Article

Assessment of satellite and model derived long term solar radiation for spatial crop models: A case study using DSSAT in Andhra Pradesh

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Abstract
Crop Simulation models are mathematical representations of the soil plant-atmosphere system that calculate crop growth and yield, as well as the soil and plant water and nutrient balances, as a function of environmental conditions and crop management practices on daily time scale. Crop simulation models require meteorological data as inputs, but data availability and quality are often problematic particularly in spatialising the model for a regional studies. Among these weather variables, daily total solar radiation and air temperature (Tmax and Tmin) have the greatest influence on crop phenology and yield potential. The scarcity of good quality solar radiation data can be a major limitation to the use of crop models. Satellite-sensed weather data have been proposed as an alternative when weather station data are not available. These satellite and modeled based products are global and, in general, contiguous in time and also been shown to be accurate enough to provide reliable solar and meteorological resource data over large regions where surface measurements are sparse or nonexistent. In the present study, an attempt was made to evaluate the satellite and model derived daily solar radiation for simulating groundnut crop growth in the rainfed distrcits of Andhra Pradesh. From our preliminary investigation, we propose that satellite derived daily solar radiation data could be used along with ground observed temperature and rainfall data for regional crop simulation studies where the information on ground observed solar radiation is missing or not available.

Keywords solar radiation; satellite; crop model.

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1 Introduction

Crop simulation models are mathematical representations of the soil plant-atmosphere system that calculate crop growth and yield, as well as the soil and plant water and nutrient balances, as a function of environmental conditions and crop management practices on daily time scale. In the era of global climate change and precision farming, crop simulation models have been proved as a potential decision support tool worldwide. Applying a crop model on a regional scale is called "spatialising" a crop model that characterizes the spatial and temporal scales of a crop system. Crop simulation models require meteorological data as inputs, but data availability and quality are often problematic particularly in spatialising the model for a regional studies. Weather data quality varies depending on the source, which can introduce uncertainty in crop simulation results unless the weather data are carefully vetted (Aggarwal, 1995; Rivington et al., 2006). Among these weather variables, daily total solar radiation and air temperature (Tmax and Tmin) have the greatest influence on crop phenology and yield potential when biotic and abiotic stresses are absent Challenges arise with daily solar radiation because high-quality pyranometers are quite expensive and the accurate measurement requires careful maintenance, including periodical calibration. The scarcity of good quality solar radiation data can be a major limitation to the use of crop models. A good number of radiation estimation methods are based on the daily sunshine hours (Ångström, 1924; Kamel, 1993; Woodward et al. 2001). Faced with a lack of reliable solar radiation data, numerous researchers have opted for generating values using data on latitude, air temperature, and precipitation as inputs. The procedures first estimate the daily extraterrestrial insolation based on latitude, date, and the solar constant. This value is then reduced based on atmospheric transmittance or similar considerations (e.g., Richardson, 1981; Bristow and Campbell, 1984; Richardson and Wright, 1984; Hodges et al., 1985; Cooter and Dhakhwa, 1995; Liu and Scott, 2001).

The required weather variables at missing points are often estimated from existing weather parameters by spatial interpolation (Stahl et al., 2006) using existing network of weather stations. Because most of these estimation methods are empirical, their accuracy across a wide range of environments and geographic regions is uncertain. Satellite-sensed weather data have been proposed as an alternative when weather station data are not available (Pinker et al., 1995; Lakshmi and Susskind, 2000). Satellite weather data have been used for crop yield simulations (de Wit and van Diepen, 2008) and evapotranspiration estimation (Bois et al., 2008).These satellite and modeled based products are global and, in general, contiguous in time and also been shown to be accurate enough to provide reliable solar and meteorological resource data over large regions where surface measurements are sparse or nonexistent. The Prediction of Worldwide Energy Resource (POWER) project of NASA is one of the activities funded by the Applied Science Program of NASA (http://appliedsciences.nasa.gov/about.php).

The POWER project was initiated in 2003 as an outgrowth of the Surface meteorology and Solar Energy project of NASA. The Agroclimatology archive was developed with agricultural Decision Supports Systems (DSS) in mind and facilitates easy download of historical data for specific site locations. The parameters contained in this archive are based upon solar radiation derived from satellite observations and meteorological data from the Goddard Earth Observing System assimilation model.The archive boasts globally comprehensive coverage at

1° latitude by 1° longitude grid dating back to July 1983 to near present time and parameters include , top – of - atmosphere insolation, insolation on a horizontal surface, downward long radiative flux, daily mean, maximum, and minimum temperature at 2m above ground surface, relative humidity at 2m above ground surface, dew point at 2m aboveground surface, wind spend at 10m above ground surface and precipitation (starts January 1997 and ends August 2009). In the POWER database, the solar radiation data are derived from an ensemble of global satellite observations of cloud parameters and reflected shortwave radiation originating from the earth's atmosphere. These data are obtained from the NASA International Satellite Cloud Climatology Project (ISCCP) DX data product (Travis, 2007). The surface solar radiation is estimated from the ISCCP data and other supporting atmospheric data according to the procedure described by (Gupta et al., 2006). At present, through the NASA POWER database, the daily solar radiation data spans the time period from 1 July 1983 to within 2 to 3 wk of current time.

2 Study Area

Groundnut is an important food legume and oil seed crop of rainfed areas of Andhra Pradesh. In Andhra Pradesh, the crop is grown in about 1.33 million hectares, mostly in nine districts namely; Anantapur, Chitoor, Cuddapah, Kurnool, Mahaboobnagar, Nalgonda, Srikakulum, Vishakhapatnam and Warangal (Fig. 1). Out of these the following districts were selected (Table 2) for this study depending on the ready availability of observed weather and ancillary information (Vittal et al.,2004).

Table 1 Daily meteorological variables available on a global 1 degree grid through the NASA/POWER project (Jeffrey et al., 2008).

Variable	Source	Time period	Availability from present day
Daily maximum and minimum temperatures, daily average temperature	Goddard Earth Observing System (GEOS) assimilation model, Version 4 GEOS, Version 5.01 GEOS, Version 5.1	January 1983 to December 2006 January 2007 to December 2007 January 2008 to present	≤ 1 month
Precipitation	Satellite and ground observations from TRMM and GPCP projects 1 January 1997 to current	January 1997 to present	≤ 2 month
Solar radiation	Satellite observations	July 1983 to June 2006; July 2006 to present	≤ 1 month
Dewpoint temperature	Goddard Earth Observing System (GEOS) assimilation model, Version 4 GEOS, Version 5.01 GEOS, Version 5.1	January 1983 to December 2000 January 2007 to December 2007 January 2008 to present	≤ 1 month

3 DSSAT Crop Simulation Model

The Decision Support System for Agrotechnology Transfer (DSSAT) is decision support system that encompasses process-based simulation models that predict growth, development and yield as a function of local weather and soil conditions, crop management scenarios and genetic information. The crops that are covered include grain cereals such as rice, wheat, maize, barley, sorghum, and millet, grain legumes, such as soybean, peanut, dry bean, chickpea, tuber crops, such as potato and cassava, cotton, sugarcane, vegetables, and various other species. DSSAT also includes a basic set module to prepare the input data, as well as application programs for seasonal, crop rotation and spatial analysis. The crop models not only predict crop yield, but also resource dynamics, such as for water, nitrogen and carbon, and environmental impact, such as nitrogen leaching and global climate change. The crop simulation models require daily weather data, including maximum and minimum temperature, solar radiation, and precipitation, a description of the soil physical and chemical characteristics of the location, and crop management, including crop, variety, planting date, plant spacing, and inputs such as fertilizer and irrigation. DSSAT can be used on point mode or on regional mode at different spatial scales, the main consideration being availability of accurate input data. The CROPGRO-Peanut model has a long history of development and improvement starting as PNUTGRO in 1985 (Boote et al., 1986). The model has been evaluated extensively against experimental data on cultivars, sowing densities, drought, and sowing dates collected in Andhra Pradesh, India (Singh et al., 1994a; 1994b; Bhatia et al., 2009).

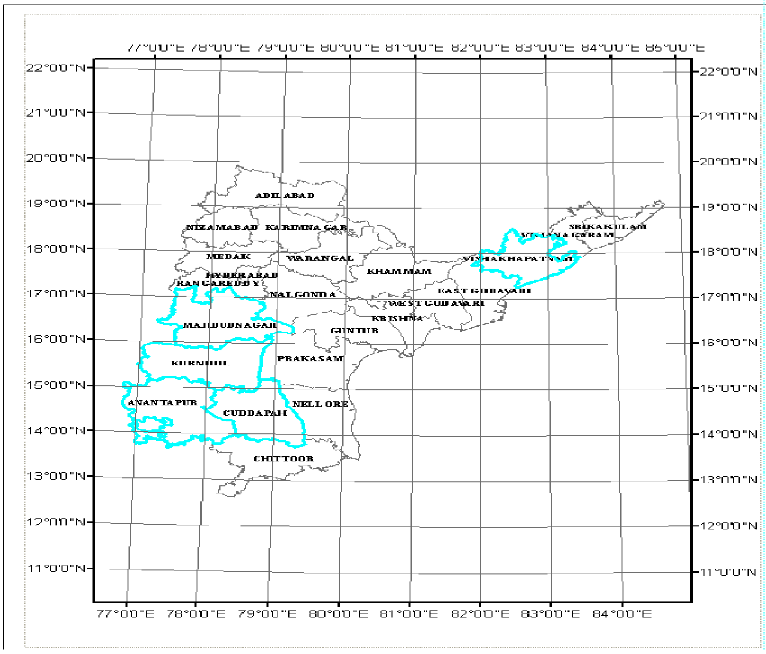


Fig. 1 Study area.

Table 2 Details of study area.

District	Climate	Soil	Annual RF (mm)	Moisture availability (days)	No of NASA POWER 1 degree grids
Anantapur	Hot arid	Deep loamy and clayey mixed red and black soils	497	60-90	4
Cuddapah	Hot dry semi arid	Deep loamy, clayey mixed red and black soils	748	80-120	3
Kurnool	Hot dry semi arid	Deep loamy, clayey mixed red and black soils	605	80-120	2
Vishakhapatnam	Hot (moist/ dry) sub humid	Medium to deep loamy red and lateritic	975	180-210	3
Mahaboobnagar	Hot moist semi arid	Deep loamy, clayey mixed red and black soils	792	120-150	2

4 Methodology

The study area was divided in to 1×1 degree grids (Fig. 1) and the daily weather data pertaining to maximum, minimum temperature, rainfall and solar radiation was downloaded from NASA POWER site. Required weather and soil files were prepared according to DSSAT format and crop simulation was carried out for the five above mentioned districts under rainfed condition for groundnut crop for 1999-2002. Two types of weather file were prepared, one with all derived weather data from NASA POWER site and the other with IMD weather data combined with solar radiation data from NASA POWER site. Most popular variety grown in the area was taken as the representative variety and predominant management practices over rainfed Andhra Pradesh were followed to simulate the groundnut yield. As regional yield was compared the simulate yield was averaged over a number of sowing dates and soil conditions. A sowing window of two months starting from 1st of June tom 31st of July was selected at an interval of one week. The soil condition was also varied in different simulations taking the major soil of the district as the representative one. Thus, the simulated yield was averaged over a district and compared with the observed average yield for the corresponding year.

Table 2 Details of study area.

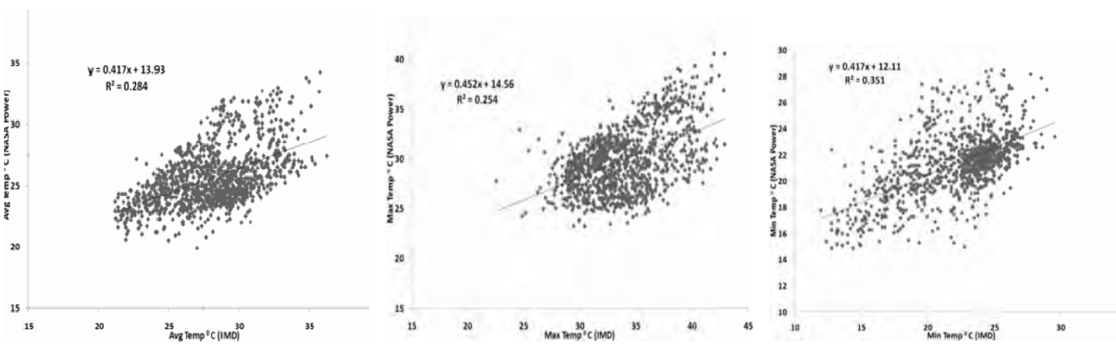
Location	Ananthpur	Cuddapah	Kurnool	Vishakhapatnam	Mahaboobnagar
Max Temp	0.503	0.603	0.756	0.527	0.797
Min Temp	0.592	0.626	0.691	0.811	0.773
Avg. Temp	0.533	0.676	0.756	0.698	0.826
Rainfall	0.260	0.238	0.185	0.308	0.201

5 Results and Discussion

5.1 Comparisons of weather data

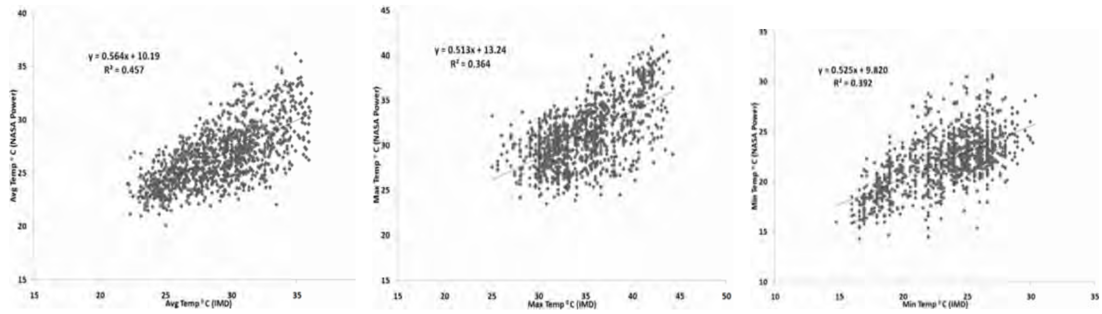
Different weather parameters derived from NASA POWER data set and ground observed weather data provided by Indian Meteorological Department (IMD) were compared for all the districts pertaining to the study area over the period 1999-2002. Scatterplots of the above relation are presented for different districts of Andhra Pradesh during the study period. The correlation matrix is presented in Table 3. It is observed that the correlation is very high between the IMD observed and corresponding NASA POWER derived meteorological parameters viz.

Table 4 Correlation coefficient between NASA POWER and IMD observed Meteorological variables Maximum, minimum and average temperatures though daily rainfall shows very low values of correlation coefficients. The annual distribution of satellite and model derived solar radiation values for the study region is presented in Fig. 6.



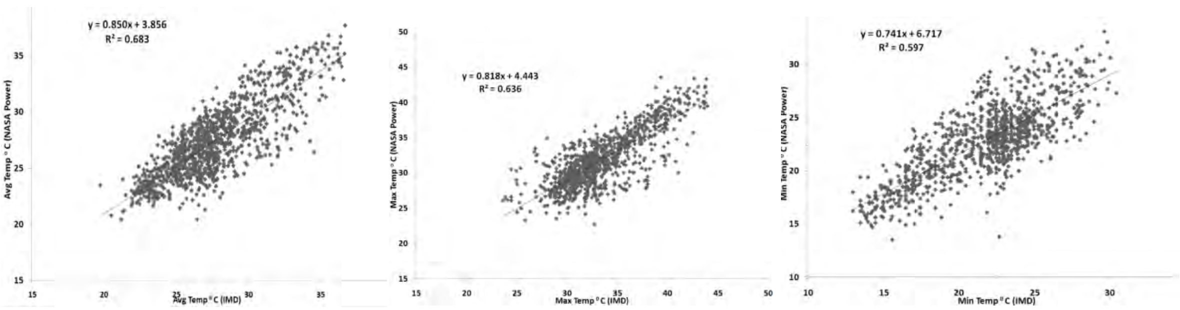
(a) (b) (c)

Fig. 1 Relation between IMD and NASA POWER derived meteorogical parameters for Ananthpur; Max temp (a), Min temp (b), average temp (c).



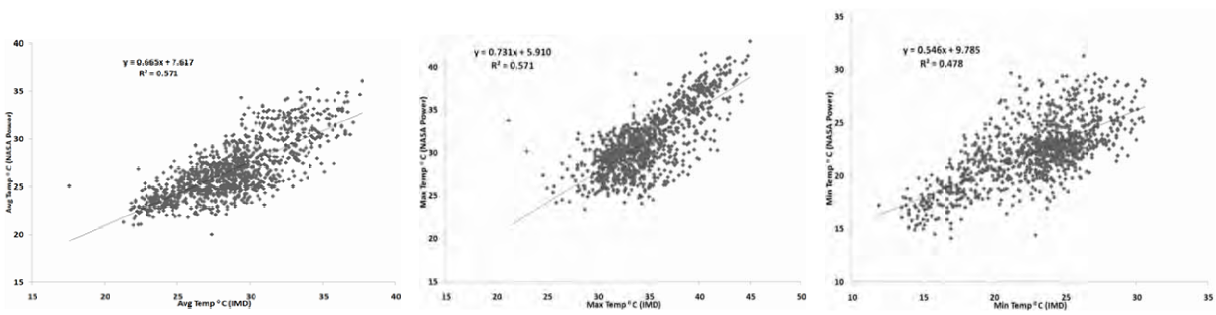
(a) (b) (c)

Fig. 2 Relation between IMD and NASA POWER derived meteorogical parameters for Cuddapah; Max temp (a), Min temp (b), average temp (c).



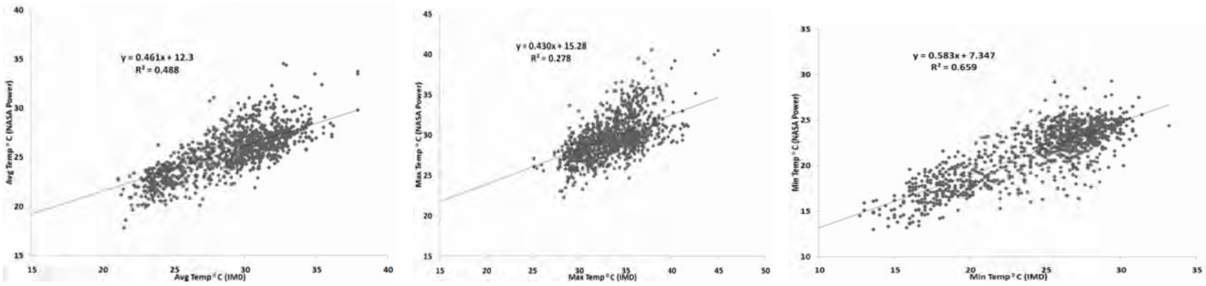
(a) (b) (c)

Fig. 3 Relation between IMD and NASA POWER derived meteorogical parameters for Mahaboob Nagar; Max temp (a), Min temp (b), average temp (c).



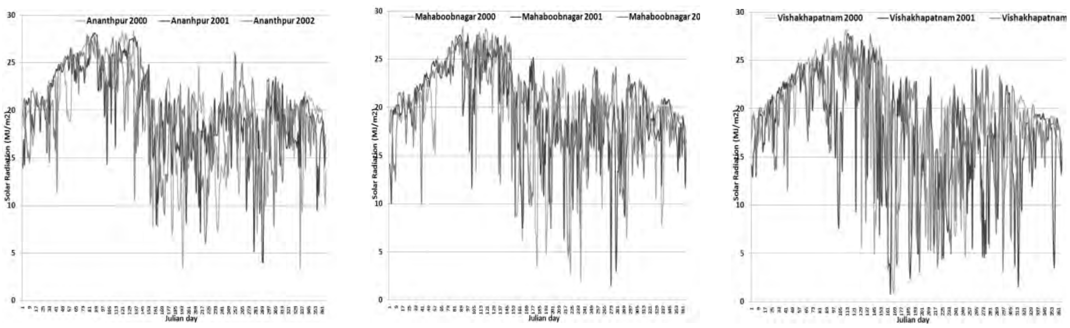
(a) (b) (c)

Fig. 4 Relation between IMD and NASA POWER derived meteorogical parameters for Kurnool; Max temp (a), Min temp (b), average temp (c).



(a) (b) (c)

Fig. 5 Relation between IMD and NASA POWER derived meteorogical parameters for Vishakhapatnam; Max temp (a), Min temp (b), average temp (c).



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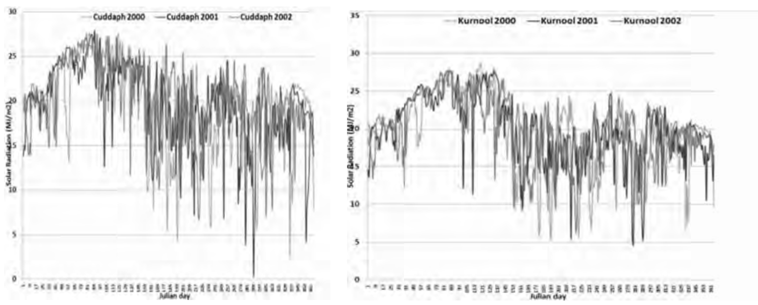


(d) (e)

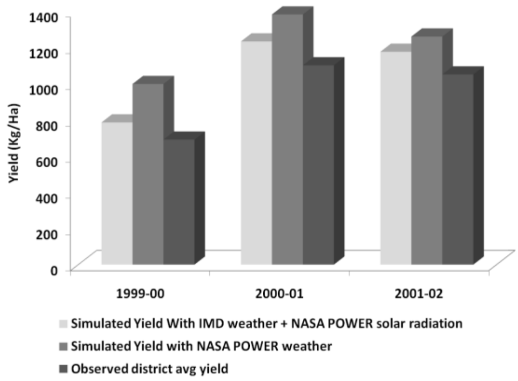
Fig. 6 Relation between IMD and NASA POWER weather data for Vishakhapatnam.

5.2 Comparisons of simulated groundnut yield

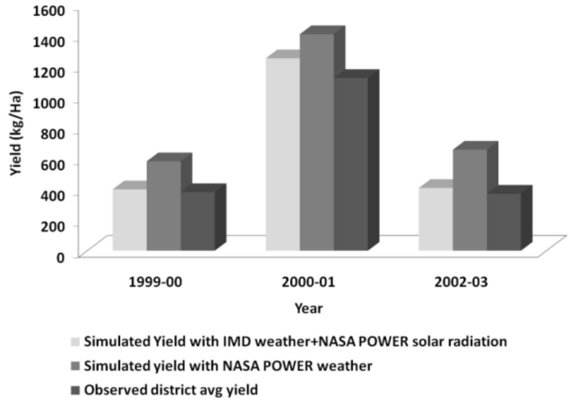
NASA satellite-derived daily solar radiation values and the NASA modeled temperature data that are used for simulating groundnut yield across the major rainfed groundnut growing area of Andhra Pradesh, India. Crop simulation was carried out with two sets of weather data for each location, one based on NASA satellite-derived weather data and the other with a weather file where observed temperature and rainfall values are kept along with the solar radiation values from NASA satellite-derived weather data. The overview of the simulation results for all the locations is presented in Table 5 as follows. This is observed that when NASA satellite-derived solar radiation was used in combination with ground station Tmax and Tmin, and averaged for the district, the simulated groundnut yield agreed reasonably well with the observed district average yield for that year (Fig. 7). Simulations based entirely on the NASA weather data, including both solar radiation and temperature, gave poor correlation with the observed average yield of the district. Though there is uncertainties related to satellite derived parameters that include pixel size, sensor resolution, navigation time, algorithm accuracy, and geographical coincidence of instantaneous information recorded by a satellite with measurements on the ground, the regional simulation result is with good agreement in the above mentioned regions suggests that NASA solar radiation data can be used with ground temperature and rainfall data for groundnut yield simulation in much of Andhra's rainfed groundnut growing area. Because many more ground weather stations in India have long-term and real-time temperature and rainfall data, supplementation by NASA solar radiation can provide much greater spatial density to estimates of groundnut yield potential across Andhra Pradesh, India.

Table 5 Overview of simulation result for a representative year.

VARIABLE	**Ananthpur**	**Cuddapah**	**Kurnool**	**Vishakhapatnam**
Anthesis day (dap)	25	25	25	26
First pod day (dap)	37	37	37	38
First seed day (dap)	44	44	44	45
Physiological maturity day (dap)	108	109	109	110
Yield at harvest maturity (kg [dm]/	1238	1487	1130	1182
Pod/Ear/Panicle weight at maturity	1608	1956	1478	1623
Number at maturity (no/m2)	484	586	454	603
Unit wt at maturity (g [dm]/unit)	0.2556	0.2536	0.2488	0.1962
Number at maturity (no/unit)	1.59	1.61	1.52	1.61
Tops weight at maturity (kg [dm]/ha	3536	4006	3919	3536
By-product produced (stalk) at maturity	2300	2520	2790	2350
Leaf area index, maximum	1.25	1.28	1.13	1.42
Harvest index at maturity	0.35	0.371	0.288	0.334
Threshing % at maturity	76.94	76.03	76.46	72.86
Grain N at maturity (kg/ha)	59	70	56	58
Tops N at maturity (kg/ha)	96	112	106	103
Stem N at maturity (kg/ha)	14	15	21	16
Grain N at maturity (%)	4.76	4.7	4.94	4.89
Tops weight at anthesis (kg [dm]/ha	97	99	93	110
Tops N at anthesis (kg/ha)	4	4	3	4
Leaf number per stem at maturity	23.04	23.49	22.98	27.01
Grain oil at maturity (%)	50.54	50.71	50.17	50.97
Canopy height (m)	0.51	0.51	0.53	0.63
Harvest maturity day (dap)	108	109	109	110



(a)



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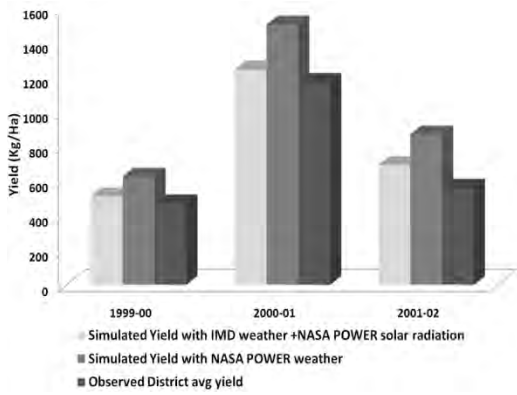

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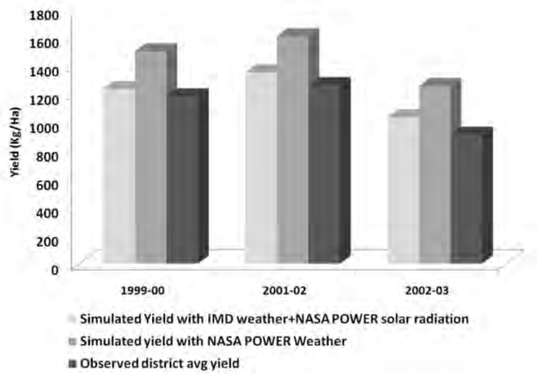

(d)

Fig. 7 Simulated and observed district average yield of groundnut for (a) Ananthpur, (b) Cuddaph (c) Kurnool (d) Vishakhapatnam.

6 Conclusions

Simulated groundnut yields based on NASA satellite-derived weather data and ground station weather data were compared at 4 districts that represent the main rainfed groundnut producing regions in Andhra Pradesh, India. From our preliminary investigation, we conclude that NASA daily solar radiation data could be used along with ground observed temperature and rainfall data for regional crop simulation studies where the information on ground observed solar radiation is missing or not available. This finding is to be validated in other agro ecological zones of India.

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