Study on Radiation Use Efficiency of Sorghum Based intercropping system

Comment [WU1]: Assessments of the effects of legume species intercropping systems on Sorghum Radiation Use Efficiency

ABSTRACT

A field experiment was executed to ~~determine~~ evaluate the Radiation use efficiency ~~in~~ of Sorghum ~~based~~ intercropping system ~~during~~ in summer 2021 under irrigation. In India, Sorghum is ~~being~~ cultivated under poor resource conditions, ~~.~~ h~~H~~ence, intercropping ~~sorghum~~ it with legumes ~~can help in~~ to ~~improving~~ improve the resource use efficiency ~~than sole sorghum~~. An ~~The~~ experiment was carried out in Randomized Block Design and was replicated thrice. 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). The treatments were irrigated once in 6 days till harvest. ~~The experiment was carried out in Randomized Block Design and was replicated thrice.~~ 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 legume in 2:1 pattern would be recommended as it has better resource use efficiency than sole sorghum.

Comment [WU2]: How important is Sorghum in this location

Comment [WU3]: Mention some statistical tool and analysis done to the data

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

INTRODUCTION

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 ~~is~~ lies between ~~of~~ wavelength ~~between~~ of 400 and 700 nm. This wavelength ~~limit~~ range is ~~so~~ called photo-synthetically active radiation(Rodríguez*et al.*, 2020). It is expressed in Photosynthetic Photon Flux Density (PPFD) µ mol m^2 s^1. Things such as cloud cover, shading, and crop arrangement ~~Anything that hinders~~ may intercepted ~~the~~ sunlight, thus affecting the ~~changes~~the amount of intercepted PAR ~~falling on~~ by the crop canopy~~such as cloud cover, shading, and crop arrangement~~.

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

Sorghum(*Sorghum bicolor*), is also known as great millet~~, -~~. It is the fourth most ~~an~~ important cereal a~~millet~~ after rice~~, and~~ wheat and millet. It is a promising crop under arid and semiarid conditions. In India, it is~~ being~~ cultivated ~~under~~ by resource-poor ~~conditions~~farmers mostly under intercropping systems. Sorghum ~~Intercropping~~ intercropping ~~Sorghum~~with legume has emerged as a strategy to maximize resource use efficiency(Maitra*et al*., 2020).In intercropping, different row arrangements result in the different light interception and radiation use efficiency (Iqbal*et al*., 2018).

In intercropping, the shading of the ~~tall~~ short crops~~ over the~~ by~~short~~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 ~~cause~~ affects~~both~~ growth and morphological changes (Gong *et al*., 2014,Gao*et al*., 2010)

~~To date,the~~ S~~s~~tud~~y~~ies of RUE in Sorghum-based intercropping with different row arrangements inTamil Nadu ~~is~~ are ~~still limited~~scarce. Therefore,~~the~~ this ~~present~~ study objective is to estimate RUE as the factor for quantifying productivity of Sorghum-based intercropping.

MATERIALS AND METHODS

Experiment site and design

~~The~~ Afield experiment was carried inSummer 2021on Field No.37 Eastern Block of Tamil Nadu Agricultural University Coimbatore,Tamil Nadu,India~~ during Summer 2021~~.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 ~~of the study were~~ consisted of T$_1$-Sorghum Sole crop (SS), T$_2$-2rows of

Comment [WU4]: Paragraph 3

Comment [WU5]: Use PAR rather than PPFD throughout the script

Comment [WU6]: Let this be paragraph 2

Comment [WU7]: This should be paragraph 1

Comment [WU8]: Recheck this from literature

Comment [WU9]: Use ' it is a drought resistant crop thus suitable for cultivation in arid and semiarid environments of the world.

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 row and intra row spacing of sole sorghum wereas 45 x 15 cm. The plant density in sole Sorghum was maintained in sole Sorghum wasat 1, 55, 555 plants ha^{-1}maintained. The intercropping arrangement and plant density maintained were are presenteddepicted in Figure 1fig1.The intercropping was designed as an addictive series. Nutrients, pests, weed management were carried out based on standard recommendations. Irrigation was done once in six days.

Comment [WU10]: A description of how the legume species were planted is required here

Comment [WU11]: Write in full if its within text

Experimental measurements

Crop Growth Parameters

Leaf Area Index (LAI)

The LAI of both sole and intercrops were measuredmeasured at 30, 45,60(Days After Sowing)(DAS).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 at 30, 45,60DAS.The plant samples were harvested at regular intervals by cutting the plants just above the soil surface. The plants were shade dried followed by oven-dried at 70˚C to constant weight.

Comment [WU12]: Normally the plant is separated by stems, leaves and grains and weighed on both fresh and dry basis.

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, Tthe k values were significantly different vary for various crop species and development stages (Chimonyo*et al*., 2018).

The calculation computationofthe extinction coefficient(k) iswas performed as follows;

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

Photosynthetically Active Radiation (PAR)

The amount of PAR intercepted by the crop was recorded usingthe 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) ~~is~~ was performedas follows;

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

The calculation of the fraction of radiation intercepted by taller crops(Rezig*et al*., 2013)

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

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

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

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

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)

Comment [WU13]: Put the model e.g(LAI-2200 Plant Canopy Analyzer, LICOR Inc.,Lincoln, NE, USA)

Comment [WU14]: Cite the literature here

The Radiation Use Efficiency of sole and intercrop (g.MJ^{-1})were ~~can be~~ calculated according to Author name (year)…………….as follows;

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

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

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

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

Statistical Analysis

RESULT AND DISCUSSION

Effects of legume species intercropping systems on Sorghum Leaf Area Index (LAI)

The results showed that there is a significant difference between LAI of sole Sorghum and intercropped Sorghum. Sorghum in 2:1 Sorghum + Lablab (T_7) registered the highest leaf area index0.7, 1.9, 8.3 ~~in~~ at 30~~DAS~~, 45 and ~~DAS,~~ 60DAS respectively.~~whereas~~ The sole Sorghum(T_1) registered the lowest ~~value~~LAI of 0.15, 1.0, 5.5 ~~in~~ at 30~~DAS~~, 45~~DAS~~a ,and 60 DAS respectively (Fig2.).This was due to a change in crop geometry in sole and intercrop configuration.

Effects of legume species intercropping systems 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 values with crop growthand 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 ~~and it was significant~~ (Fig3.).The K value of the sorghum under different planting patternwas presented in Table1.

Comment [WU15]: Cite the literature here or It could be nice you find your RUE from the linear relationship of PAR and TDM

Comment [WU16]: Mention some statistical tool and analysis done to the data which made you have Table 1

Comment [WU17]: Indicate ($p<0.05$)

Comment [WU18]: Follow the comment on RUE here how does you k values differ with other sorghum k values in intercropping and why

Effects of legume species intercropping systems on Sorghum **Fraction of Intercepted PAR (fPAR)**

The fPAR was high in the sole Sorghum~~in~~ at 30, 45 and 60 DAS. The increased spacing between 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.

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

Similar toLAI, DMP produced by theSorghum 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 values3.4,26.6,67.3g 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 for resource utilization which resulting 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 2:2 pattern (Wang *et al.*, 2017).

Comment [WU19]: No need of listing values just show as in Table 1. Do the same for RUE, fPAR

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

RUE of different treatments were presented in fig6. The RUE was highin 2:1 Sorghum+ Lablab (T_7)followed by T_3(2:1 Sorghum + Cowpea) and ~~where~~ sole Sorghum (T_1) registered the lowest values at 30, 45 and 60 DAS.The ~~RUE of different treatments were presented in fig6.The PAR intercepted by the~~Ss~~ole sorghum was ~~mostly direct which is~~ less efficient in converting intercepted PAR to biomass. 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 (Table2). Similarly, 2:1 pattern had better RUE than 2:2 pattern. This was due to the reduced dry matter production 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}.

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Comment [WU22]: How does this compare with other RUEs for sorghum in literature and why. Link to literature like you have done for DMP

CONCLUSION

Intercropping Sorghum with Lablab and Cowpeahas 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 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 2:1 pattern would be recommended since it had better radiation use efficiency than 2:2 pattern.

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Table 1: **Effects of**f legume species intercropping systems on Sorghum k values

~~Values of K of Sorghum under different planting pattern~~**at 30, 45, 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

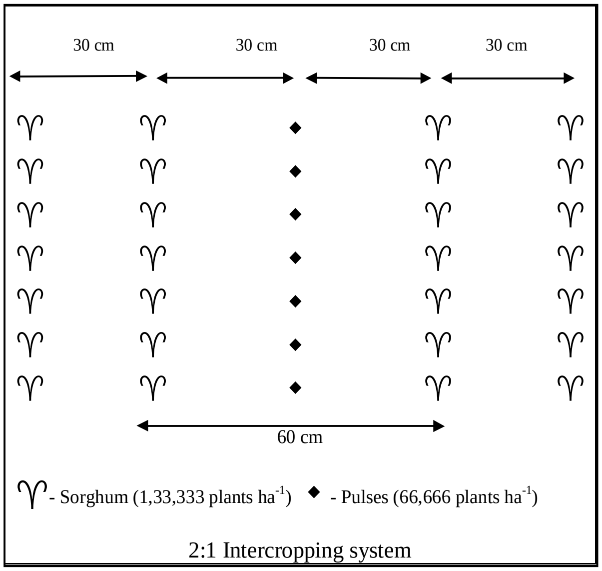
T_3 - Paired row of Sorghum + 1 row of Cowpea (2S:1C)	0.17^{b}	0.13^{b}	0.09^{c}
T_4 - Paired row of Sorghum + 2 rows of Greengram (2S:2G)	0.43^{d}	0.32^{c}	0.08^{b}
T_5 - Paired row of Sorghum + 1 row of Greengram (2S:1G)	0.34^{c}	0.16^{a}	0.08^{b}
T_6 - Paired row of Sorghum + 2 rows of Lablab (2S:2L)	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
CD(.05)	0.04**	0.07**	0.01**

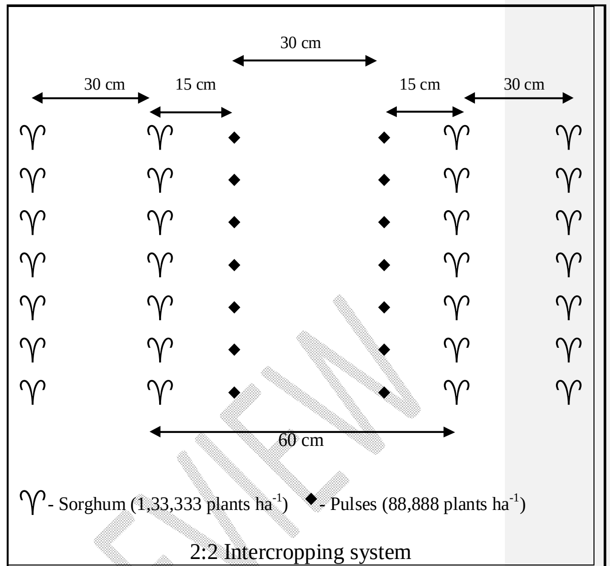
Table 2 Percent improvement in RUE of intercropping system than sole sorghum

Treatments	**% Improvement of RUE than sole Sorghum**		
	30DAS	**45 DAS**	**60DAS**
T_2(2S:2C)	63.6	24.6	118.0
T_3(2S:1C)	90.0	211.5	210.5
T_4(2S:2G)	81.5	67.4	137.4
T_5(2S:1G)	84.2	144.5	215.4
T_6(2S:2L)	82.6	82.3	145.5
T_7(2S:1L)	93.0	227.3	243.0

Comment [WU23]: These can be mentioned in the text when comparing or describing the results

Fig1. The Spatial arrangement of intercropping system





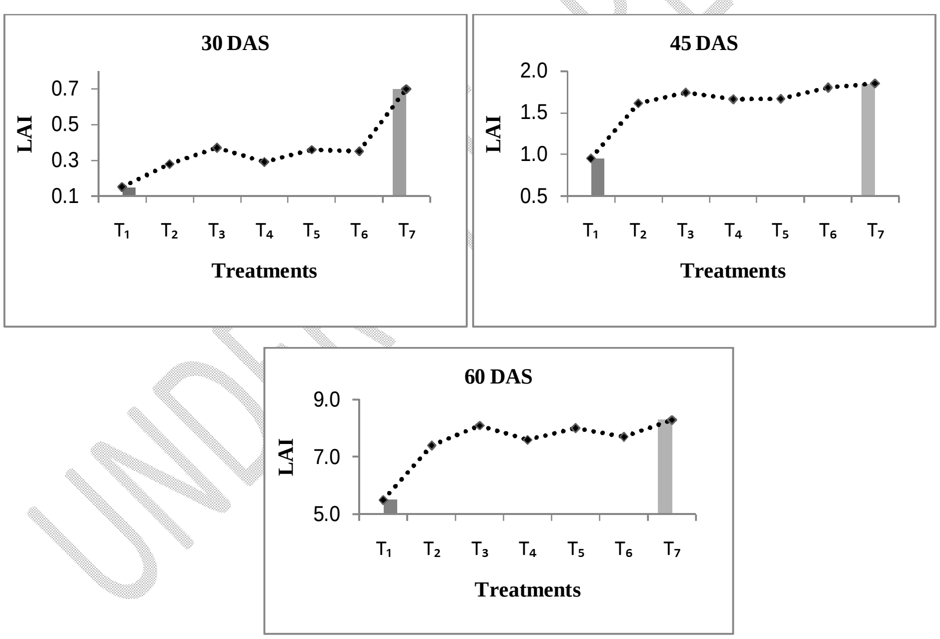


Fig2: Leaf Area Index of Sorghum in the different intercropping systems at 30, 45, 60DAS

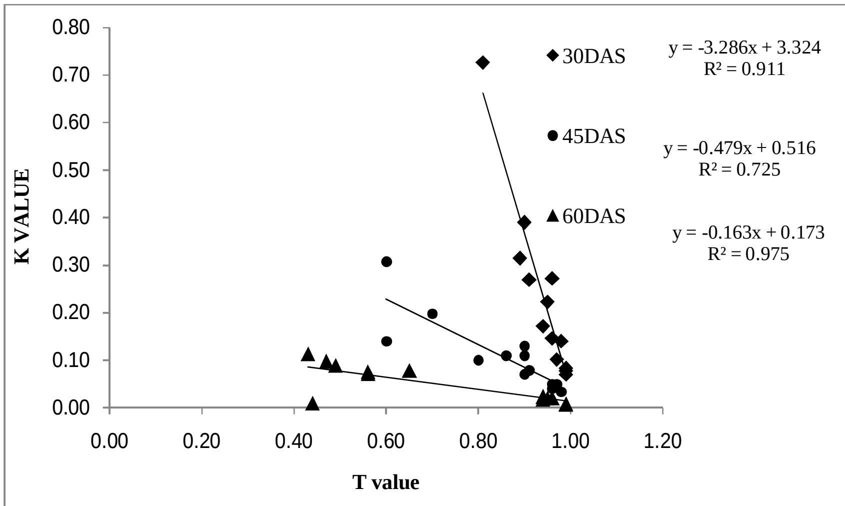


Fig3. Linear Regression between k and T at 30, 45, and 60 DAS

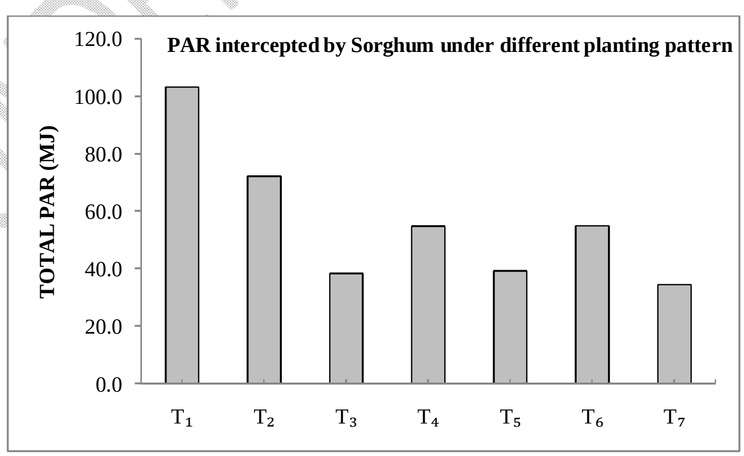
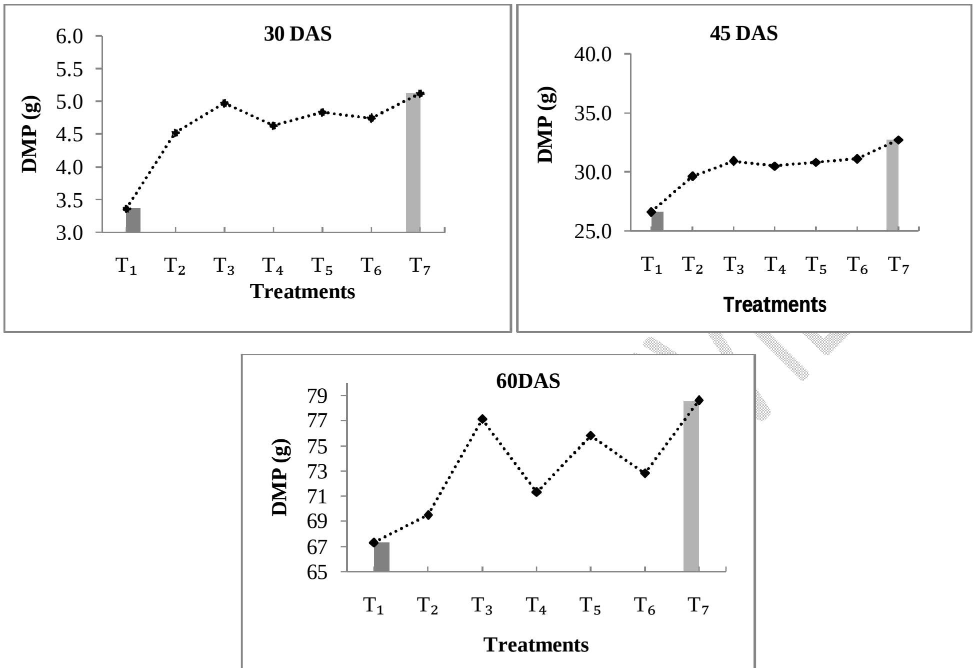


Fig4. Total PAR intercepted (fPAR) by Sorghum under different planting pattern



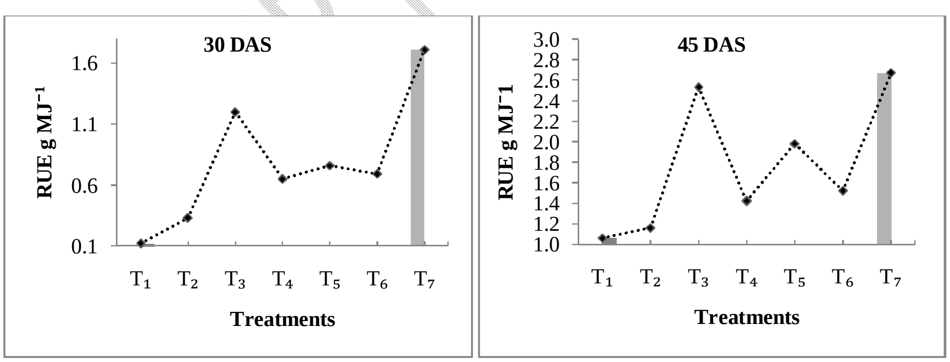


Fig5. **. Effects of** legume species intercropping systems on Sorghum Total Dry matter ~~produced by the Sorghum under different planting pattern~~ at 30, 45, 60DAS

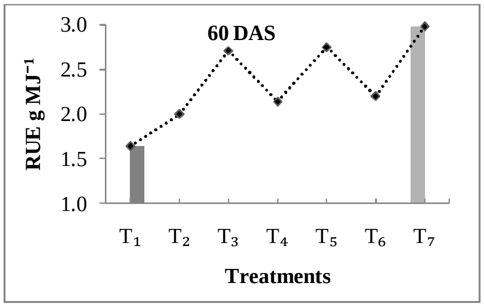


Fig6.**Effects of** legume species intercropping systems on Sorghum RUE values

at 30, 45, 60 DAS Radiation Use Efficiency of Sorghum under different planting pattern at 30, 45, 60DAS