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Research Paper

Maize yield prediction using NDVI derived from Sentinal 2 data in Siddipet district of Telangana state

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ABSTRACT

Maize is a short duration crop. Accurate and up-to-date assessment of the spatial distribution of cultivated area and its production is a key information requirement for all stake holders including policy makers, farmers and consumers. The study utilized Sentinel-2A/2B satellite based NDVI (Normalized Difference Vegetation Index) data to study yield variability of maize in Siddipet district of Telangana state, in 2019. NDVI is a quantitative measurement of crop vigour, which denotes the crop biomass and health status. A regression analysis was developed between observed yield from crop cut experimental plots and seasonal maximum NDVI of maize area. Results showed that there was statistically significant relation (R^2=0.87) between NDVI and observed yield at respective field plots. Validation of yield model with Root Mean Squared Error (RSME) computed for all observed and predicted yields was 0.50 explaining higher accuracy of the yield model. The average seasonal rainfall received in different mandals of Siddipet district was between 727 to 799 mm and during the crop growth period the yields were recorded in the range of 4.2 to 5.0 t ha^{-1}. This showed that the distribution of rainfall has played a major role in yield prediction. The 31st Standard Week Rainfall (SWR) coinciding with the peak vegetative growth showed a significant positive correlation (r=0.68***) with maize yield data at $p \leq 0.001$.

***Key words*: Maize, NDVI, Seasonal rainfall, Standard Week Rainfall.

Maize is grown throughout the year in India, but mainly as *kharif* crop with 85 percent of the area under cultivation in the season. Maize is globally a top ranked cereal, not only in productivity but also as human food, animal feed and as a source of large number of industrial products. The potential for enhanced use of maize for special purposes, based on existing uses and new products to meet the needs of future generation provides the researchers with unique challenges. Major proportion (55 %) of maize is consumed as food and additional use of maize includes as feed, forage and in processing industry. India contributes merely about 2 per cent in total world maize production (Anonymous, 2022).

Life cycle of maize crop depends upon water availability. The water deficit at any phonological stages i.e. vegetative, reproductive and maturity have different response and can damage the grain yield (Cakir, 2004). Drought is harmful for crop growth and development. Drought stress also damages the grain yield when it occurs at the reproductive stage of the crop. During stem elongation, the development and growth of leaves and stem is so rapid that it requires sufficient amount of water. The water stress at this stage can reduce the height of plant and also affect the leaf of plant (Muchow, 1989). The most crucial time of water stress in maize crop is ten to fifteen days before and after flowering. Chivasa *et al*. (2019) concluded that water deficit during the flowering phenophase resulted in 75% decrease of maize grain yield. According to Butts-Wilmsmeyer *et al*. (2019), water availability during the two critical growth stages of flowering and grain filling is largely responsible for grain yield. Crop yield is primarily determined by a combination of temperature and rainfall because temperatures have to be in the range for plant growth and rainfall has to supply crop water requirements for a given environment.

Remote sensing can also relate the final yield with the cumulative values of vegetation indices obtained during the whole growing season or during a specific plant growth period (vegetative or reproductive stages) depending on the model used (normalized difference vegetation index, NDVI) (Labus, 2002, Mkhabela, 2005 and Wall *et al*., 2008). Decreasing cost of Earth observation satellites data opened opportunities for maize yield estimation in heterogeneous African agricultural landscapes (Shanahan, 2001,

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Doraiswamy, 2007, Sud *et al*., 2016, Chivasa *et al*., 2017) and the integration of crop models and remote sensing data can improve the accuracy of crop yield simulations (Jin *et al*., 2017). Achieving robust smallholder landscape yield predictions is important where subsistence agriculture still determines food security and for profitable farmer participation. These yield predictions should be robust at an individual crop level, to adequately represent the diversity of food, income sources and for economic efficiency.

The current study examines the maize yield variability and the impact of rainfall on maize yields in different mandals of Siddipet district during *kharif*, 2019.

MATERIAL AND METHODS

Study area

The study area is Siddipet district situated in the Northern Telangana zone with 18.12°N Latitude and 78.85°E Longitude. The Siddipet district is first major district in area and production of maize crop in Telangana state. Total geographical area is about 3,425.19 km^2. The climate in the district is tropical and is characterized by hot summer and dry conditions except during the south-west monsoon season. The mean daily maximum temperature is about 41°C and a mean daily minimum temperature 27°C is experienced during the summer. The days are intensively very hot and the temperature may rise up to 44°C. The average annual rainfall of the district is 812 mm. Most of the soils in Siddipet district are red and black soils with sandy loam texture. Major crops grown are paddy, maize, cotton during *kharif* season and jowar, bengalgram, sunflower and chillies are grown in *rabi* season.

Crop cutting experiment for yield estimation

The crop yield estimation in Siddipet district was done through crop cut experiments (CCE). Crop cut experiments were conducted from Siddipet rural, Siddipet urban, Dubbaka, Mirdoddi, Gajwel, Wargal, and Jagdevpur mandals of Siddipet district. Randomly selected 5m x 5m sampling unit from each ground truth (GT) site was used for measuring the yield data. The grain yield was recorded at 14 % moisture from each 5 m x 5 m plot area including the yield obtained from selected five plants and extrapolated to hectare yield which was expressed as t ha^{-1}.

Sentinel-2 MSI data

Sentinel-2 mission constellation with two satellites (Sentinel-2A and 2B) by ESA contains multi-spectral sensor (MSI) with thirteen spectral channels in the visible/near infrared (VNIR) and short wave infrared spectral range (SWIR) at spatial resolutions of 10m, 20m and 60m respectively. Both Sentinel-2A and 2B satellite data collected during crop growth period from June to November month are used. All images from Sentinel satellite constellations are freely available and can be downloaded at https://scihub.copernicus.eu/dhus/#/home.

The MSI bands of Blue (B2), Green (B3), Red (B4) and NIR (B8) were used prepare false colour composite of 10m spectral resolution. The NDVI images are computed as the difference between NIR (B8) and Red (B4) reflectance divided by their sum. Seasonal maximum NDVI image of the maize crop was derived by compositing the NDVI of first fortnight June, July, August, September, October and first fortnight of November for yield estimation during *kharif*, 2019. The NDVI statistics, extracted from this image for each CCE plot was used to establish the relationship between NDVI and maize yield observed at CCE plots through the development of simple regression equation.

$$\text{Yield (t ha}^{-1}\text{)} = a*NDVI_m - b$$

where, $NDVI_m$ = Seasonal maximum NDVI of maize crop,
a = 32.37, b = 17.61

The above regression equation was further used to generate the pixel level spatial yield map for the maize crop.

Prediction of Mandal level average maize yields

The mandal level average predicted yields of maize crop in Siddipet district was carried out by calculating zonal mean statistics and by intersecting the administrative mandal boundaries on pixel level yield map.

RESULTS AND DISCUSSION

Relationship between yield and NDVI

A regression analysis was developed between yield obtained from CCE plots and NDVI values extracted from maize area. The maximum NDVI values were considered for each crop pixel, which normally occurs at peak vegetation growth of maize. The scatter diagram and regression line between yield and NDVI are shown in Fig 1 from which yield model was obtained for yield prediction during *kharif,* 2019.

There was significant and positive relationship (R^2=0.87) between NDVI and observed yield at respective CCE plots and hence considered very goodfor crop yield estimation. The coefficients were found to be statistically significant with maximum NDVI which represents peak vegetative growth during crop season. The maize yield model generated based on CCE data and satellite data for Siddipet district for *kharif,* 2019 was applied to generated maize yield map. The relationship between remotely sensed NDVI and yield showed better image yield prediction when crop reached full cover for maize and soybean crops and the best yield estimates were obtained with NDVI data (Zhang *et al*., 1999). Ewa and Dariusz (2020) reported that an increase in the NDVI in early spring by 0.1 unit increases the grain yield of cereals by about 1.1–2.6 tha^{-1} and it can be used to forecast cereal grain yield at the regional level, three–four months before the harvest, which is important for planning food policy and Sadia and Qingmin (2021) used the NDVI and EVI based growth metrics for crop growth monitoring and yield modelling which can be applied to other types of crop monitoring in different climate zones.

Validation of yield estimates

There is a significant positive relationship showed between observed and predicted yields with R^2 value of 0.87 during *kharif* season, Root Mean Squared Error (RSME) values computed

Table 1: Pearson's correlation between yield (t ha^{-1}) and weekly rainfall (mm) in different mandals of Siddipet district.

SMW	Correlation	SMW	Correlation	SMW	Correlation
23	-0.41*	29	-0.65*	35	-0.36
24	-0.39	30	0.41*	36	-0.36
25	0.10	31	0.68***	37	-0.5
26	-0.59*	32	-0.46*	38	0.26
27	-0.04	33	-0.17	39	0.29
28	0.09	34	0.04		

SMW: Standard Meteorological Week, d.f : 20; Significance at $p=0.05$: => 0.41* at $p\leq 0.001$:>0.68***

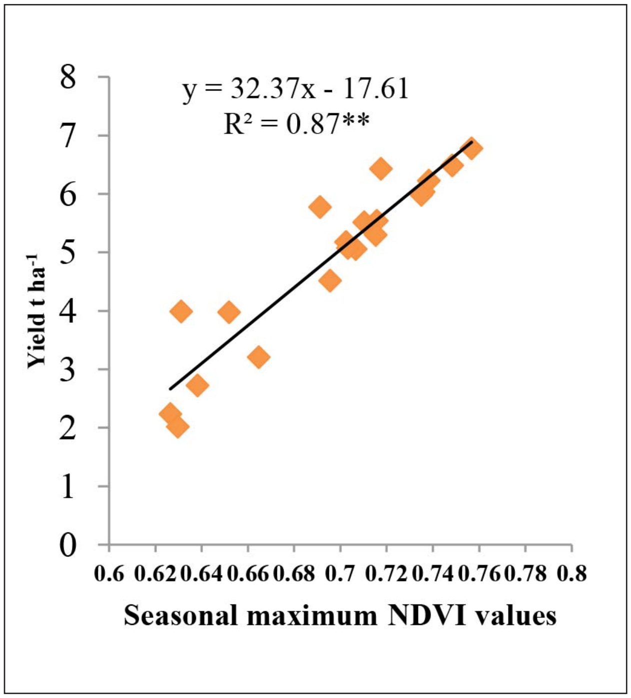

Fig. 1: Maize yield model for Siddipet district during kharif, 2019

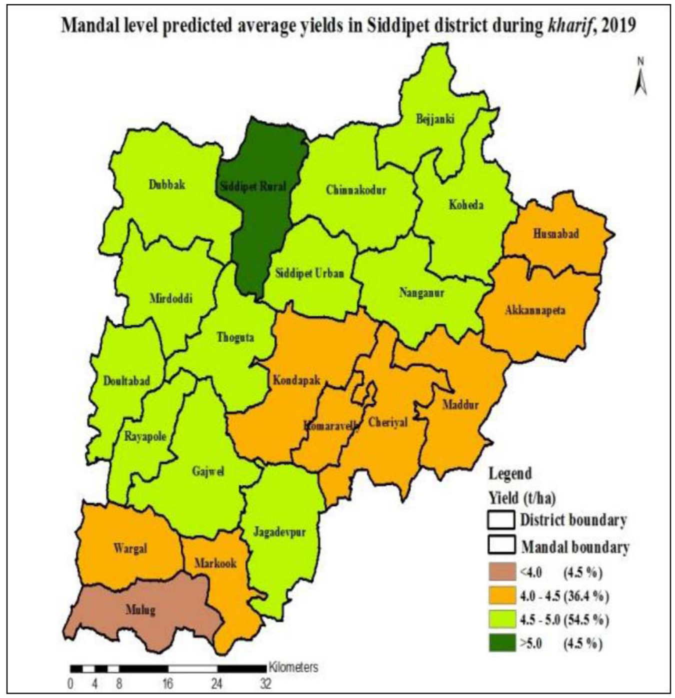

Fig. 2: Mandal level predicted average maize yields in Siddipet district during *kharif*, 2019

for all observed and predicted yields were 0.50t ha^{-1}during *kharif*, 2019 explaining higher accuracy of the yield model. Johnson *et al*., (2021) reported that modeling using seasonal maximum peak NDVI have given a significant improvement of the R^2value of 0.88 over 0.48 trend model for corn.

Mandal level average predicted yields

The predicted yields of Siddipet district ranged from 3.9 to 5.0 t ha^{-1}. They are the highest in Siddipet rural mandal (5.02 t ha^{-1}) and the lowest (3.9 t ha^{-1}) in Mulugu mandal. Overall, the predicted yields were found to be in the range of 4.5-5.0 t ha^{-1} and 4.0-4.5 t ha^{-1} in twelve and eight mandals of Siddipet district (Fig 2).

Correlation between rainfall and yields

The correlation studies between average predicted maize yields in different mandals of Siddipet district and the Standard Week Rainfall (SWR) during crop growth period is presented in the Table 1. The results revealed that the rainfall received during 31st Standard Meteorological Week (SMW) coincided with peak vegetative growth i.e. between Leaf stage (Vn) and Vegetative tassel (VT) stages which was the critical stage for moisture, has shown a highly significant positive correlation (0.68***) with yield data at p≤ 0.001 level. The rainfall received during 30th (r=0.41*) and 32nd (r=0.46*) SMW showed positive correlation and coincided with vegetative (Vn stage) and pre-flowering crop growth stage (VT) at p<0.05 level. In general, any stress during ten to fifteen days before and after flowering is considered to be highly sensitive to moisture stress, and has been observed to reduce the grain yield by two to three times more than the water deficit at other growing stages. The correlation between rainfall and the grain yield during Vn, VT and R1 (Silking) stages were 59 %, 61 % and 60 %, respectively (Rashid and Rasul, 2011). Though the crop received excess rainfall during the crop growth period, the standard week rainfall received during the critical stages has shown positive correlation than that of the other stages. The yield variations may be the result of effect of the temperature and rainfall on the growth and phenology of maize (Navneet Kaur and Prabhjyot Kaur, 2019) and rice (Parul Setia and Nain, 2021)

CONCLUSION

The yield prediction model developed from a linear regression equation between CCE yields with corresponding seasonal maximum NDVI values showed that there was a statistically significant relation (R^2=0.87**) between NDVI and observed yield at respective CCE plots and it was reasonable for crop yield estimation. Root Mean Squared Error (RSME) values computed for all observed and predicted yields were 0.50 (t ha^{-1}) during *kharif*, 2019 explaining higher accuracy of the yield model. Rainfall received during 31st Standard Week Rainfall (SWR) coincided with peak vegetative growth (between Vn and VT stages) which was the critical stage for moisture and has shown a highly significant positive correlation (r=0.68***) with yield data at $p\leq$ 0.001 level.

Conflict of Interest Statement: The author (s) declares (s) that there is no conflict of interest.

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