__Original Research Article__

Identification of Rainfall Deviation Thresholds Based on WRSI for Monitoring Water Stress in Pulses

ABSTRACT

The study was conducted to identify rainfall deviation thresholds based on water requirement satisfaction index (WRSI) in pulses for monitoring water stress due to drought during *kharif* season in Telangana. The districts of Medak, Warangal and Mahabubnagar with major areas under blackgram, greengram and redgram crops, respectively were considered as study area. The rainfall deviation frequency was estimated in 20 representative sites under each crop and accordingly WRSI was calculated. The rainfall and WRSI estimated were related for their dependability in the estimation of water stress occurring due to drought during *kharif* season in the crops under study. Based on rainfall frequency, the rainfall was deficit for blackgram and normal for greengram and redgram in most of the study period. WRSI predicted mediocre growth of blackgram and average to good growth of greengram and redgram. The total explained variation in the prediction of crop performance by WRSI index in relation to rainfall was 0.26 to 0.77 for blackgram, 0.57 to 0.96 for redgram, 0.35 to 0.94 for greengram during the study period. The rainfall deviation thresholds were identified irrespective of soil type and depth in blackgram. Whereas, in case of greengram and redgram, the thresholds varied with soil type and depth.

Keywords: blackgram, greengram, rainfall deviation thresholds, redgram, water stress, WRSI

1. INTRODUCTION

Agricultural drought is considered as a situation in which soil, rainfall, and plant-water requirements are not enough to mature a healthy crop.It is defined as a period of four consecutive weeks with a rainfall deficiency of more than 50 percent of the long-term average (LTA) or within a week, rainfall of 5cm or less during the period from mid-May to mid-October (the *kharif* Season) (Anonymous, 2009).More than 50% of India's productive farmland is rainfed, which is complex, highly diverse, and risk-prone to agricultural drought. Agricultural drought results in poor productivity, decreased fertility, poor animal health and a rise in livestock mortality. Because of water deficit during drought, water supply to roots become difficult causing water stress in plants. Water stress occurs during any stage of crop from germination to reproductive stage. A plant subjected to water stress has to undergo molecular, biochemical, physiological, morphological and ecological traits which cause reduction in photosynthesisand, leaf area reduction, early maturity, reduction in height, reduction in yield etc. (Seleiman*et. al*., 2021). Water holding capacity of soil is also one of the factors which cause water stress in plants. It is high in loamy to clay loam soils and less in sandy soils, hence sandy soils dry out more quickly after rain and plants growing on them show drought signs sooner compared to clay loam soils (Preston, 2002). According to Simbeye *et. al*., (2023) judging whether a crop is short of water should start from the three aspects, namely: soil, climate, and crops. There are many indicators to study water stress in plants which are very efficient in monitoring and quantifying crop water stress and scheduling irrigation as well. The water-stress indicators in crops can be categorized as soil and plant-based measures. The soil-based measures require sophisticated instruments and some of them are time consuming. The estimation of soil moisture or crop evapotranspiration from climatic parameters provides objective criteria for irrigation management. But the methods of estimating evapotranspiration require huge climatic data (Krishnan, 2012). Keeping in view that the thresholds for deviation in rainfall at which water stress triggers vary according to crops, soils and climatic conditions, there is a need to

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Formatted: Font color: Red, Strikethrough identify those thresholds for different crops as an alternative for repetitive usage of traditional methods. The Water requirement satisfaction index (WRSI) is one such indicator of crop performance based on the availability of water to the crop during a growing season. Identification of rainfall deviation thresholds based on WRSI for different crops may be an effective method of crop water stress monitoring. Manivasagam and Nagarajan (2018) estimated the frequency of water stress occurrence based on weekly rainfall classification for maize crop and classified rainfall into four categories to analyse water availability for crop growth at different stages. Masupha and Moeletsi (2020). identified that the optimal planting date for rainfed maize crop in the Luvuvhu River catchment area is from October to November, with WRSI values relative to more intense drought conditions reflected during the December planting decades for all stations in the catchment. Similarly, Jayasree *et al*., (2008) studied the impact of moisture stress at different growth phases in maize using WRSI during *kharif* and noted a significant positive correlation between WRSI and yield (r = 0.79). Higher water use efficiency was observed with skipping of irrigation at vegetative stage and in rainfed treatments.

In India about 56% of the net cultivated area is rainfed which depend mainly on South West Monsoon. The *kharif* crops cultivated during this season mainly consists of paddy, pulses, cereals, oilseeds, sugarcane, jute and cotton. India is the largest producer of pulses in the world and covering an area of 131 lakh hectares (Anonymous, 2022). Pulses are recognized as a source of vegetarian protein and in agriculture they play a vital role in maintaining soil fertility by fixing atmospheric nitrogen (Dharbale, 2019). Major pulses such as chickpea, pigeonpea, lentil grown under rainfed conditions are subjected to water stress due to drought especially during reproductive stage when pods are developed. Present study focuses on identification of rainfall deviation thresholds based on WRSI in pulses for monitoring water stress due to drought during *kharif* season in Telangana.

2. MATERIAL AND METHODS

2.1 STUDY AREA

The study was conducted in Medak, Warangal and Mahabubnagar districts of Telangana state (Fig. 1). Telangana is situated on the south-central stretch of the Indian peninsula on the high Deccan plateau at 17.824400°N latitude and 79.187900°E longitude and with a geographical area of 112,077 km^2. Telangana is a semi-arid region and has a predominantly hot and dry climate. Summers in the state start in March, and peak in May with average high temperatures in the range of 46 °C (115 °F). The monsoon arrives in June and lasts until September with about an average of 755 mm (29.7 inches) of precipitation. A dry, mild winter starts in late November and lasts until early February with little humidity and average temperaturesin the range of 22–23 °C (72–73 °F). The annual rainfall due to south-west monsoons is between 900 and 1500 mm in northern Telangana and 700 to 900 mm in southern Telangana.

The districts, Medak, Warangal and Mahabubnagar having maximum acreage of the pulses - blackgram, greengram, redgram, respectively were selected as study area. The soils of the representative site are majorly shallow to deep clay soils and shallow to deep loamy soils.

For estimating WRSI and for calculating rainfall deviation, a 0.25 x 0.25 resolution gridded rainfall and temperature data (Maximum, Minimum) was acquired from India Meteorological Department (IMD) for the period 2000 to 2015. Soil information is collected from the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP).

2.1.1 RAINFALL DEVIATION CALULATION

Weekly rainfall deviation for the period 2000 to 2016 is calculated using the equation1.

The Rainfall Deviation (Rfdev) expressed in percentage terms is calculated as below:

$$RFdev = \{ (RFi - RFn) / RFn \} * 100 \text{ --------------------- equation 1}$$

RFi = Actual rainfall

RFn= Normal Rainfall (30 years average)

2.1.2 ESTIMATION OF WATER REQUIREMENT SATISFACTION INDEX (WRSI)

WRSI is the ratio of seasonal actual crop evapotranspiration (AET_c) to the seasonal crop water requirement, which is the same as the potential crop evapotranspiration (PET_c). PET_c denotes crop specific potential evapotranspiration after an adjustment is made to the reference crop potential evapotranspiration (PET) by the use of appropriate crop coefficients (Kc). Evapotranspiration is calculated using Hargreaves-Samani method and AET_c, PET_c are calculated using Soil Water Balance (SWB) Model and equation 3 is used to run the model.

$$WRSI = (\sum AET_C / \sum PET_C) * 100 \text{ ------equation 2}$$

$$S = (P+I+U) - (Q+DP+E+T) \text{ -------equation 3}$$

P = Precipitation

U = Upward Capillary Flux

Q = Runoff

DP = Deep Percolation

E = Evapotranspiration

T = Transpiration

3. RESULTS AND DISCUSSION

Weekly rainfall deviation frequency for *kharif* season at all representative sites of blackgram, redgram and greengram for the period 2000 – 2016 is shown in table 1. The results reported that during the study period, at blackgram representative sites frequency of deficit and normal rainfall is between 18.75 to 62.5 percent, frequency of excess rainfall is between 6.25 to 25 percent and large excess rainfall frequency is between 6.25 to 12.5 percent. At redgram representative sites frequency of deficit rainfall is between 18.75 to 31.25, normal rainfall frequency is between 43.75 to 68.75 percent, frequency of excess rainfall is between 12.5 to 18.75 percent and large excess rainfall frequency is between 0 to 6.25 percent. At greengram representative sites, frequency of large deficit rainfall is between 12.5 and 37.5, deficit rainfall frequency is between 6.25 to 37.5 percent, normal rainfall frequency is between 25 to 56.25 percent, frequency of excess rainfall is between 12.5 to

31.25 percent. It is observed that at blackgram representative sites most of the time rainfall was deficit during the study period. Whereas the rainfall was normal at redgram and greengram representative sites.

Crop condition with respect to WRSI at all representative sites of blackgram, redgram and greengram for the period 2000 – 2016 is shown in table 2. The results revealed that during the study period, *kharif*blackgram has put up mediocre growth in the study area and redgram, greengram has put up average to good growth. A relation (Fig. 1) established between rainfall and WRSI for blackgram, redgram and greengram suggested that the first-degree polynomial i.e., the linear function represented the data more than 50 percent for the deficit and excess rainfall years except in blackgram where it is less than 50 percent in excess rainfall year. Both the linear (b) term and determination coefficient (R^2) (Table 3) indicated that the predictive efficiency of the functions was high. The total explained variation in the prediction of crop performance by WRSI index in relation to rainfall was 0.26 to 0.77 for blackgram, 0.57 to 0.96 for redgram, 0.35 to 0.94 for greengram. However, considering an explained variation of more than 0.5 in 11 out of 16 years in blackgram, 0.90 in 14 out of 16 years in redgram, 0.5 in 13 out of 16 years in greengram, WRSI was found to be a highly dependable index in the prediction of crop performance in response to soil moisture availability.

Irrespective of soil type and depth, the blackgram locations with a deviation in rainfall of more than 30 percent have been reported to have poor crop condition by WRSI, and locations with a deviation of more than 40 percent from the normal rainfall have been correspondingly reported with crop failure by WRSI. On the other hand, the crop condition estimated by WRSI in relation to rainfall varied with soil type and depth at different locations of redgram and greengram (Table 4). The above results indicated that the rainfall deviation thresholds for short duration sensitive pulse crops like blackgram could be established irrespective of soil type and depth. While the rainfall deviation thresholds varied according to soil type and depth in case of more studier pulse crops viz., greengram and redgram. In a similar study, Santos *et al*. (2012) was able to conduct climatic risk zoning using WRSI for the joint planting of corn and palisade grass in the state of Sao Paulo, in order to indicate the most favourable period for establishment of these crops based on the risk of water deficiency, considering both rainfall and soil type.

A similar study on assessment of water requirement of tobacco at Rajamundry by Rajavel *et. al*. (2012) indicated that the yield of tobacco was linearly and significantly correlated with the amount of rainfall, water use and WRSI. Fenner *et. al*. (2017) in the zoning of WRSI for common bean in Mato Grosso, mentioned the importance of rainfall distribution because it directly influenced the development of the common bean crop for the different sowing periods in the state. According to Senay and Verdin (2002) the WRSI model was particularly successful in capturing the response of the crop during a relatively dry year as part of monitoring and forecasting tool for region-wide food security analyses in drought prone countries in Sub-Saharan Africa. Pinto *et. al*. (2021) identified low climate risk areas as those with WRSI greater than or equal to 0.5 during flowering and early grain development and less than 20 mm of total rainfall during grain maturation and harvest for at least 80% of the simulated sowings of the crop.

Capturing crop condition in blackgram by WRSI based on available soil moisture, precipitation, and actual evapotranspiration holds reliable. Greengram being sturdier and with quick canopy coverage than blackgram WRSI exhibited varied crop condition based on soil type and depth due to differences in soil moisture holding capacity and evapotranspiration of individual soil in the estimation of crop condition. Further, in redgram based on the canopy spread, rooting nature and other morphological characteristics, the crops varied in theirresponse to water availability as indexed by WRSI. The soil physical characteristics in terms of soil moisture holding capacity and texture also might had brought about the variation in the crop condition assessed through WRSI. Hence, it can be inferred that the dependability on WRSI for crop condition or drought assessment vary with soil type, soil depth and crop type.

Table 1. Weekly rainfall deviation frequency of *kharif* pulses at respective representative sites

	Rainfall Deviation Frequency														
	Blackgram					Redgram					Greengram				
Location	**LD**	**D**	**N**	**E**	**LE**	**LD**	**D**	**N**	**E**	**LE**	**LD**	**D**	**N**	**E**	**LE**
1	0.0	31.3	56.3	6.3	6.3	0.0	31.3	50.0	18.8	0.0	18.8	12.5	43.8	25.0	0.0
2	0.0	31.3	56.3	12.5	0.0	0.0	18.8	62.5	18.8	0.0	18.8	18.8	37.5	25.0	0.0
3	0.0	31.3	50.0	12.5	6.3	0.0	18.8	68.8	12.5	0.0	31.3	12.5	37.5	18.8	0.0
4	0.0	50.0	37.5	0.0	12.5	0.0	18.8	68.8	12.5	0.0	25.0	12.5	43.8	18.8	0.0
5	0.0	37.5	50.0	6.3	6.3	0.0	18.8	62.5	18.8	0.0	25.0	18.8	31.3	25.0	0.0
6	0.0	37.5	50.0	6.3	6.3	0.0	31.3	50.0	18.8	0.0	18.8	31.3	31.3	18.8	0.0
7	0.0	56.3	25.0	6.3	6.3	0.0	18.8	68.8	12.5	0.0	25.0	37.5	25.0	12.5	0.0
8	0.0	37.5	43.8	12.5	6.3	0.0	18.8	62.5	18.8	0.0	31.3	6.3	31.3	31.3	0.0
9	0.0	62.5	18.8	18.8	0.0	0.0	18.8	68.8	12.5	0.0	12.5	25.0	37.5	25.0	0.0
10	0.0	62.5	31.3	6.3	0.0	0.0	18.8	68.8	12.5	0.0	25.0	12.5	37.5	25.0	0.0
11	0.0	50.0	31.3	6.3	12.5	0.0	25.0	56.3	12.5	6.3	18.8	18.8	43.8	18.8	0.0
12	0.0	56.3	31.3	6.3	6.3	0.0	31.3	50.0	12.5	6.3	18.8	18.8	37.5	25.0	0.0
13	0.0	43.8	50.0	6.3	0.0	0.0	25.0	56.3	12.5	6.3	18.8	31.3	31.3	18.8	0.0
14	0.0	31.3	56.3	6.3	6.3	0.0	31.3	43.8	18.8	6.3	18.8	6.3	56.3	18.8	0.0
15	0.0	18.8	62.5	12.5	6.3	0.0	31.3	43.8	18.8	6.3	18.8	18.8	37.5	25.0	0.0
16	0.0	43.8	37.5	18.8	0.0	0.0	25.0	56.3	18.8	0.0	18.8	18.8	37.5	25.0	0.0
17	0.0	56.3	25.0	18.8	0.0	0.0	25.0	56.3	18.8	0.0	25.0	12.5	37.5	25.0	0.0
18	0.0	56.3	31.3	12.5	0.0	0.0	25.0	50.0	18.8	6.3	37.5	6.3	37.5	18.8	0.0
19	0.0	50.0	25.0	25.0	0.0	0.0	25.0	56.3	18.8	0.0	25.0	12.5	37.5	25.0	0.0

20	0.0	37.5	43.8	18.8	0.0	0.0	18.8	56.3	18.8	6.3	18.8	18.8	43.8	18.8	0.0

**LD- Large Deficit; D – Deficit; N – Normal; E – Excess; LE – Large Excess*

Table 2: WRSI frequency of *Kharif* pulses at respective representative sites

	WRSI Frequency																	
	Blackgram						Redgram						Greengram					
Location	**F**	**P**	**A**	**M**	**G**	**VG**	**F**	**P**	**A**	**M**	**G**	**VG**	**F**	**P**	**A**	**M**	**G**	**VG**
1	0.0	25.0	25.0	37.5	12.5	0.0	0.0	0.0	56.3	25.0	18.8	0.0	0.0	0.0	31.3	0.0	68.8	0.0
2	6.3	18.8	18.8	50.0	0.0	6.3	0.0	0.0	68.8	25.0	68.8	0.0	0.0	0.0	56.3	12.5	31.3	0.0
3	12.5	12.5	25.0	43.8	6.3	0.0	0.0	0.0	43.8	50.0	43.8	0.0	0.0	0.0	50.0	12.5	37.5	0.0
4	18.8	12.5	18.8	43.8	0.0	6.3	0.0	0.0	50.0	43.8	50.0	0.0	0.0	0.0	43.8	0.0	56.3	0.0
5	18.8	0.0	18.8	56.3	6.3	0.0	0.0	0.0	31.3	62.5	31.3	0.0	0.0	0.0	25.0	0.0	75.0	0.0
6	12.5	12.5	12.5	50.0	6.3	6.3	0.0	0.0	56.3	18.8	56.3	0.0	0.0	0.0	37.5	0.0	56.3	6.3
7	0.0	25.0	25.0	43.8	0.0	6.3	0.0	0.0	37.5	56.3	37.5	0.0	0.0	0.0	43.8	6.3	50.0	0.0
8	6.3	0.0	18.8	75.0	0.0	0.0	0.0	0.0	37.5	56.3	37.5	0.0	0.0	0.0	25.0	0.0	68.8	6.3
9	0.0	12.5	6.3	68.8	6.3	6.3	0.0	0.0	37.5	56.3	37.5	0.0	0.0	0.0	68.8	0.0	31.3	0.0
10	12.5	0.0	12.5	75.0	0.0	0.0	0.0	0.0	43.8	50.0	43.8	0.0	0.0	0.0	31.3	6.3	62.5	0.0
11	6.3	12.5	18.8	56.3	0.0	6.3	0.0	0.0	75.0	12.5	75.0	0.0	0.0	0.0	25.0	0.0	75.0	0.0
12	0.0	18.8	0.0	68.8	6.3	6.3	0.0	0.0	62.5	25.0	62.5	0.0	0.0	0.0	18.8	0.0	75.0	6.3
13	6.3	18.8	25.0	43.8	6.3	0.0	0.0	0.0	56.3	37.5	56.3	0.0	0.0	0.0	25.0	0.0	68.8	6.3
14	0.0	18.8	18.8	56.3	6.3	0.0	0.0	0.0	56.3	25.0	56.3	0.0	0.0	0.0	25.0	0.0	75.0	0.0
15	6.3	6.3	37.5	50.0	0.0	0.0	0.0	0.0	50.0	31.3	50.0	0.0	0.0	0.0	31.3	0.0	68.8	0.0
16	6.3	18.8	18.8	43.8	12.5	0.0	0.0	0.0	62.5	31.3	62.5	0.0	0.0	0.0	25.0	6.3	68.8	0.0
17	6.3	18.8	25.0	43.8	6.3	0.0	0.0	0.0	43.8	43.8	43.8	0.0	0.0	0.0	62.5	6.3	31.3	0.0
18	6.3	0.0	31.3	62.5	0.0	0.0	0.0	0.0	43.8	43.8	43.8	0.0	0.0	0.0	43.8	6.3	50.0	0.0

19	0.0	31.3	25.0	31.3	12.5	0.0	0.0	0.0	50.0	43.8	50.0	0.0	0.0	0.0	56.3	0.0	43.8	0.0
20	6.3	0.0	18.8	68.8	6.3	0.0	0.0	0.0	37.5	56.3	37.5	0.0	0.0	0.0	37.5	6.3	56.3	0.0

**F – Failure; P – Poor; A- Average; M- Mediocre; G – Good; VG – Very Good*

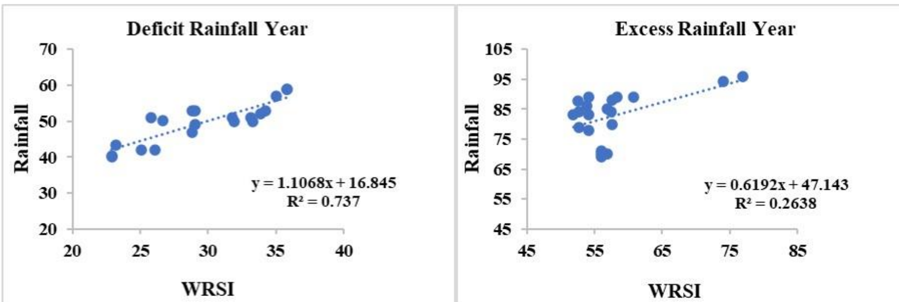

Fig. 1: Relationship between rainfall and WRSI during deficit and excess rainfall rears in Blackgram

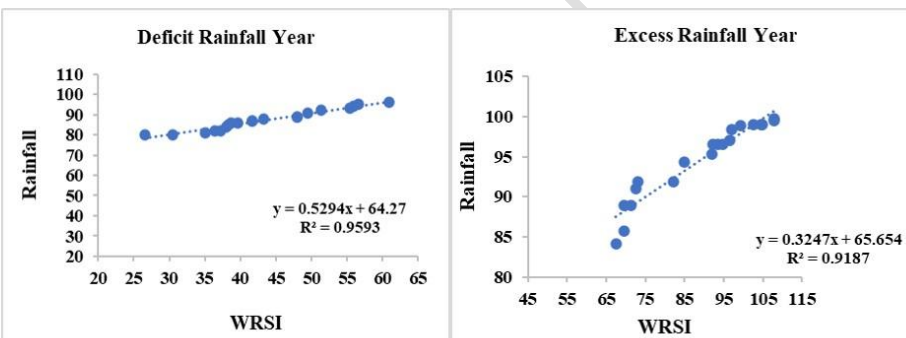

Fig. 2: Relationship between rainfall and WRSI during deficit and excess rainfall rears in Redgram

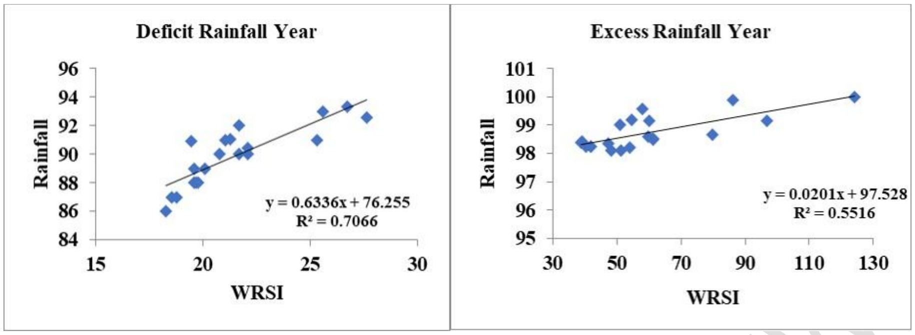

Fig. 3: Relationship between rainfall and WRSI during deficit and excess rainfall years in Greengram

Table 3. The determination coefficient (R^2) for *kharif* pulses in response to rainfall and WRSI during the study period

	R^2 (Rainfall vs WRSI)		
Year	**Blackgram**	**Redgram**	**Greengram**
2000	0.65	0.83	0.71
2001	0.5	0.95	0.51
2002	0.77	0.94	0.85
2003	0.7	0.93	0.78
2004	0.71	0.85	0.6
2005	0.74	0.57	0.57
2006	0.61	0.87	0.35
2007	0.35	0.95	0.55
2008	0.53	0.96	0.39
2009	0.74	0.94	0.71
2010	0.72	0.81	0.9
2011	0.27	0.9	0.94
2012	0.49	0.84	0.64
2013	0.26	0.92	0.55
2014	0.52	0.61	0.63
2015	0.32	0.73	0.39

Table 4. Rainfall deviation thresholds for *kharif* pulses in relation to soil type and depth

		Rainfall Deviation Threshold					
Crop	**Soil type/depth**	**Very Good**	**Good**	**Average**	**Mediocre**	**Poor**	**Failure**
Redgram	Deep Clays		> 40	39 to -29	> -30	-	-
	Shallow Clays		>20	19 to -19	> -20	-	-
	Deep Loams		> 20	19 to -29	> -30	-	-
	Shallow loams		> 20	19 to -29	> -30	-	-
Greengram	Deep Clays	50	-14 to +50	- 40 to -15	-41 to -60	< -61	-
	Deep Loams	-	-39 to +50	-40 to -50	-	-	-
	Shallow loams	-	-39 to +30	-40 to -60	-	-	-
Blackgram	Shallow loams	-	-	-	< 30	30-40	>40

4. CONCLUSION

Dependability on indices to capture crop condition in relation to moisture availability varies from crop to crop. Besides the soil factors, the length of the crop growing season, growth habit and rooting habit of the crop are some other factors that can influence the crop condition estimation based on rainfall through WRSI. Estimation of moisture stress using WRSI was ~~categorised~~categorized with respective to soil type and depth in the crops which are more sturdier and drought tolerant viz., greengram and redgram. However, the crop condition assessment in relatively sensitive crops like blackgram was classified broadly irrespective of soil type and depth.

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