# Assessments of the effects of legume species intercropping on Radiation Use Efficiency of Sorghum


## ABSTRACT

A field experiment was executed to assess the effect of legume species intercropping on the Radiation use efficiency of Sorghum during summer 2021. In India, Sorghum is primarily raised for poultry and animal feed and it is being cultivated under poor resource conditions. Hence, intercropping sorghum with legumes can help in improving the resource use efficiency than sole sorghum and also enable farmers to boost their livelihood. The treatments were $T_1$-Sorghum Sole crop (SS), $T_2$-2rows of Sorghum+2rows of Cowpea (2S:2C), $T_3$-2rows of Sorghum+1row of Cowpea (2S:1C), $T_4$-2rows of Sorghum+2rows of Greengram (2S:2G), $T_5$-2rows of Sorghum+1rows of Greengram (2S:1G), $T_6$-2rows of Sorghum+2rows of Lablab (2S:2L), $T_7$-2rows of Sorghum+1rows of Lablab (2S:1L). An experiment was carried out in Randomized Block Design and was replicated thrice. The results were statistically analysed using SPSS software. The results revealed that Sorghum + Lablab in 2:1 registered the highest leaf area index, dry matter production which ultimately resulted in high Radiation Use Efficiency. Overall, the intercropping system had high RUE than sole Sorghum**.** Thus it was concluded that planting sorghum with a legume in a 2:1 pattern would be recommended as it has better resource use efficiency than sole sorghum.



**KEYWORDS:** Sorghum, Dry matter production, Radiation Use efficiency, Intercepted PAR**,** Intercropping system


## INTRODUCTION

Sorghum (*Sorghum bicolor*), is also known as great millet. It is fifth important millet after rice and wheat. It is a promising crop that can withstand drought under arid and semiarid conditions. In India, it is being cultivated under resource-poor conditions. Sorghum intercropping with legume has emerged as a strategy to maximize resource use efficiency (Maitra and Duvvada, 2020). In intercropping, different row arrangements result in the different light interception and radiation use efficiency (Iqbal, 2018).

Under optimum water and nutrient condition, the efficiency of photosynthesis is determined by absorbed PAR. Radiation Use Efficiency is an important factor determining the growth of crops under optimum conditions (Rahman *et al.*, 2019). The change in crop geometry changes the amount of PAR intercepted by the green canopy which ultimately affects the RUE of crops.

Solar radiation is the most important factor for crop growth and development (Yang *et al.*, 2018). The portion of the solar spectrum that plants use in photosynthesis for converting light energy into biomass lies between wavelength of 400 and 700 nm. This wavelength range is called photo-synthetically active radiation (García-Rodríguez *et al.*, 2020). It is expressed in Photosynthetic Photon Flux Density (PPFD) μ mol $m^2$ $s^1$. Factors such as cloud cover, shading and crop arrangement may intercept the sunlight thus affecting the amount of PAR intercepted by the canopy.

In intercropping, the shading of the short crops by the tall crops changes the light environment in terms of both quantity and quality (Liu *et al.*, 2017). These changes are highly influenced by the row arrangement of component crops and affect both growth and morphology (Gong *et al.*, 2014, Gao *et al.*, 2010)

To date, the studies of RUE in Sorghum-based intercropping with different row arrangements in Tamil Nadu are scarce. Therefore this study objective is to estimate RUE as the factor for quantifying productivity of Sorghum-based intercropping.

## MATERIALS AND METHODS

### Experiment site and design

A field experiment was carried in Summer 2021 on Field No.37 Eastern Block of Tamil Nadu Agricultural University Coimbatore, Tamil Nadu, India. The soil of experimental field was heavy clay with EC of 0.13dS $m^{-1}$ and pH of 8.7. The soil analysis revealed that the initial nutrient status was low in nitrogen, high in phosphorous and potassium. The intercropping system consists of Sorghum as the main Crop, Cowpea, Greengram, and Lablab as intercrops. The experiment was laid out in Randomized Block Design with 7 treatments and 3 replications. The treatments consisted of $T_1$-Sorghum Sole crop (SS), $T_2$-2rows of Sorghum+2rows of

Cowpea (2S:2C), $T_3$-2rows of Sorghum+1row of Cowpea (2S:1C), $T_4$-2rows of Sorghum+2rows of Greengram (2S:2G), $T_5$-2rows of Sorghum+1rows of Greengram (2S:1G), $T_6$-2rows of Sorghum+2rows of Lablab (2S:2L), $T_7$-2rows of Sorghum+1rows of Lablab (2S:1L). The inter and intra row spacing of sole sorghum were 45 x 15 cm. The plant density maintained in sole Sorghum was 1, 55, 555 plants $ha^{-1}$ maintained. The intercropping arrangement and plant density maintained were depicted in fig1.The intercropping was designed as an addictive series. The row to row spacing was maintained as 30 cm and 60 cm was maintained between pairs. Nutrients, pests, weed management were carried out based on standard recommendations. Irrigation was done once in six days.

**Experimental measurements**

**Crop Growth Parameters**

**Leaf Area Index (LAI)**

The LAI of both sole and intercrops were measured at 30, 45, 60 DAS (Days After Sowing). The length and breadth of the leaf were measured and the LAI was worked out based on the following formula.

$$\mathbf{LAI} = \frac{\mathbf{Leaf\ Area}}{\mathbf{Ground\ Area}}$$

**Dry Matter Production (DMP)**

The DMP was measured 30, 45, 60 DAS. The plant samples were harvested at regular intervals by cutting the plants just above the soil surface. The plants were separated as stem, leaves, roots and it was shade dried followed by oven-dried at 70˚C to constant weight.

**Extinction Coefficient (k)**

Extinction coefficient (k) is the measure of extinction of any transmitted light in crop canopy (Lunagaria and Shekh, 2006). It follows that the erect leaves have a low k value. Generally the k values significantly vary for various crop species and development stages (Chimonyo *et al.*, 2018). The computation of the extinction coefficient (k) was performed as follows

$$\mathbf{k} = \frac{-\ln(\mathbf{T})}{\mathbf{LAI}}$$

**Photosynthetically Active Radiation (PAR)**

The amount of PAR intercepted by the crop was recorded using the EMCON Line quantum sensor. During bright sunshine hours, the PAR was measured at the top ($I_0$) and bottom of the canopy (I). The readings were taken at regular intervals. Measurements were normally taken between 10:00–14:00hrs IST. The calculation of the fraction of PAR transmitted (T) was as follows;

$$\mathbf{T = \frac{I}{I_0}}$$

The calculation of the fraction of radiation intercepted by taller crops

$$\mathbf{F_{tall} = 1 - e^{(-k\,.LAI)}}$$

k - Extinction coefficient of tall crop

LAI - Leaf area Index of tall crop

The fraction of radiation intercepted by a lower turbid layer comprising short and taller crop (Rezig *et al*., 2013)

$$\boldsymbol{F_{TALL} = \frac{k_t \times LAI_t}{k_t \times LAI_t + k_s \times LAI_s} \times \left(1 - exp^{(-k_t \times LAI_t - k_s \times LAI_s)}\right)}$$

$$\boldsymbol{F_{SHORT} = \frac{k_s \times LAI_s}{k_t \times LAI_t + k_s \times LAI_s} \times \left(1 - exp^{(-k_t \times LAI_t - k_s \times LAI_s)}\right)}$$

$LAI_t$, $LAI_s$ - Leaf Area Index of Tall (Solecrop) and short crop (Intercrop) in the lower turbid layer.

$k_t$, $k_s$ - Extinction coefficient of Tall (Solecrop) and short crop (Intercrop)

**Radiation Use Efficiency (RUE)**

The Radiation Use Efficiency of sole and intercrop (g. $MJ^{-1}$) can be calculated as follows (Rezig *et al*., 2013)

$$RUE_{Tall} = \frac{TDM_{Tall}}{PAR_o(Ftall + Fshort)}$$

$$RUE_{Intercrop} = \frac{TDM_{Intercrop}}{PAR_o(Fshort)}$$

$$RUE_{System} = RUE_{Tall} + RUE_{Intercrop}$$

$RUE_{Tall}$ – Radiation Use Efficiency of Tall crop (g.$MJ^{-1}$)

$RUE_{Intercrop}$ – Radiation Use Efficiency of Intercrop (g.$MJ^{-1}$)

TDM – Total Dry matter (g)

**STATISTICAL ANALYSIS**

The data on various parameters recorded were analyzed in Randomized Block design. The differences among the treatments were examined using critical differences (CD) at 5% level of probability and *p* values.

**RESULT AND DISCUSSION**

**Effect of legume species intercropping on Sorghum Leaf Area Index (LAI)**

The results showed that there is a significant difference ($p<0.05$) between LAI of sole Sorghum and intercropped Sorghum. Sorghum in 2:1 Sorghum + Lablab ($T_7$) registered the highest leaf area index 0.7, 1.9, 8.3 at 30, 45 and, 60 DAS respectively whereas sole Sorghum ($T_1$) registered lowest value 0.15, 1.0, 5.5 at 30, 45, 60 DAS respectively (Fig2.). This was due to a change in crop geometry in sole and intercrop configuration.

**Effect of legume species intercropping on Sorghum Extinction Coefficient (k)**

The Extinction coefficient determines the transmission of radiation through the canopy and canopy layers. The result showed that there was a gradual decline in K value with crop growth and these changes were due to change in canopy characters like LAI. There was a significant linear relationship between K value and transmission of leaf in all three stages (Fig3.). The K value of the sorghum under different planting patterns was presented in Table1. The different planting pattern of Sorghum altered the amount of light fallen on top and bottom of canopy which impacted transmission of light through the canopy that resulted in different k values for Sorghum.

**Effect of legume species intercropping on Fraction of Intercepted PAR (fPAR) by Sorghum**

The fPAR was high in the sole Sorghum at 30, 45 and 60 DAS. The increased inter row spacing maintained in sole sorghum (45 cm) allowed more direct light to intercept by the crop. At 60DAS the fPAR value was found to be higher because of the increased height of the component crops. Among the different treatments of intercropping, the Sorghum in 2:2 pattern intercepted more PAR ($T_2$, $T_4$, T6). The higher plant density and foliage cover of component crops at the 2:2 pattern intercepted more PAR than the 2:1 pattern. The total fPAR intercepted by the Sorghum was presented in the fig4.

**Effect of legume species intercropping on Sorghum Dry matter production (DMP)**

Similar to LAI, DMP produced by the Sorghum in 2:1 Sorghum+ Lablab ($T_7$) 5.1, 32.7, 78.6g plant$^{-1}$ in 30DAS, 45DAS, 60DAS respectively was higher than all other treatments. The sole crop Sorghum ($T_1$) registered lower values 3.4, 26.6, 67.3 g plant$^{-1}$ in 30DAS, 45DAS, 60 DAS respectively (Fig5.). The increased DMP in $T_7$ might be due to the ability of component crops in maximum utilization of resources due to the differential rooting pattern of resource utilization which results in reduced competition (Bedoussac *et al.*, 2015). The maximum dry matter, as well as LAI was enhanced by the low level of competition that prevailed in the 2:1 intercropping system than the 2:2 pattern (Wang *et al.*, 2017).

**Effect of legume species intercropping on Sorghum Radiation Use Efficiency (RUE)**

The RUE of different treatments was presented in fig6. The RUE was high in 2:1 Sorghum+ Lablab ($T_7$) followed by $T_3$ (2:1 Sorghum + Cowpea) where sole Sorghum ($T_1$) registered the low value at 30, 45 and 60 DAS. The PAR intercepted by the sole sorghum was mostly direct which is less efficient in converting to biomass (Gu *et al.*, 2002). The addition of legume rows in the intercropping system allowed more diffuse light which was highly efficient in converting to biomass. This resulted in high RUE in intercropping treatments than solitary cropping. The intercropping system had 63-93%, 25-227%, and 118-240% improvement in radiation use efficiency at 30, 45 and 60 DAS respectively than sole Sorghum. Similarly, 2:1 pattern had better RUE than 2:2 pattern. The radiation use efficiency was significantly influenced by dry matter accumulation. The high dry matter accumulation in $T_7$ resulted in high radiation use efficiency than other treatments. The reduced dry matter production was noticed in 2:2 pattern than 2:1 pattern. The competition that existed in 2:2 pattern reduced the dry matter production that ultimately reduced the RUE. The average value of RUE of the intercropped Sorghum was 1.4 to 2.5 g $MJ^{-1}$. This was supported by Chimonyo *et al.*, 2018 who found the maximum RUE value of Sorghum with cowpea as 2.71 $MJ^{-1}$ and with bottle guard as 3.20 $MJ^{-1}$

## CONCLUSION

Intercropping Sorghum with Lablab and Cowpea has enhanced the leaf area index, dry matter production which resulted in high Radiation Use efficiency. The intercropping improved the overall light capture and use efficiency of Sorghum than sole cropping. The RUE of Sorghum+ Lablab in the 2:1 pattern was stable across all days of observation. Introducing the additional single row of pulses in 2:2 reduced the growth performance of both Sorghum and pulses. Hence intercropping Sorghum with pulses in the 2:1 pattern would be recommended since it had better radiation use efficiency than 2:2 pattern.

## REFERENCES

1. Bedoussac L, Journet EP, Hauggaard-Nielsen H, Naudin C, Corre-Hellou G, Jensen ES, Prieur L, Justes E. Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. Agronomy for sustainable development. 2015;35(3):911-35.
2. Chimonyo VG, Modi AT, Mabhaudhi T. Sorghum radiation use efficiency and biomass partitioning in intercrop systems. South African Journal of Botany. 2018;118:76-84.
3. García-Rodríguez A, García-Rodríguez S, Díez-Mediavilla M, Alonso-Tristán C. Photosynthetic active radiation, solar irradiance and the CIE standard sky classification. Applied Sciences. 2020;10(22):8007.

4. Gao Y, Duan A, Qiu X, Sun J, Zhang J, Liu H, Wang H. Distribution and use efficiency of photosynthetically active radiation in strip intercropping of maize and soybean. Agronomy Journal. 2010;102(4):1149-57.
5. Gong W, Qi P, Du J, Sun X, Wu X, Song C, Liu W, Wu Y, Yu X, Yong T, Wang X. Transcriptome analysis of shade-induced inhibition on leaf size in relay intercropped soybean. PLoS One. 2014; 9(6):e98465.
6. Gu L, Baldocchi D, Verma SB, Black TA, Vesala T, Falge EM, Dowty PR. Advantages of diffuse radiation for terrestrial ecosystem productivity. Journal of Geophysical Research: Atmospheres. 2002;107(D6):ACL-2.
7. Iqbal MA. Comparative performance of forage cluster bean accessions as companion crops with sorghum under varied harvesting times. Bragantia. 2018;77: 476-84.
8. Lunagaria MM, Shekh AM. Radiation interception, light extinction coefficient and leaf area index of wheat (*Triticum aestivum* L.) crop as influenced by row orientation and row spacing. The Journal of Agricultural Sciences. 2006; 2(2):43-54.
9. Liu X, Rahman T, Yang F, Song C, Yong T, Liu J, Zhang C, Yang W. PAR interception and utilization in different maize and soybean intercropping patterns. PloS one. 2017; 12(1):e0169218.
10. Maitra S and Duvvada SK. Sorghum-based Intercropping System for Agricultural Sustainability. Indian Journal of Natural Sciences. 2020;10(60):20306-20313
11. Rezig M, Sahli A, Hachicha M, Jeddi FB, Harbaoui Y. Potato (*Solanum tuberosum* L.) and bean (*Phaseolus vulgaris* L.) in sole intercropping: effects on light interception and radiation use efficiency. Journal of Agricultural Science. 2013; 5(9):65.
12. Rahman MH, Ahmad A, Wajid A, Hussain M, Rasul F, Ishaque W, Islam MA, Shelia V, Awais M, Ullah A, Wahid A. Application of CSM-CROPGRO-Cotton model for cultivars and optimum planting dates: Evaluation in changing semi-arid climate. Field Crops Research. 2019 ;238:139-52.
13. Wang, Z, X Zhao, P Wu, Y Gao, Q Yang, and Y Shen. Border row effects on light interception in wheat/maize strip intercropping systems. Field Crops Research. 2017; 214:1-13.

14. Yang F, Feng L, Liu Q, Wu X, Fan Y, Raza MA, Cheng Y, Chen J, Wang X, Yong T, Liu W. Effect of interactions between light intensity and red-to-far-red ratio on the photosynthesis of soybean leaves under shade condition. Environmental and Experimental Botany. 2018 ;150:79-87.

**Table1. Effect of legume species intercropping on Sorghum Extinction Coefficient (k) at 30,45 and 60 DAS**

| Treatment details | Days After Sowing | | |
|---|---|---|---|
| | 30 | 45 | 60 |
| $T_1$ - Sorghum sole cropping | 1.40$^{e}$ | 0.54$^{d}$ | 0.15$^{e}$ |
| $T_2$ - Paired row of Sorghum + 2 rows of Cowpea (2S:2C) | 0.36$^{c}$ | 0.21$^{c}$ | 0.10$^{d}$ |
| $T_3$ - Paired row of Sorghum + 1 row of Cowpea (2S:1C) | 0.17$^{b}$ | 0.13$^{b}$ | 0.09$^{c}$ |
| $T_4$ - Paired row of Sorghum + 2 rows of Greengram (2S:2G) | 0.43$^{d}$ | 0.32$^{c}$ | 0.08$^{b}$ |
| $T_5$ - Paired row of Sorghum + 1 row of Greengram (2S:1G) | 0.34$^{c}$ | 0.16$^{a}$ | 0.08$^{b}$ |
| $T_6$ - Paired row of Sorghum + 2 rows of Lablab (2S:2L) | 0.12$^{b}$ | 0.06$^{a}$ | 0.10$^{d}$ |
| $T_7$ - Paired row of Sorghum +1 row of Lablab (2S:1L) | 0.11$^{a}$ | 0.06$^{a}$ | 0.05$^{a}$ |
| SEd | 0.02 | 0.03 | 0.03 |
| Critical difference(.05) | 0.04** | 0.07** | 0.01** |

** -Highly significant
The Mean followed by same alphabets are statistically similar

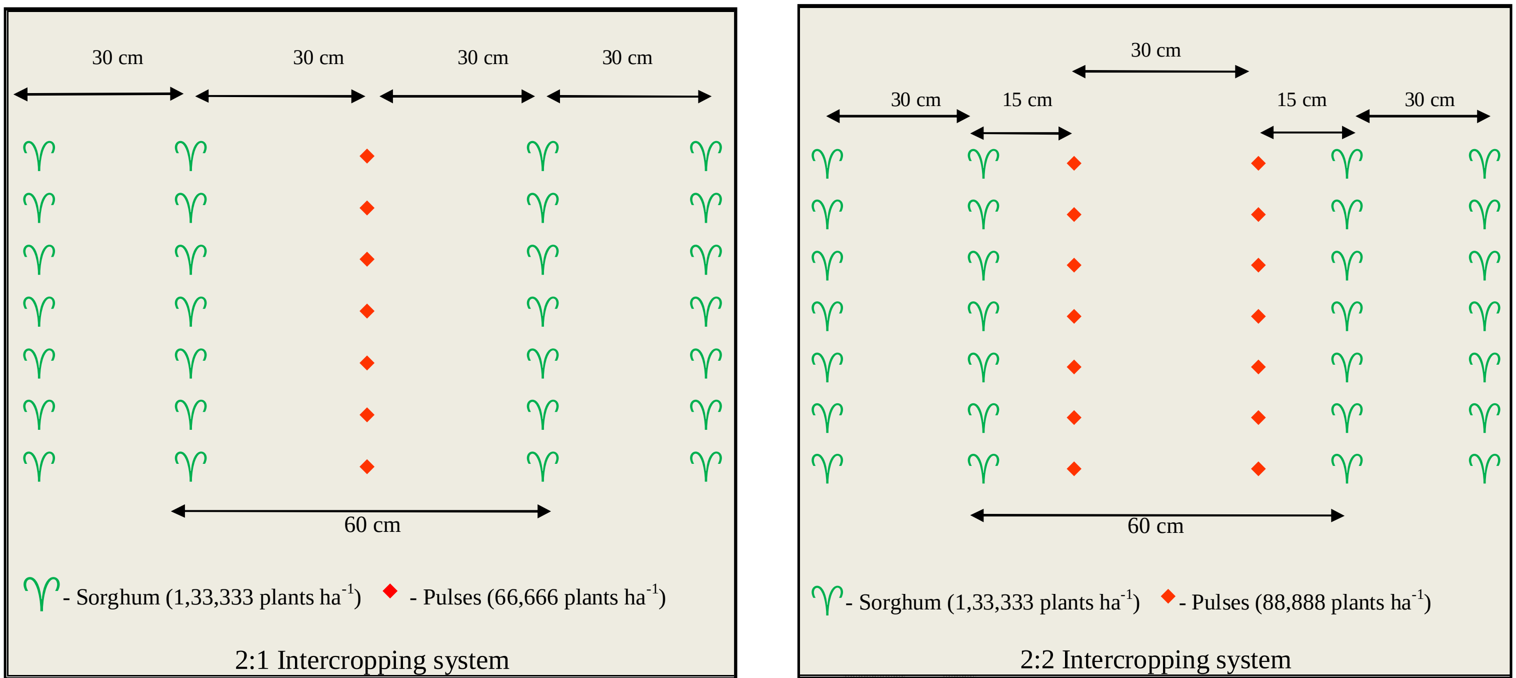


**Fig 1. Arrangements of Sorghum and pulses under intercropping system**

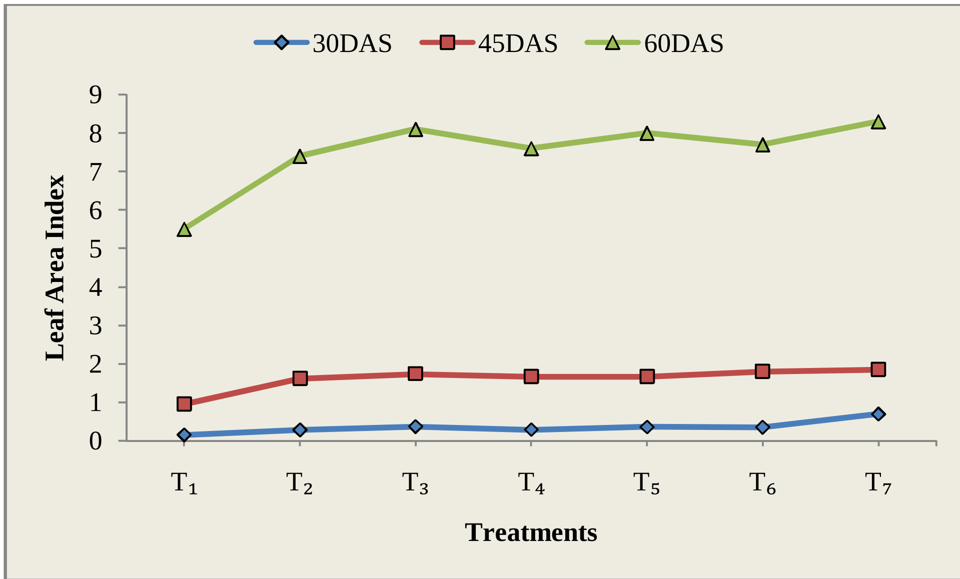


**Fig 2. Effect of legume species intercropping on Sorghum Leaf Area Index (LAI) at 30, 45 and 60DAS**

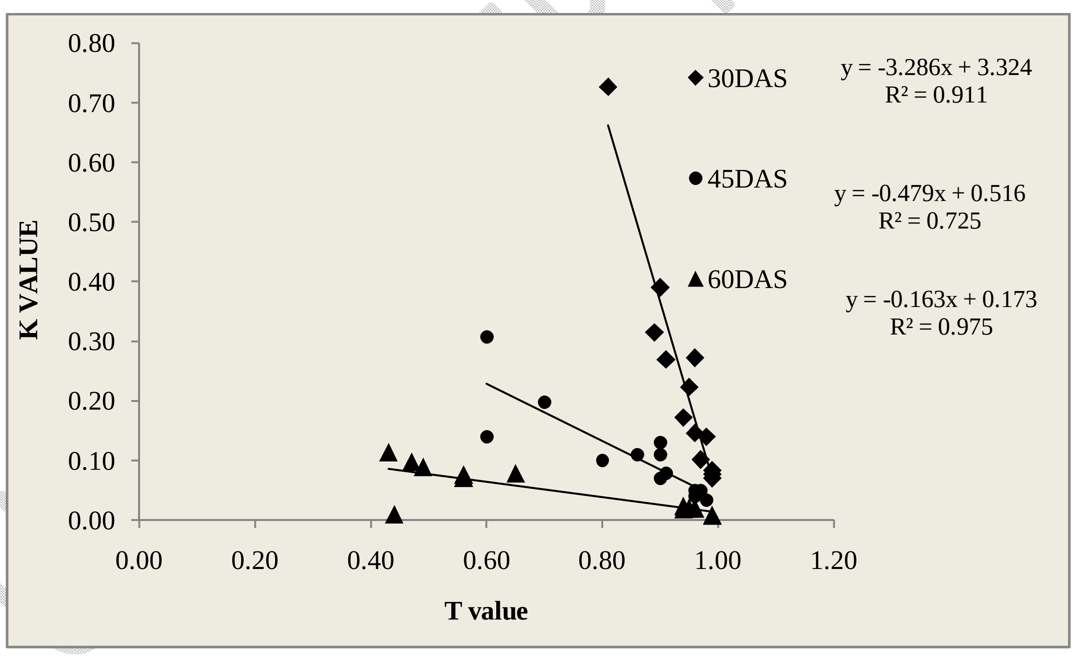


**Fig3. Linear Regression between k and T at 30, 45, and 60 DAS**

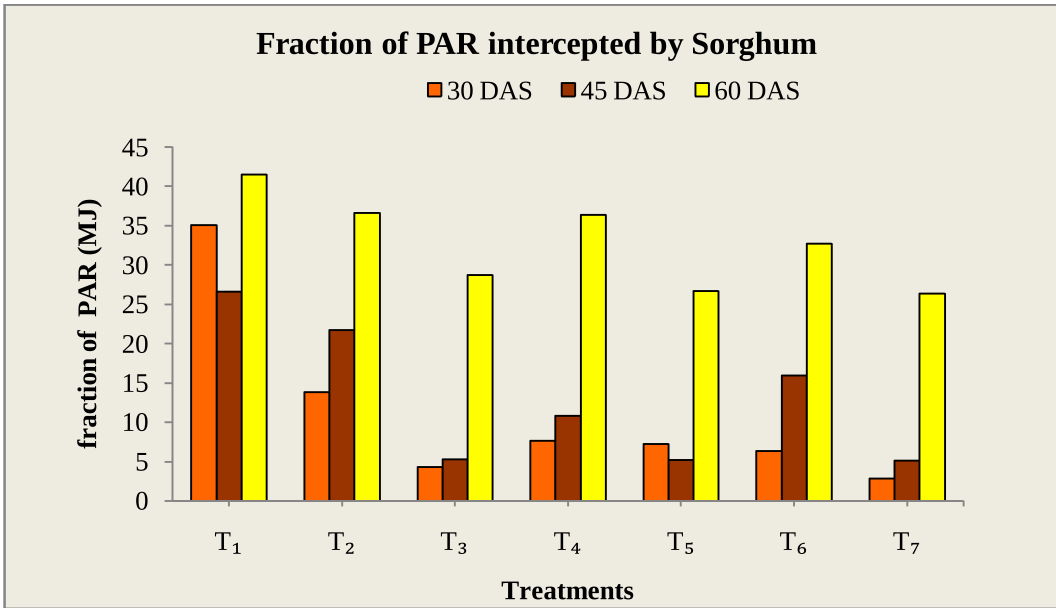


**Fig4. Effect of legume species intercropping on Fraction of Intercepted PAR (fPAR) by Sorghum at 30, 45 and 60DAS**

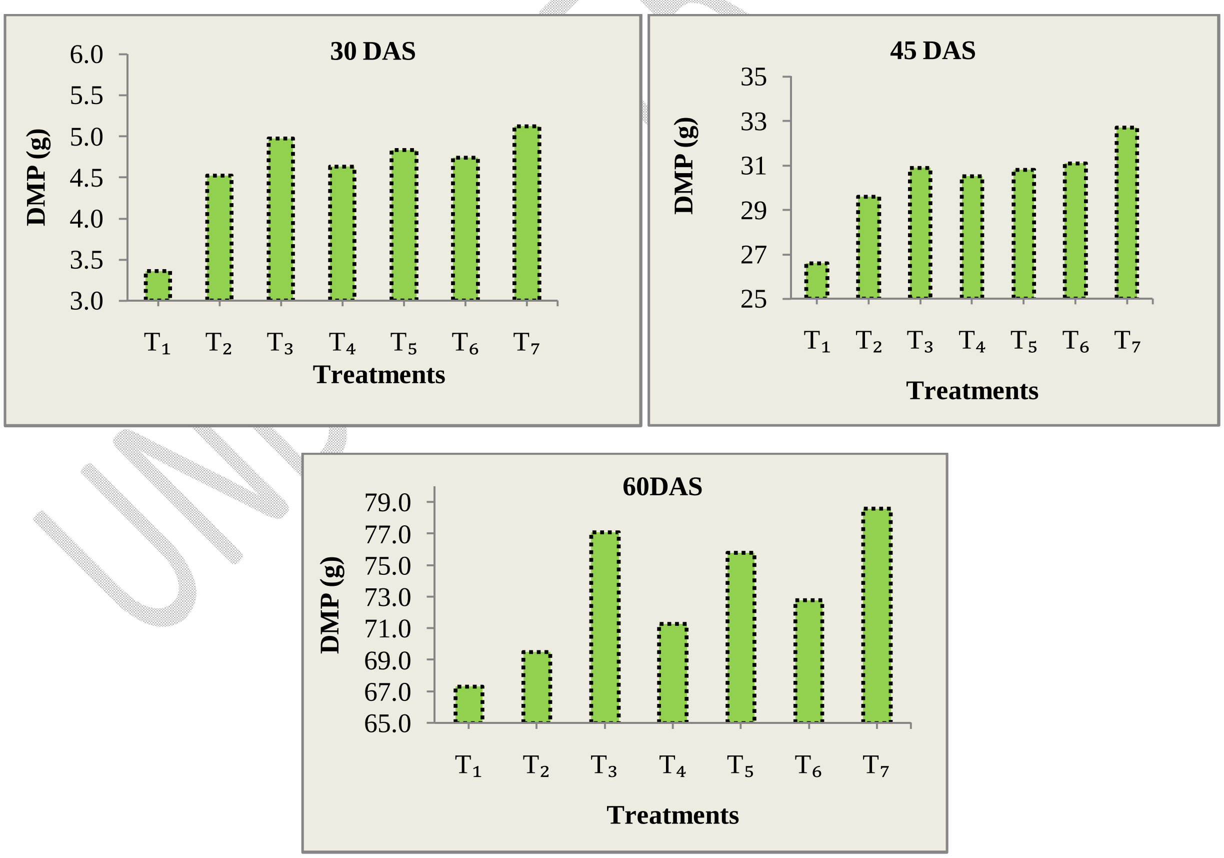


**Fig5. Effect of legume species intercropping on Sorghum Dry matter production (DMP) at 30, 45, 60DAS**

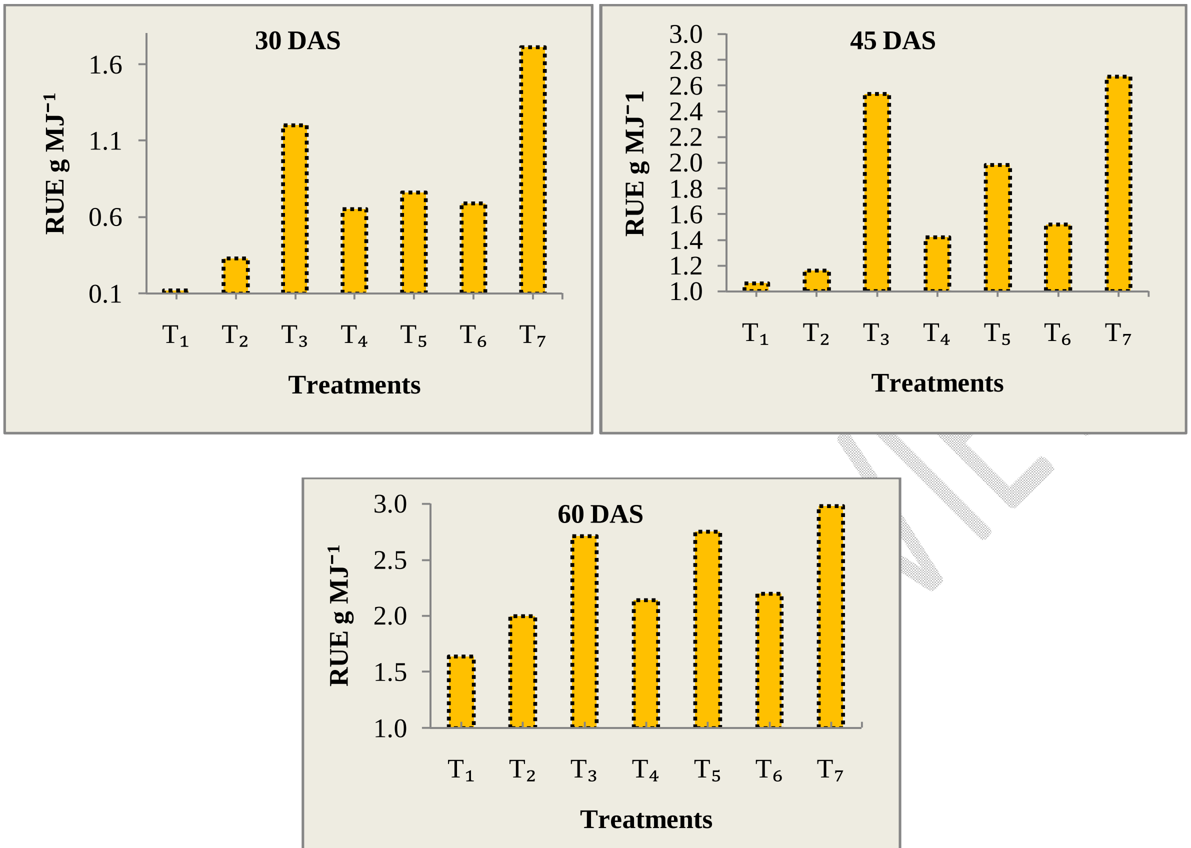


**Fig6. Effect of legume species intercropping on Sorghum Radiation Use Efficiency (RUE) at 30, 45 and 60DAS**