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RESEARCH ARTICLE :

Deciding sowing dates based on estimated evapotranspiration and water requirement and planning irrigation scheduling of lentil crop (*Lens culinaris*) using CROPWAT 8.0 model

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SUMMARY : Due to over exploitation of available water resources, it has become very important to define appropriate strategies for planning and management of water in semiarid conditions for successful growing of Lentil crop (*Lens culinaris*) as it is highly profitable. To achieve effective water allocation and planning, the information about Lentil crop water requirements, irrigation withdrawals, soil types and climate conditions were gathered from the study area *i.e.* Anthanpur district of Andhra Pradesh (A.P). The main objectives of the study area were to estimate the Lentil crop water requirement (*i.e.*, evapotranspiration) and deciding the proper sowing time in semi-arid agro climatic conditions of Ananthapur, A. P.To estimate the climatic water deficit, net irrigation requirement (NIR) and gross irrigation requirement (GIR) under different rain fed and irrigated conditions with six different growing dates with interval of 10 days starting from 1st September to 20 October.The results showed that the best sowing dates were last week of September to 1st week of October, which gives best utilization of rainfall as effective rain fall. The net and gross irrigation requirement (NIR and GIR) varied from a minimum to maximum as 69.7 mm, 110.3 mm, 78.2 mm, 119.4 mm, 114 mm and 165.9 mm; respectively for all sowing dates. Thus, by adopting a proper sowing date and irrigation scheduling criteria, it is possible to save 49.7 mm of water as NIR for early sown crop. Hence, the Lentil crop can be successfully grown in the semi-arid condition of Anthapur, Kadapa, Kurnool district of A.P. as well as similar other areas in the Telangana and which often suffer from the want of water. Farmer can fetch high return by selling Lentils than other crops.

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BACKGROUND AND OBJECTIVES

The population of India is expected to stabilize around 1640 million by the year 2050. As a result, gross per capita water availability will decline from 1820 m^3 /yr in 2001 to as low as 1140 m^3/yr in 2050. (Kumar and Rao, 2017). Total water requirement of the country for various activities around the year 2050 has been assessed to be 1450 km^3/yr. This is significantly more than the current estimate of utilizable water resource potential (1122 km^3/yr) through conventional development strategies (Rao *et al.*, 2017). Therefore, when compared with the availability of 500 km^3/year at present the water availability around 2050 needs to be almost trebled. Various options have been considered in quantitative terms, as possible sources to augment the anticipated deficit (Reddy *et al*., 2017).

It is important that the water requirements of crops are known at different management levels within the irrigated area to accomplish effective irrigation management. The crop water requirements are met from the effective rainfall, irrigation water applied and the available soil moisture (Reddy, 2012). Assuming that the change in available soil moisture before and after crop seasons is negligible, the water requirements of crop are met from effective rainfall and irrigation water. The potential evapotranspiration $ET_p$of a crop is the volume of water required by it to meet its evapotranspiration requirements. The crop irrigation water requirement therefore consists of potential evapotranspiration, $ET_{p,}$ minus the effective precipitation.

Climatic water demands, that govern the crop water requirement, are highly location specific hence, required to be establish with high accuracy and precision. Depending up on the climatic water demand alternatively refereed as reference evapotranspiration (ET_o) all other components of root zone water balancemay be determined accurately. Present study was attempted to estimate the components of root zone water balance using standard methodologies with FAO, CROPWAT model 8.0 for Lentil crop (*Lens culinaris*).Lentil is a pulse crop predominantly grown in rain fed conditions with low yield in our country. Lentil name was derived from 'Lens' having the 'lens' shaped seeds, is one of the important and most nutritious *Rabi* pulses. Lentil is a typically dry land crops, can be grown under irrigation with careful water management. Excess water in lentil crops can cause problems including delayed maturity, increased disease, and lower yields. It has the potential to cover the risk of rain fed farming. It is also used as a cover crop to check the soil erosion in problem areas (Othman and Dahim, 2016 and Donna Fleury, 2016). Lentil seeds also provide a source of starch for textiles and printing. Lentil residues form important livestock feed. Lentil floor is used for thickening of soups. It is mixed with wheat flour in bread and cake production.

RESOURCES AND METHODS

In order to achieve the objectives set for the present study, experiments were carried out in the laboratory as well as in the field of Precision Farming Development Centre (PFDC), Water Technology Centre (WTC), ICAR-Indian Agricultural Research institute (IARI), New Delhi. (Latitude 28°37'30" - 28°30'0" N, Longitude 77°8'45" -77°10'24" E and AMSL 228.61 m) during October to February two years (2013-14, 2014-15).

Study area:

The Ananthapur district is located in the northern region of the state of Andhra Pradesh district in the Rayalaseema region, on the southern part of India(Fig. A).The study area comprising 2200 sq km extends from Anantapur town in the south to border of Kurnool and Kadapa districts in NE and E, respectively in Andhra Pradesh State.The total geographical area it is the largest district of Andhra Pradesh spanning an area of 19,130 square kilometres. The study area is located at 14°30' - 15°30' and E longitudes 77°45' - 78°10'.An average elevation is about 624 m above mean sea level. This region is under semi-arid climate predominated by hot and dry weather throughout the year. Average annual rainfall of Annthapur district is about 582 mm (Hand book of Statistics, 2010-11) and is drained by 2 major rivers Pennarand Chitravatirivers with their tributaries drain the

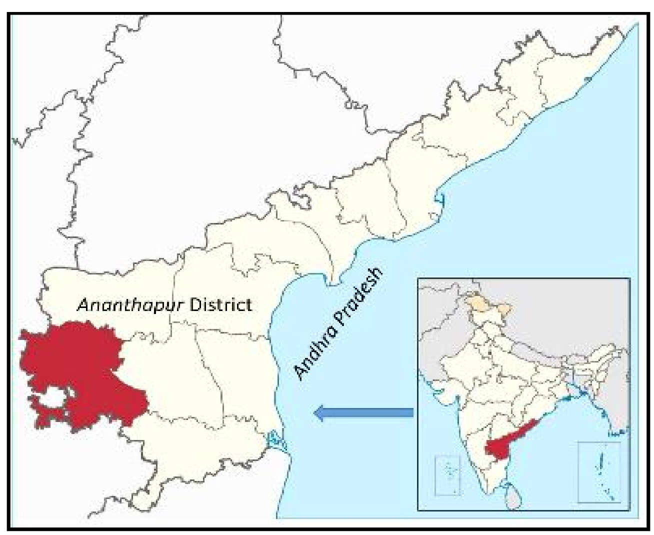

Fig. A : Study area Ananthapur district, Andhra Pradesh, India

area. Except Pennar all other rivers, streams have seasonal flow and are ephemeral. Agriculture is the principle occupation of the people and is the backbone of rural economy. Majority of agriculture activity is dependent on groundwater, as surface water resources like minor irrigation projects or tanks are almost defunct due to continuous low rainfall.

Climatic and rainfall-runoff characteristics:

The growth of lentil crop is adversely affected at temperatures above 27°C. Hence, it is grown as a winter season crop in semi-arid tropics. The present study area has average minimum and maximum temperature, relative humidity, sunshine hours and wind speed as 21.5°C, 34.1°C, 54.4 %, 7.8and 234.8 km/day; respectively (Table 1). Lentils require a minimum of 350 mm and maximum of 550 mm rainfall.In the higher rainfall areas, good drainage is essential. Water logging will have a great effect on yields and disease spread. Drought and severe or prolonged hot weather can cause loss in yields through pod cracking. The study area receivesan average low rainfall around 400-450 mm.The total effective rainfall were also presented in the (Table 1). Effective rainfall was computed according to the "USDA Soil Conservation Service Method" formula.(FAO, 1998 and 2009) using FAO CROPWAT 8.0 model by following equations.

$$\text{Rainfall excess (Pe)} = \frac{(P*(125-0.2*3*P))}{(125)} \quad \text{if rainfall} \le \frac{250}{3}\ mm$$

$$\text{Rainfall excess} \quad -\frac{125}{3}+0.1*P \qquad \text{if rainfall} \ge \frac{250}{3}\ mm$$

where, P = Total rainfall (mm)

In other hand, The runoff can be estimates for different conditions of soil group, land use land cover classes and antecedent moisture conditions (AMC) classes estimated by the Soil Conservation Service Curve Number (SCS-CN) has been used (Kadam *et al*., 2012). Therefore, the simplified assumption formed as a following runoff equations.

$$\text{Rainfall excess (Pe)} = \frac{(P-0.2S)^2}{(P+0.8S)} \quad \text{if rainfall} > 0.$$

$$\text{Rainfall excess} \quad = 0 \qquad \text{if rainfall} \le 0.2$$

where, P = Total rainfall (mm), S = Potential maximum retention of watershed (mm); $S=\left(\frac{1000}{CN}-10\right)$. In the present study the curve number was taken as 75 (Machiwal and Jha, 2017).

Percentage deviation from normal:

The percentage deviation is very useful to determining variation in the rain fall pattern. If the per cent deviation is a negative number that means the annual rainfall value is lesser than the normal annual rainfall. Similarly per cent deviation is a positive number, that means the yearly annual rainfall value is higher than the normal annual rainfall (Fig. B).

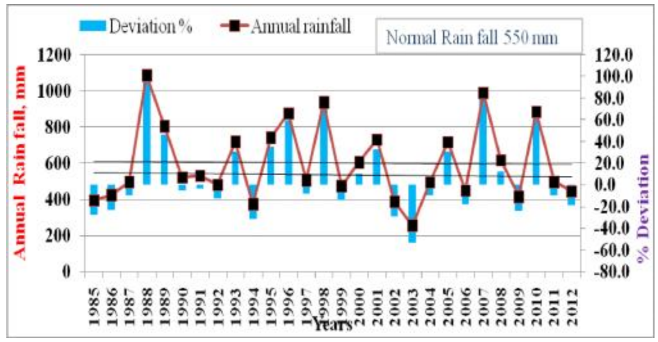

Fig. B : Annual rainfall and its percentage deviation over the period, 1985-2012

Soil data:

For any crop growth the soil will pay major role for crop production and productivity. The major soil types raised on light loams and alluvial soils in upper India, and on well-drained, moderately deep, light black soils, loam soils in Madhya Pradesh, Maharashtra and some parts of Andhra Pradesh (Some districts of A.P. like Kadapa, Kurnool and Chitoor). It is also grown on low lands, poor soils. The soil type date used with CROPWAT 8.0 model for Anthapur district presented in (Table 2). The crop can withstand moderate alkalinity however, it can't tolerate water logging. Soil should be made friable and weed free so that seed could be placed at a uniform depth. In case of light soils, less tillage is required to prepare an ideal seed-bed. In heavy soils, one deep ploughing followed by 2-3 cross harrowing should be given. After harrowing, the field should be levelled by giving a gentle slope for easy irrigation. There should be proper moisture in the soil at the time of sowing for proper germination of seeds.

Time of sowing based on the availability of water resources :

The sowing of seed mainly depends on the Antecedent Moisture Condition (AMC) of soil. The performance of the crop greatly depends on rainfall, irrigation condition, type of soil, storage capacity of soil and infiltration condition. In the present steady, the different sowing time was used based on soil moisture and rainfall condition to proper irrigation scheduling. The different sowing dates are presented in the (Table 3). Early sowing generally increases potential yields, but also increases the likelihood of crop lodging and delay in planting causes reduction in yield. Hence, one has to make it sure that there is good soil moisture before sowing and that seed has been inoculated. The reduction in yield could be minimized upto a certain extent by relatively closer spacing and use of higher seed rate. In central zone, where moisture is a limitation, early planting in mid-October is recommended to ensure proper germination. In north-west plains zone, end of October and in north-east zone. Sowing depth should be 4-6 cm. Under late-sown conditions, the row spacing should be reduced to 20 cm. Lentil seed should be sown at a depth of 3-4 cm in heavy soil. Target plant density should be 120-150 plants/m^2.However, the higher plant density for lower rainfall areas and short season environments is recommended. An ideal germination percentage is 80 %, if less, sowing rates may need to be increased to compensate. The seeding rate is expressed by following equation as given by Peter, 2005.

$$Seed\ rate\ \left(\frac{kg}{ha}\right) - \frac{Target\ plant\ density\ \left(\frac{plant}{m^2 X 100}\right) X\ seed\ weight\ (grams)\ X\ 10}{Germination\ per\ centage\ X\ Establishment\ per\ centage}$$

Influence of crop type on crop water needs:

The influence of the crop type on the crop water need is important in two ways. The crop type has an influence on the daily water needs of a fully grown crop; *i.e.* the peak daily water needs of a fully developed Lentil crop will need more water per day than a fully developed mustard crop. Second one is that the crop type has an influence on the duration of the total growing season of the crop. There are short duration crops, e.g. peas, with a duration of the total growing season of 90-100 days and longer duration crops, e.g. melons, with a duration of the total growing season of 120-160 days. There are, many perennial crops that require more water than Lentil.

Calculation of crop water requirements:

The calculation of Lentil crop water requirements was done using FAO Penman-Monteith equation. The basic formula for the calculation of crop evapotran spiration given in the following equation:

$$ET_{crop} = K_c \times ET_o$$

where, ET_{crop} is the water requirement of a given crop in mm per unit of time (mm/day, mm/month or mm/ season)., K_c is the crop factor, ET_o is the reference crop evapotranspiration in mm per unit of time (mm/day).ET_o is calculated by FAO-Penman- Monteith equation.

FAO Penman-Monteith equation:

The FAO Penman-Monteith method is used to estimate ET_o based on the original Penman Monteith equation and the equations of the aerodynamic and surface resistance can be given as in the equation (FAO, 1998 and 2009 and Shah *et al.*,2015).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

where, ET_o = reference evapotranspiration (mm/ day); R_n= net radiation at the crop surface ($MJ.m^{-2}.d^{-1}$); G = soil heat flux density ($MJ.m^{-2}.d^{-1}$); T = mean daily air temperature at 2 m high (°C); u_2 = wind speed at 2 m high ($m.s^{-1}$); e_s = saturation vapor pressure (kPa); e_a = actual vapor pressure (kPa); e_s-e_a = saturation vapor pressure deficit (kPa); Δ = slope vapor pressure curve ($kPa.°C^{-1}$); γ = psychrometric constant ($kPa.°C^{-1}$). The equation uses standard climatological records of solar radiation (*i.e.* sunshine), air temperature, humidity and wind speed. In other hand the following imperials namely, Evaporation pan, Balneycriddle, Thornthwaite formula were also used for estimation of crop water requirements using the different climatic parameters based on the suitability and availability of data base.

Selection of crop factor K_c for crops:

In order to obtain the crop water requirement (ET_{crop}) the reference crop evapotranspiration (ETo) must be multiplied by the crop factor (K_c). The crop factor (crop co-efficient) varies according to the growth stage of the crop. There are four growth stages to distinguish: (i). Theinitial stage: when the crop uses little water (ii). Thecrop development stage, when the water consumption increases (iii). Themidseason stage, when water consumption reaches a peak (iv). The late season stage, when the maturing crop once again requires less water (FAO, 1998 and 2009 and Shah *et al.*, 2015).

Irrigation scheduling and water requirement of Lentil crop:

The efficiency of water in agricultural production is generally low. Only 40 to 60 % of the water is effectively used by the crop, the rest of the water is lost in the system or in the farm either through evaporation runoff, or by percolation into the groundwater. Irrigation scheduling, if properly managed can offer a good solution to improve water efficiency in the farm. Irrigation scheduling involves deciding when and how much water to apply to a field. Good scheduling will apply water at the right time and in the right quantity in order to optimize production and minimize adverse environmental impacts. Bad scheduling will mean that either not enough water is applied or it is not applied at the right time, resulting in underwatering, or too much is applied or it is applied too soon resulting in over watering (Shah *et al.,* 2015 and Othman and Dahim, 2016).

Under or overwatering or deficit conditions can lead to reduced yields, lower quality and inefficient use of nutrients. In the present study the irrigation scheduling makes sure that water is consistently available to the plant and that it is applied according to crop requirements. The irrigation scheduling was prepared using CROPWAT 8.0 model, irrigation at 100% critical depletion, irrigation at fixed interval per stage and method of irrigation application, refill soil moisture content to 100% to field capacity. For the present study the standard procedure was followed for irrigation scheduling of Lentil crop under most acceptable criterion.

Calculation of irrigation water requirements based on climatic parameters:

Net irrigation water requirement (NIWR) or (NIR) is the quantity of water necessary for crop growth. It is expressed in mm per year or in m^3/ha per year (1 mm = 10 m^3/ha). It depends on the cropping pattern and the climate. Crop water requirements (CWR in mm) for a given crop, i, given in following equation.

$$CWR_i = \sum_{t=0}^{T} (K_{ci} \cdot ET_o \quad P)$$

where, K_{ci} is the crop co-efficient of the given crop i during the growth stage t and where T is the final growth stage. Each crop has its own water requirements. Net irrigation water requirements (NIWR) in a specific scheme for a given year are thus the sum of individual crop water requirements (CWR_i) calculated for each irrigated crop i. Multiple cropping (several cropping periods per year) is thus automatically taken into account by separately computing crop water requirements for each cropping period. By dividing by the area of the scheme (S. in ha), a value for irrigation water requirements is obtained and can be expressed in mm or in m^3/ha (1 mm = 10 m^3/ha).

The FAO's CROPWAT software (version 8.0) was used to compute NIWR for the study area and the model was run for six different scenarios of sowing dates; six sowing dates were simulated (2 each) for early sowing, normal sowing and late sowing date conditions. Gross irrigation water requirement (GIWR) is the amount of water to be extracted (by diversion, pumping) and applied to the irrigation scheme. It includes NIWR plus water losses: The GIWR in mm was given by the following equation.

$$GIWR = \frac{NIWR}{E}$$

where, E is the global efficiency of the irrigation system.

OBSERVATIONS AND ANALYSIS

The study area has received annual rainfall around 400-582 mm. The maximum rainfall is received during the months from August to November as shown in (Table 1). The results showed that more amount of water results into effective rainfall, this can be used for crop growth. The excess water can be stored as infiltration in the show soil depth that can be used for crop production when there is absence of rain or irrigation supply or deficit irrigation in the field. (Fig. 1) shows that the six different sowing dates with interval of 10 days sowing periods namely; earliest sowing dates starts from 1st September, early sowing date, normal sowing date-1, normal sowing date-2, late sowing and latest sowing upto 20 October as shown in (Table 3). The results speaks that effective rainfall can be maximum during the crop growing periods due to field preparation as results of less runoff.

The sowing date and period play vital role in the crop production and yield as well as the productivity of crop.It mainly depends on the Antecedent soil Moisture Condition and soil moisture storage in the soil root zone. The results speaks that the maximum utilization of rainfall is on the normal sowing dates that is 1st October to 10 October as shown in (Table 3). The earliest or latest sowing date'sresults into less efficiency of rain due to more runoff and rainfall periods.

Establishment of irrigation water requirements of lentil crop :

Based on the effective rainfall data in the study area, irrigation water requirements can be calculated from the difference between effective rainfall and the total water requirement (Fig. 2). The net irrigation and gross irrigation requirement are in increasing orderthrough growing period of crop. It is mainly depends on the growth stages of Lentil, crop co-efficient, variety, soil type etc. Fig. shows the NIR and GIR during the six different sowing date's starts from September 1st to October 20 with interval of 10 days period as shown in (Table 3). The (Fig. 3) shows the actual water requirement for the lentil crop during the crop period and the moisture deficit.

Water budgeting of Anantapur region for different scenario:

The water budgeting of the region for different scenario of different years were estimated using

Table 1: Average long term climatic parameters and the estimated reference evapotranspiration ET_o using FAO-Penmain Motieth equation of study area (Anthapur, A.P.) for Lentil crop

Months	Min temp, (^OC)	Maxi Temp, (^OC)	RH, (%)	Wind speed, (km/day)	Sunshine hours	Rainfall, (mm)	Effective rainfall, (mm)	ETo, mm/day
January	17.0	31.7	54	187	9.4	1.8	1.8	4.88
February	19.7	34.8	50	195	9.7	0.5	0.5	5.84
March	21.9	37.2	43	202	9.9	6.9	6.4	6.88
April	24.7	38.7	40	215	9.8	21.4	19.6	7.60
May	25.7	39.0	42	296	9.4	48.7	43.8	8.51
June	24.3	35.6	51	383	7.5	82.1	64.6	7.78
July	23.2	33.2	59	372	5.2	155.7	100.5	6.28
August	22.8	32.7	62	321	5.4	169.2	108.4	5.76
September	22.4	32.2	64	223	6.5	177.2	114.6	5.20
October	21.4	32.1	63	133	7.0	114.4	88.0	4.51
November	18.7	31.5	62	138	8.2	23.0	21.0	4.35
December	16.7	30.1	63	153	7.8	10.0	9.2	3.98
Total rain fall (All good year)						811.3	578.7	5.90

Table 2 : The soil type date used with CROPWAT 8.0 model for Anthapur district

Soil data	Red sandy loam	Red sandy	Red loam
Total available soil moisture (mm/meter)	142	135	120
Maximum rain infiltration rate (mm/day)	31	33	35
Maximum rooting depth (cm)	61	62	65
Initial soil moisture depletion (as % TAM)	0	0	0
Initial available soil moisture (mm/meter)	140	140	140

Table 3 : Irrigation scheduling, sowing, net and gross irrigation requirements for lentil crop

Planting date	Earliest sowing date (01-Sep)	Early sowing date (10-Sep)	Normal sowing date-1 (20-Sep)	Normal sowing date-2 (01-Oct)	Late sowing date (10-Oct)	Latest sowing date (20-Oct)
Gross irrigation (mm)	98.7	148.3	111.6	170.1	170.2	230.8
Net irrigation (mm)	69.7	110.3	78.2	119.4	111.4	165.9
Actual water use by crop (mm)	269.5	250.5	241.9	234.7	230.2	234.3
Potential water use by crop (mm)	265.5	250.5	241.9	234.7	234.2	234.3
Rainfall (mm)	188.1	172.2	178.2	170.4	145.9	107.7
Effective rainfall (mm)	170.9	134.6	125.6	102.7	75.7	56.9
Total rain loss (mm)	11.2	42.6	52.6	71.3	64.3	47.8
Moisture deficit at harvest (mm)	25.9	4.7	38.2	12.9	35.1	18.5
Actual irrigation requirement (mm)	92.6	114.3	116.3	132	153.6	174.4
Efficiency rain (%)	98.3	75.1	70.5	59	54.3	51.5

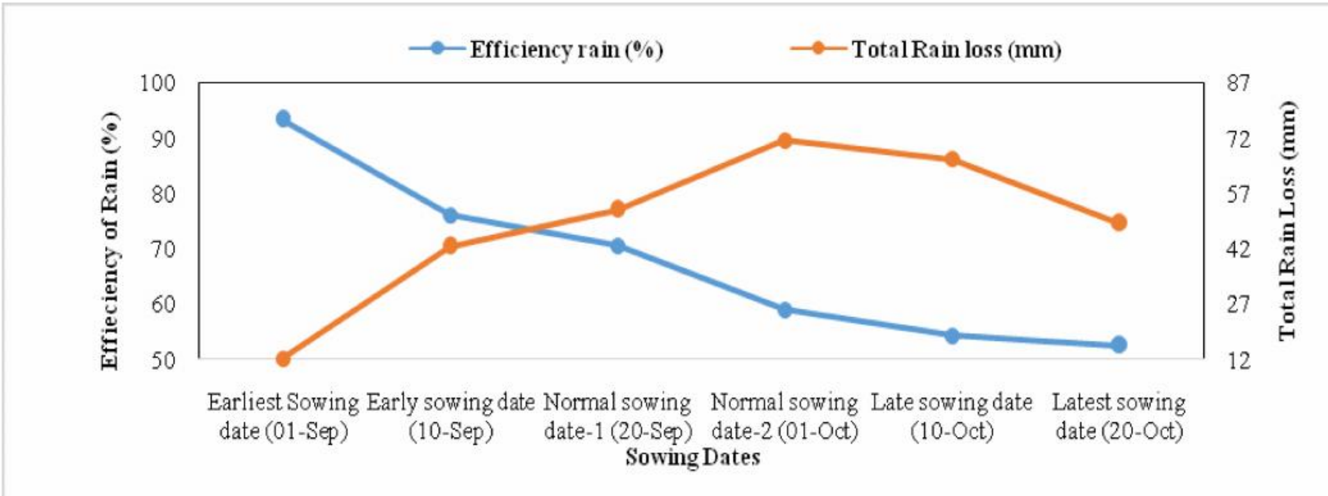

Fig. 1: The relation between efficiency of rain and total rain loss for the study area

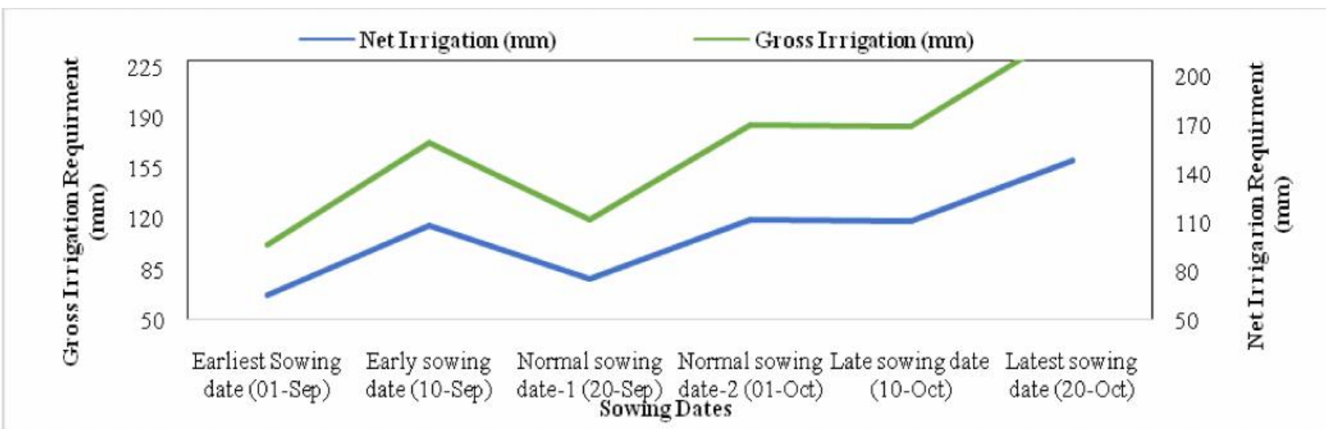

Fig. 2: Relation between gross and net irrigation requirement of Lentil crop (GIR and NIR)

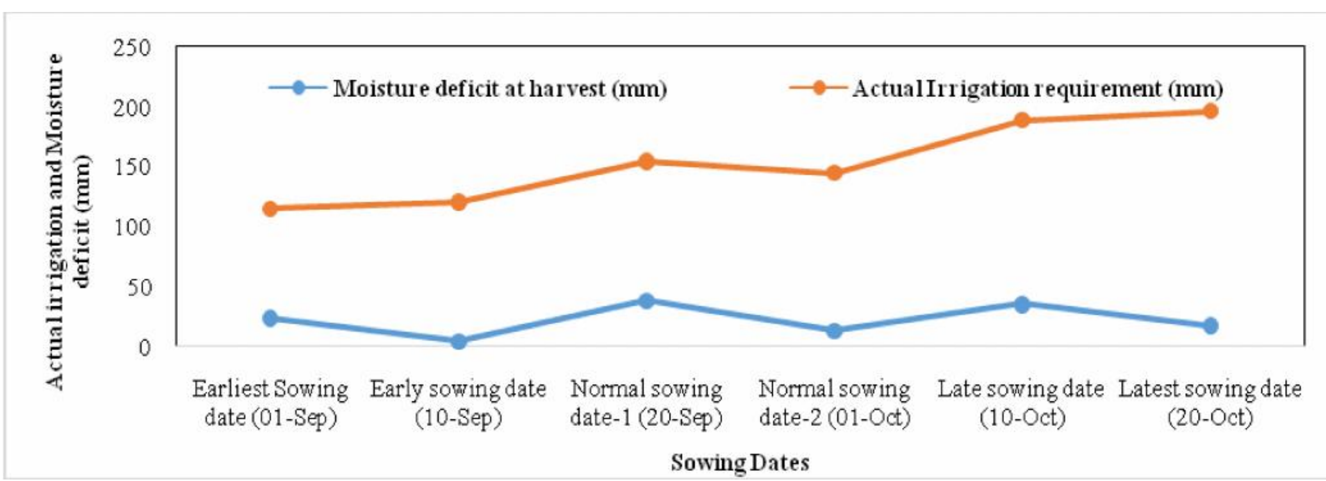

Fig. 3: The relation between actual irrigation requirement and moisture deficit at harvesting time of lentil crop

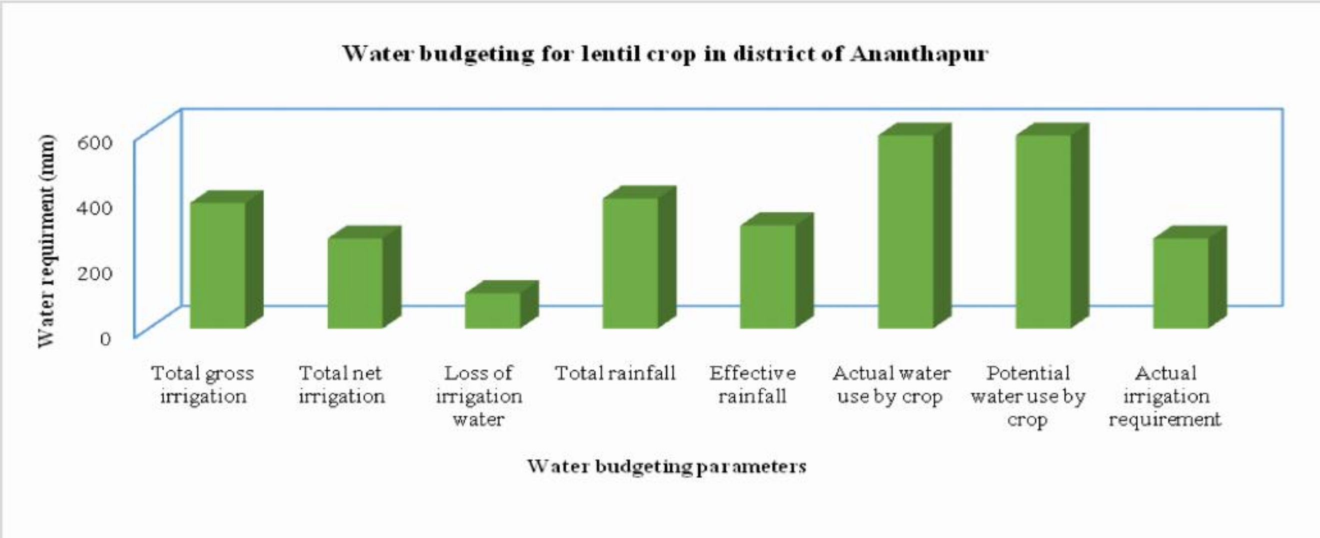

Fig. 4: Water budgeting for the Anantapur region lentil crop

CROPWAT 8.0 and data results were shown in (Table 3) as well as in (Fig. 1). The gross irrigation was 154.95 mm; net irrigation was 109.5mm; actual water use by crop 243.5 mm potential water use by crop 243.5 mm and the efficiency of application of irrigation was calculated as 68.11%, respectively.

Conclusion:

An attempt was made to estimate the crop water requirement, net irrigation requirement (NIR) and the gross irrigation requirement (GIR) and sowing dates of Lentil crop (Lens culinaris) grown in semi-arid climatic region of Ananthapur district of Andhra Pradesh. This district receives very low scanty of rainfall varies from 400-450 mm. The results showedthat 5.90 mm/day under the six different crop sowing dates staring from 1st September to 20 October with lag of 10 days period. The results revealed that the less NIR, GIR requirement was observed under normal date-1 and early sowing dates *i.e.* 69.7 mm to165 mm and 98.7 mm to 230.8 mm, respectively. The study concluded that the Lentil crop,one of the highly nutritional crop, needs relatively less water requirement and it can tolerate the water scarcity so that the normal dates for sowing are mid-September to mid-October.

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