low) of potential and attainable zones of cultivation for sugarcane (Table 4).

#### 3.2.1 Potential yield ($Y_p$)

Mean potential yield simulated under the unlimited water supply conditions of the state is depicted in the Figure 3a. It shows the high potential yield areas over the Bundelkhand Zone (BZ), and South western semi arid zone (SWSAZ) of Uttar Pradesh. But, these zones have low sugarcane area mainly due to no or a few sugar mills, very poor irrigation facility and overall the regions are also prone to agricultural drought. The mean potential yield reaches to as high as 92.9 t $ha^{-1}$ in Bundelkhand followed by 90.5 in SWSAZ and 89.2 t $ha^{-1}$ in Vindhyan zone. These areas comprise the Banda, Hamirpur, Jhansi and Mahoba districts of Bundelkhand zone where potential yield ranges from 87 to 97 t $ha^{-1}$ and Agra, Aligarh, Etah, Mainpuri and Mathura districts of SWSAZ where mean potential yield varies from 86-93 t $ha^{-1}$. High potential yield in this zone is attributed due to predominance of clear sky condition, high solar radiation, air temperature and photoperiod condition which might lead to very high simulated growth and yield of sugarcane. In the MWPZ low potential yield were found mainly over Pilibhit and Rampur districts with 79 & 78 t $ha^{-1}$, respectively. Low potential zone are due to lower incoming solar radiation as well as lower air temperature at higher latitude as compared to the high potential yield zone of southern Uttar Pradesh. Hence geographic location together with clear sky conditions of the area defines the agro-climatic potential zones for the sugarcane crop.

#### 3.2.2 Attainable yield ($Y_a$)

Spatial distribution of attainable yield is depicted in the Figure 3b and also listed in Table 3 & 4 the yield which could be achieved through available water resources and management practices depicts the high value (77.7 t $ha^{-1}$) over WPZ followed by NEPZ (69.1 t $ha^{-1}$) & EPZ (67.5 t $ha^{-1}$). Soil water availability, good rainfall values and distribution, high water table depth in this area also supports the sugarcane

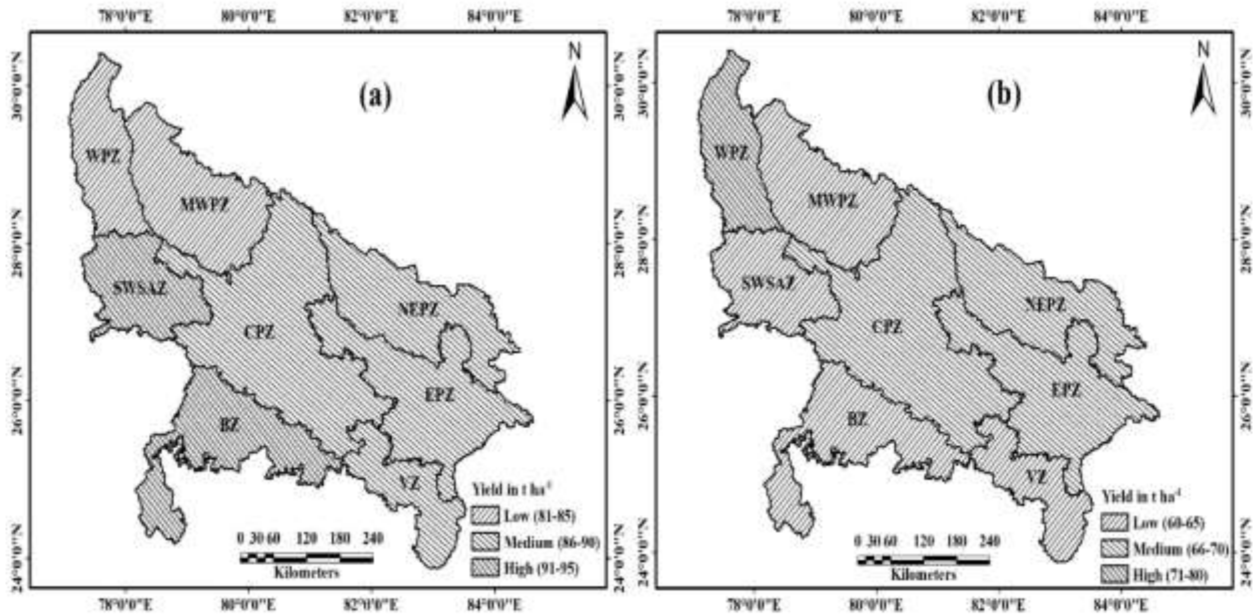


**Figure 3a&b: Categorization of (a) simulated mean potential yield and (b) simulated mean attainable yield over different agro – climatic zones of Uttar Pradesh**

production in the area. Whereas lowest attainable yield values (60.1 t ha$^{-1}$) found over VZ followed by SWSAZ (61.5 t ha$^{-1}$) of the state due to, in general, no assured irrigation and in particular, poor crop management under the field conditions. Further the Fig 3a & b has indicated that high potential yield in BZ, SWSAZ and VZ of the state and moderate potential yield in NEPZ and CPZ and low potential yield in MWPZ and WPZ of the Uttar Pradesh. In contrary to this, attainable yield was simulated high in WPZ & NEPZ, moderate yield in EPZ, CPZ & MWPZ and low attainable yield obtained in VZ, SWSAZ & BZ of the state. Despite of low potential yield (81-85 t ha$^{-1}$), the attainable yield was high (71-77 t ha$^{-1}$) in WPZ was primarily due to assured irrigation & better crop management in the zone. In general, farmers are also progressive in the WPZ and do intensive sugarcane cultivation with recommended and better management of irrigation and other package of practices. Therefore, this practice has lead to high reported yield (69-63 t ha$^{-1}$) in the WPZ, which was more close to the simulated potential and attainable yield in comparison to all other agro-climatic zones in the state.

### 3.3 Yield gap assessment

#### 3.3.1 Total yield gap (TYG)

Difference between potential an actual yield depicts the highest values for Bundelkhand zone 56.5 t ha$^{-1}$ followed by 47.1 t ha$^{-1}$ for Vindhyan zone and the lowest (22.8 t ha$^{-1}$ for WPZ followed by MWPZ (27.4 t ha$^{-1}$). Since the southern zones (BZ & SWSAZ) of Uttar Pradesh have the comparatively high solar radiation value under clear sky condition and the water management is the only limiting factor for growth and yield of sugarcane. These areas depicts high total yield gap values, therefore, it was inferred that water deficit was the major reason for spatial variability in the actual reported yield. On the other hand WPZ and adjoining areas showing low yield gap (Table 3) follows better water management practices and technological applications in the presence of assured irrigation facility. The districts Bahraich, Basti, Kushinagar, Gonda, Deoria though fall mainly under NEPZ and Lakhimpur kheri under CPZ and Gorakhpur under EPZ show moderately high total yield gap due to large agro climatic potential of these areas. This region is known as *tarai* area of the state, also have the advantage of high water table which always suffice the irrigation requirement of the crop.

### 3.3.2 Sowing Yield Gap (SYG)

Under the given climatic condition and available management practices sowing date adjustment is the only method to harness the maximum benefit from the climate. Sowing date could be a sub optimal management practice for better yield. In this study sowing date experiment was performed for 5 to 10 different dates at fortnightly intervals for all the varieties and for all the zones. For early cultivars optimum sowing date found on 15 Feb whereas for mid and mid late maturing varieties optimum sowing date found on 15 April with highest yield values. Sowing yield gap obtained with the optimum sowing dates in all the zones are found highest 31.5 t $ha^{-1}$ for BZ followed by SWSAZ (31.4 t $ha^{-1}$) and VZ (31.2 t $ha^{-1}$) and minimum 7.9 t $ha^{-1}$ for WPZ followed by 17.4 t $ha^{-1}$ for EPZ, 19.8 t $ha^{-1}$ for MWPZ and 19.9 t $ha^{-1}$ for NEPZ (Table 3). The reason behind this wide sowing yield gap in BZ and nearby zone is due to water limiting factor & availability of ample solar radiation. The water deficiency in the region was further aggravated by delayed planting, which has lead to low sugarcane productivity and high yield gap. Somewhat still high sowing yield gap in WPZ, MWPZ & SWSAZ with the values ranging from 7.9 to 31.4 t $ha^{-1}$ indicated the possibility to obtain higher attainable yield from these areas with the fine adjustment of sowing dates.

### 3.3.3 Management yield gap (MYG)

Management yield gap is the difference between the attainable and actual yield. The BZ recorded the highest MYG with mean value of 25 t $ha^{-1}$ for Jhansi and lowest (7.6 t $ha^{-1}$) value in MWPZ over Shahjahanpur followed by WPZ & SASAZ. Since, the total yield gap represents sowing and management including of the genetic gains. However, Table 3 indicated that there is low management gap in the MWPZ and surrounding areas of West Uttar Pradesh. Therefore, further reduction in the total yield gap is possible only through minimizing the sowing gap through early planting of the sugarcane during spring season as the delayed planting in this zone resulted in a decrease in overall productivity.

Patel et al., 2008 have reported wheat yield gap of 18 kg ha$^{-1}$ day$^{-1}$, whereas Aggrawal and Kalra (1994) have quantified a wheat yield gap of 50 kg ha$^{-1}$ day$^{-1}$ to be delayed sowing.

The moisture gap can be narrowed by irrigation for the cultivars. In rainfed system, this gap is mainly determined by factors that are difficult to control including the variation in climatic conditions. The moisture gap, therefore, is usually smaller in seasons with very favorable weather conditions (Pasuquin and Witt, 2007) since adequate moisture allows for the greater utilization of available nutrients, $CO_2$, radiation, and temperature, throughout the cropping season. The genetic gap represents the difference between the top performing variety in that location and the varieties that were chosen. Therefore, the genetic gap can be reduced by selecting the appropriate cultivar, and these gains would continue as new and improved varieties became available.

Yield gaps provide important guidance in the identification of these constraints. If the gaps are large despite using improved management practices, maximum/attainable yields must be limited by an unknown constraint (Pasuquin and Witt, 2007). If the gaps are small, it is usually not economical to aim to fully reducing the gap because of the large amounts of inputs required and the high risk of crop failure and economic losses. Therefore, estimation of yield gap based on the past crop data and subsequent adjustment of appropriate sowing window may help to some extent to obtain the potential yields.

## 4. Conclusions

In WPZ and MWPZ, the farmers were able to harvest almost three-fourths and two-thirds respectively of the potential yield of sugarcane; however, in BZ and VZ the total yield gap was wider and ranged from 52% to 59% of potential yield & farmers are not able to harvest even half of the potential yield. Further, the actual yields particularly, in WPZ & MWPZ is closure to the attainable yield of the zone leading to low management yield gap mainly due to availability of assured irrigation facility in those regions. This has revealed that farmers could increase the stalk yield further closure to the potential yield by minimizing the sowing yield gap only through manipulation/adjustment of the planting time (sowing window) and selection of better cultivar of sugarcane in those regions.

Mean management yield gap (MYG) for entire UP was found 23 percent of the simulated attainable yield, but the agro-climatic zones (WPZ, MWPZ & SWSAZ) situated in the western part of Uttar Pradesh having reported low (12-19%) MYG. The mean sowing yield gap (SYG) was computed 24% of the simulated potential yield over the entire state. But, the mean SYG over the some of the western agro-climatic zone were quite high (24-34%). Hence it is clear that our efforts to further minimize the total yield gap (TYG) must be through reduction of the SYG by early planting or optimizing the planting time in the western zones.

Lastly, the results of this study have revealed the management crisis in the Bundelkhand and adjoining areas whereas the agro-climatic zone/districts of western Uttar Pradesh (WPZ, MWPZ & SWSAZ) have their reported yield closure/touching (76-88%) of their attainable yield values and they have only scope of adjusting the sowing dates and use of high yield varieties in order to enhance the yield further.

**Acknowledgements**

Financial support provided in terms of SRF from RGNF, GOI, New Delhi to the third author is thankfully acknowledged.

**References**

Aggarwal, P. K. and Kalra, N., 1994, 'Analysing the limitation set by climatic factors, genotype and water and nitrogen availability on productivity of wheat II. Climatic potential yield and management strategies', Field Crop Res., vol. 38, pp 93-103.

Bhengra, A.H., Yadav, M.K., Patel, Chandrabhan, Singh, P. K., Singh, K.K., and Singh, R. S., 2016,'Calibration and validation study of sugarcane (DSSAT-CANEGRO V4.6.1) model over North Indian region', Journal of Agrometeorology, vol. 18, No. 2, pp 234-239.

Chand, M., Kumar, D., Singh, D., Roy, N and Singh, D. K., 2011, 'Analysis of Rainfall for crop planning in Jhansi District of Bundelkhand zone of Uttar Pradesh', Indian Journal of Soil Conservation, vol. **39**, No. 1, pp 22-26.

Chaurasia, G., Saxena, S., Tripathy, R.., Chaudhari, K. N. and Ray, S.S., 2017, 'Semi-physical approach for sugarcane yield modeling with remotely sensed inputs', Vayu Mandal, Vol 43 No. 1, pp 89-104.

Deokate Tai Balasaheb., 2013, 'Quantification of yield gaps in different planting types of sugarcane in Maharashtra. Indira Gandhi Institute of Development Research (IGIDR), Mumbai-400065, Publication no. WP-2013-011, pp 86.

Fischer R. A., Byerlee D., Edmeades G. O. 2009, 'Can Technology Deliver on the Yield Challenge to 2050? Expert Meeting on How to feed the World in 2050', Rome: Food and Agriculture .

Ghosh, S.P., 1991; Agro-climatic Zone Specific Research-India Perspective under NARP, ICAR, pp. 539, New Delhi.

Grassini, P., J.Thorbun, C.Burr, and K.G.Cassman., 2011,'High-yield irrigated maize in the western U.S. cornbelt. I. On-farm yield, yield-potential and impact of agronomic practices,' Field Crops Res., vol. 120, pp 142–

150.IISR., 2011,'Vision 2030, Indian Institute of Sugarcane Research, Lucknow, 1-28.

Laborte, A., Nelson, A., Jagadish, K., Aunario, J., Sparks, Adam., Ye, Changrong and Redona, Ed., 2012,' Rice feels the heat. Rice Today, 30-31.Mall, R.K., Sonkar, G., Bhatt, D., Sharma, N.K., Baxla, A.K. and Singh, K.K., 2016,' Managing impact of extreme weather events in Sugarcane in different Agro-Climatic Zones of Uttar Pradesh,' Mausam, vol. 67, No. 1, pp 233-250. Niti Aayog, 2015, 'Raising agricultural productivity and making farming remunerative for Farmers: An occasional paper', p 46.

Pai, D. S., Sridhar, L., Badwaik, M. R., and Rajeevan, M, 2015, 'Analysis of the daily rainfall events over India using a new long period (1901–2010) high resolution (0.25× 0.25) gridded rainfall data set', Climate Dynamics, 1-22.

Pasuquin J. M. C. A., Witt C. 2007, 'Yield potential and yield gaps of maize in Southeast Asia," in *Proceedings of the International Potash Institute e-fic No. 14 IPI* Southeast Asia Program, Singapore.

Patel,V.J., Patel, H.R., and Pandey,V., 2008, 'Estimation of wheat yield gap in Anand and Panchmahal districts using CERES-wheat model', J. Agrometeorology, (spec. Issue-part2), pp 393-397.

Samui, R.P., Kulkarni, P.S., Kamble, M.V., and Vaidya, N.G., 2014, 'A Critical Evaluation of Sugarcane Yield Variation as Influenced by Climatic Parameters in Uttar Pradesh and Maharashtra States of India', Times of Journals of Agriculture and Veternary Sciences, vol. 2, pp 163-69.

Singh, R.S., 2012,'Rainfall record and climatic water balance over BHU, Varanasi in the Eastern Uttar Pradesh Region', Published by Agro-Meteorological Field Unit, Department of Geophysics, Banaras Hindu University, Varanasi-221 005. p. 55.

Singh, R.S., Singh, K.K., Mall, R.K., Yadav, M.K. and Gupta, J.P., 2012,' Climate of Varanasi', Published by Agro-meteorological Field Unit, Department of Geophysics, B.H.U., KBD Printer Varanasi, ISBN No. 81-85305-68-8, p. 78.

Singh, S.P., Gangwar, B. and Sinsh, M.P., 2009,' Economics of Farming Systems in Uttar Pradesh', Agricultural Economics Research Review, Vol. 22 (January-June 2009), pp 129-138. Singh, P.K., Singh, K.K. Bhan, S.C., Baxla, A.K., Gupta, A., Balasubramanian, R. and

Rathore, L.S., 2015, 'Potential yield and yield gap analysis of rice (Oryza SativaL) in eastern and north eastern regions of India using CERES-rice model, 'Journal of Agrometeorology, vol. 17, No. 2, pp 194-198.

Singh, P.K., Singh, K.K., Rathore, L.S., Baxla, A.K., Bhan, S.C., Gupta A., Gohain, G.B., Balasubramanian, R., Singh, R.S., and Mall R.K., 2016,' Rice (Oryza sativa L.) yield gap using the CERES-rice model of climate variability for different agroclimatic zones of India', Current Science, Vol. 110, No. 3, pp 405-413.

Tsuji, G.Y., Uehara, G., and Balas, S., 1994,'DSSAT version 3 Volumes 1, 2, and 3. International Benchmark Sites Network for Agrotechnology Transfer. University of Hawaii, Honolulu, Hawaii (Eds).

Van Ittersum., M.K., and Donatelli, M., 2003, 'Modelling Cropping Systems—Highlights of the Symposium and Preface to the Special issues', European Journal of Agronomy, vol. 18, pp 187-197.

Van Ittersum M. K., Cassman K. G., Grassini P., Wolf G., Tittonell P., Hochman Z. ,2013, 'Yield gap analysis with local to global relevance: a review. Field Crop Res. Vol. 143, pp 4–17.