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Influence of Arbuscular Mycorrhizal Species on Photosynthetic Attributes of Groundnut under Drought Stress

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ABSTRACT: Drought is a major limiting factor reducing the photosynthetic rate, gas exchange which in turn directly affect the yield of groundnut in arid regions. Mycorrhizae with their role in enhancing water uptake could be the potential inputs to reduce the negative impacts of drought stress. But, identifying the most effective mycorrhiza under drought stress is an important challenge ahead. Therefore, a study was undertaken at Agriculture College Farm, Bapatla, India during during *rabi* 2019-20 and 2020-21 to study the role of arbuscular mycorrhizal species on the photosynthetic attributes of groundnut under water stress. The experiment consisted of two main treatments (irrigation, water stress imposed at pegging and pod formation stages) and seven mycorrhizal treatments (No mycorrhizal application, soil application of *Glomus fasciculatum*, *Glomus aggregatum*, *Glomus mosseae*, *Glomus intraradices*, *Gigaspora* sps., *Acaulospora* sps. each @ 12.5 kg ha^{-1}). Our findings revealed that the photosynthetic rate, stomatal conductance and transpiration rate of groundnut were substantially reduced after the plants were exposed to water stress compared to those under irrigation. Among the mycorrhizal treatments, the groundnut plants that received the soil application of *Glomus mosseae* and *Gigaspora* sps. @ 12.5 kg ha^{-1} were recorded with the highest photosynthetic rate, transpiration rate and stomatal conductance in groundnut under irrigated and water stress conditions. The lowest photosynthetic rate, stomatal conductance and the transpiration rate were noticed in the treatment without mycorrhizal application.

Keywords: Gas exchange, net photosynthetic rate, stomatal conductance, groundnut, mycorrhiza

INTRODUCTION

Groundnut is an important oil seed legume grown throughout the world. It is grown in an area of 27.66 million hectares with a production of 43.98 million tonnes and productivity of 1509 kg ha^{-1} in the world. The average productivity of groundnut in India is much lower (1182 kg ha^{-1}) compared to world's average (1509.1 kg ha^{-1}). The area and production of groundnut have been increasing but the total productivity remained almost constant (Patel and Golakiya, 1988). These low yields are attributed to cultivation of the crop mostly in rain fed and marginal lands subjected to the vagaries of the weather. Only 14-15 % of groundnut area is under irrigation, it is grown mainly on poor fertility soils and in rainfed (85% rainfed) areas.

Drought is a normal feature in semi-arid and arid regions of the tropics, which covers more than one third of the land surface. It adversely effects water relations (Babu and Rao, 1983), photosynthesis (Bhagsari *et al.*, 1976), mineral nutrition, metabolism, growth and yield of groundnut (Suther and Patel, 1992). An annual estimated loss in groundnut production due to drought is equivalent to over US$520 million. Increased nutrient and water uptake under drought stress could result in increased yield under drought stress. The abundant use of chemical fertilisers in agriculture leads to deleterious environmental consequences and it is a global concern (Bohlool *et al.*, 1992; Tilman *et al.*, 2002). Alternate technologies which can play a major role in sustaining and increasing the productivity of oilseed crops under drought stress should be adopted.

The use of mycorrhiza with the aim of improving water uptake and nutrient availability for plants is a novel approach. Mycorrhizal fungi improve the nutrient status of the plants by increasing the availability of nutrients, and the host plant provides for fungal growth and reproduction by supplying carbon in the form of photosynthates (Smith and Gianinazzi, 1988; Smith and Read, 1997).

Mycorrhizal establishment in the root are known to increase the plant tolerance to a wide range of biotic and abiotic stresses (Auge *et al.,* 2004; Whipps, 2004; Jansa *et al.,* 2009). Colonization of plants with arbuscular mycorrhizal fungi (AMF) under abiotic stresses assist the plants by enhancing plant growth, productivity, and nutrient uptake under stress conditions. They influence plant-water relation, rate of photosynthesis and alter leaf water potential, ionic balance, antioxidant production and other physiological and biological parameters and thus improve plant's capacity to tolerate abiotic stresses. AMF being non-host specific in nature (Evelin *et al.,* 2009) can be successfully used in the soil to establish low-cost sustainable agricultural systems (Hooker and Black, 1995).

The symbiosis of arbuscular mycorrhizal (AM) fungi with plant roots has been shown to improve the rate of photosynthesis, stomatal conductance of plants under abiotic stress (Gholamhoseini *et al.,* 2013; Auge *et al.,* 2015; Chitarra *et al.,* 2016). However, identifying moisture stress tolerant AM fungi strains (species) will help in sustaining growth of plants under drought conditions. Hence, it is necessary to select AMF species best adapted to the environment in which a plant is to be grown. Therefore, the present investigation is taken up to study the effect of different arbuscular mycorrhizal species on photosynthetic attributes of groundnut under drought stress.

MATERIALS AND METHODS

A. Description of study area

The field experiments were conducted at Field No. 11 in Orchard Block of Agricultural College Farm, Bapatla. The experiment was conducted during *rabi* 2019-20 and *rabi* 2020-21. The experimental site is geographically located at 15°54′N latitude and 80°25′ E longitude and at an altitude of 5.49 m above mean sea level (MSL), which is about 8 Km away from the Bay of Bengal in the Krishna Agro-Climatic zone of Andhra Pradesh, India.

During the crop growth period of groundnut, the mean weekly maximum and minimum temperature fluctuated between 19.6°C to 31.7°C during 2019-20 and 17.4°C to 32.6°C during 2020-21. The experimental crop received 96.7 and 40.6 mm of rainfall with 4 and 5 rainy days during 2019-20 and 2020-21, respectively. The average weekly relative humidity fluctuated between 69.4 to 82.4 % and 66.6 to 80.1 % during 2019-20 and 2020-21, respectively. The soil of the experimental field was sandy loam in texture, neutral with a pH of 7.2 and is low in organic carbon and available nitrogen, medium in available phosphorus, high in available potassium, sufficient in sulphur, manganese and copper and deficient in iron and zinc.

B. Experimental design and procedure

The experiments were laid out in a split plot design (SPD) and replicated thrice. The treatments were randomly allotted to different plots. Different mycorrhizal inoculants were obtained from Agricultural Research Station, Amaravathi. The experiment consisted of two main treatments and seven sub treatments. The details of the treatments are furnished below.

Main treatments: 2

M_0: No stress (Irrigated condition)

M_1: Moisture stress at pegging and pod formation stage (*i.e.* 40-60 DAS)

Sub treatments: 7

S_0: No application of mycorrhiza

S_1: Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}

S_2: Soil application of *Glomus aggergatum* @12.5 kg ha^{-1}

S_3: Soil application of *Glomus mosseae* @12.5 kg ha^{-1}

S_4: Soil application of *Glomus intraradices* @12.5 kg ha^{-1}

S_5: Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}

S_6: Soil application of *Acaulospora* sps. @12.5 kg ha^{-1}

Groundnut cultivar Trombay Akola Groundnut (TAG-24) was used in the current experiment. It is a spanish bunch mutant variety developed by Babha Atomic Research Centre through mutation breeding. It is tolerant to peanut bud necrosis disease and leaf spots. It is an early maturing high yielding variety suitable for rainy and post-rainy situations in many states with stable yields and is used as national check variety in all India coordinated varietal trials.

The experimental field was ploughed with a tractor-drawn mouldboard plough and then worked twice with a rotovator and the stubbles were removed from the field manually. The field was divided into forty-two plots as per the layout and levelling was done within the plots.FYM was applied before 15 days of the crop for proper mixing and decomposition of the manure. The recommended dose of 20 kg N, 40 kg P_2O_5 and 50 kg K_2O ha^{-1} was applied uniformly to all the plots through urea, single super phosphate (SSP) and muriate of potash (MOP). The entire quantity of phosphorus and potassium fertilizers were applied as basal before sowing, whereas nitrogen was applied in two equal splits (1/2 at the time of sowing, 1/2 at 30 DAS of the crop). Calcium and sulphur were supplied through gypsum @ 500 kg ha^{-1} at 35-45DAS.

The above arbuscular mycorrhizal species were applied each @ 12.5 kg ha^{-1} at the time of sowing. The required amount of mycorrhiza was weighed and was mixed with a small amount of soil. This was broadcasted in the field to ensure uniform distribution of mycorrhiza in the plot followed by a light irrigation.

The groundnut crop was sown on 16th November 2019 and 25th November 2020 during *rabi* 2019-20 and *rabi* 2020-21, respectively. The seeds were sown with a spacing of 22.5 cm between rows and 10 cm between plants in a plot of 4 m × 3 m, and uniform plant population was maintained in all the plots. Irrigation was given on the day of sowing to ensure uniform germination. Irrigation channels were placed between the replication for easy flow of irrigation water and later irrigations were provided based on the soil moisture status. To impose water stress, irrigation was withheld from 40 to 60DAS (*i.e.,* during pegging and pod formation stage) in the drought stress treatments in both the years (2019-20 and 2020-21). After 60DAS, irrigation was given to the stressed plots also.

Infra-Red Gas Analyser (IRGA model TPS-2) was used to analyze the net photosynthetic rate, stomatal conductance and transpiration rate of groundnut plants. A mature young leaf has been selected from non-destructive samples and was clamped in the leaf chamber of IRGA to measure the net photosynthetic rate, stomatal conductance and transpiration rate. The readings were taken between 10:00 AM to 12:00 Noon.

The collected data were analysed statistically following the analysis of variance (ANOVA) technique suggested for split plot design (Panse and Sukhatme, 1978). The statistically hypothesis of equalities of treatment means was tested by F-test at 5% level of significance.

RESULTS AND DISCUSSION

A. Net photosynthetic rate

The data pertaining to the net photosynthetic rate of groundnut as influenced by AM species under drought stress during 2019-20 and 2020-21 were presented in the Tables 1 and 2, respectively.

Table 1: Influence of arbuscular mycorrhizal species on net photosynthetic rate (μ mol $CO_2 m^{-2}s^{-1}$) of groundnut during *rabi* 2019-20.

Treatments	Net photosynthetic rate (μ mol $CO_2m^{-2}s^{-1}$)											
Sub treatments	20DAS			40DAS			60DAS			80DAS		
	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean
S_0-No application of mycorrhiza	6.64	6.89	6.76	10.23	11.01	10.62	12.11	6.50	9.31	11.74	7.26	9.50
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	6.86	6.51	6.68	12.36	12.62	12.49	16.81	8.16	12.48	13.98	12.15	13.07
S_2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	6.47	6.63	6.55	12.57	11.42	12.00	15.49	9.00	12.25	12.42	9.68	11.05
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	7.75	8.03	7.89	18.55	15.68	17.12	17.44	10.85	14.14	15.58	14.61	15.09
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	7.18	7.38	7.28	14.82	13.87	14.34	16.79	9.66	13.23	14.76	12.15	13.45
S_5- Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}	7.99	8.11	8.05	16.79	16.67	16.73	17.71	10.30	14.01	15.83	12.74	14.28
S_6- Soil application of *Acaulospora* sps @12.5 kg ha^{-1}	6.51	7.23	6.87	11.75	11.48	11.62	13.66	8.10	10.88	11.11	9.76	10.43
Mean	7.06	7.25		13.87	13.25		15.72	8.91		13.63	11.19	

	20DAS			40DAS			60DAS			80DAS		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm±	0.18	0.43	0.60	0.27	0.50	0.71	0.23	0.32	0.44	0.19	0.35	0.49
CD (P=0.05)	NS	NS	NS	NS	1.47	NS	1.39	0.90	1.27	1.13	1.01	1.43
CV (%)	11.80	14.58		9.12	9.11		8.50	6.13		6.84	6.84	

Table 2: Influence of arbuscular mycorrhizal species on net photosynthetic rate (μ mol $CO_2 m^{-2}s^{-1}$) of groundnut during *rabi* 2020-21.

Treatments	Net photosynthetic rate (μ mol $CO_2m^{-2}s^{-1}$)											
Sub treatments	20DAS			40DAS			60DAS			80DAS		
	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean
S_0-No application of mycorrhiza	5.91	6.18	6.04	6.14	6.54	6.34	11.42	6.88	9.15	9.37	5.52	7.44
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	6.40	6.08	6.24	9.55	9.57	9.56	13.04	8.32	10.68	12.29	7.61	9.95
S_2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	5.84	5.72	5.78	9.54	9.32	9.43	12.83	7.91	10.37	10.43	6.11	8.27
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	7.02	7.05	7.04	14.21	14.47	14.34	16.95	9.81	13.38	14.49	9.17	11.83
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	7.15	7.20	7.17	10.05	10.36	10.20	13.37	8.33	10.85	12.53	7.85	10.19
S_5- Soil application of *Gigaspora sps.* @12.5 kg ha^{-1}	7.11	7.17	7.14	14.56	13.31	13.94	17.79	8.74	13.27	14.59	8.15	11.37
S_6- Soil application of *Acaulospora* sps @12.5 kg ha^{-1}	5.78	6.16	5.97	6.07	7.26	6.67	11.86	7.59	9.72	9.25	7.12	8.19
Mean	6.46	6.51		10.02	10.12		13.89	8.23		11.85	7.36	

	20DAS			40DAS			60DAS			80DAS		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm±	0.11	0.40	0.56	0.14	0.31	0.44	0.16	0.25	0.36	0.14	0.27	0.38
CD (P=0.05)	NS	NS	NS	NS	0.90	NS	0.99	0.74	1.03	0.85	0.78	1.10
CV (%)	7.60	14.99		6.35	7.52		6.75	5.58		6.69	6.82	

Net photosynthetic rate differed significantly among the main plots at 60 and 80 DAS. Among the main treatments, net photosynthetic rate was significantly declined under water stress condition (M_1- 8.91 and 8.23µ mol CO_2 $m^{-2}s^{-1}$) compared to irrigated condition (M_0- 15.72 and 13.89 µ mol $CO_2m^{-2}s^{-1}$) during 2019-20 and 2020-21, respectively, at 60DAS. At 80DAS, irrigation treatment recorded higher net photosynthetic rate (M_0- 13.63 and 11.85 µ mol CO_2 $m^{-2}s^{-1}$) than the water stress treatment (M_1- 11.19 and 7.36 µ mol $CO_2m^{-2}s^{-1}$) in both the years. Water stress treatment reduced the net photosynthetic rate of groundnut plants by 43.3 and 40.7 % compared to the irrigation treatment at 60DAS and was reduced by 17.9 and 37.9 per cent at 80 DAS in both the years, respectively. The reduction of net photosynthetic rate under drought stress may be due to several coordinated events, such as stomatal closure which reduces CO_2 availability in the leaves. This in turn inhibits carbon fixation and reduced activity of photosynthetic enzymes (Neto *et al.*, 2010) such as rubisco. These findings are in conformity with the report of Vaidya *et al.*, (2015) who reported that net photosynthetic rate reduced significantly under drought stress compared to control in groundnut genotypes.

Significant differences among the my corrhizal treatments were noticed at 40, 60 and 80DAS. Net photosynthetic rate of groundnut ranged from 10.62 to 17.12 µ mol $CO_2m^{-2}s^{-1}$ at 40DAS, 9.31 to 14.14 µ mol $CO_2m^{-2}s^{-1}$ at 60DAS and from 9.50 to 15.09 µ mol $CO_2m^{-2}s^{-1}$ at 80DAS, respectively during 2019-20 and it ranged from 6.34 to 14.34 µ mol $CO_2m^{-2}s^{-1}$ at 40DAS, 9.15 to 13.38 µ mol $CO_2m^{-2}s^{-1}$ at 60DAS and from 7.44 to 11.83 µ mol $CO_2m^{-2}s^{-1}$ at 80DAS, respectively during 2020-21. Among the different mycorrhizal treatments, higher net photosynthetic rate was recorded in the groundnut plants that received the soil application of *Glomus mosseae* @ 12.5 kg ha^{-1} (S_3- 17.12, 14.14 and 15.09 µ mol $CO_2m^{-2}s^{-1}$ at 40, 60 and 80 DAS, respectively) during 2019-20 and (S_3- 14.34, 13.38 and 11.83 µ mol $CO_2m^{-2}s^{-1}$at 40, 60 and 80 DAS, respectively) during 2020-21. It was found to be on a par with the treatment that received *Gigaspora* sps. @ 12.5 kg ha^{-1} (S_5- 16.73, 14.01 and 14.28 µ mol $CO_2m^{-2}s^{-1}$at 40, 60 and 80 DAS, respectively) during 2019-20 and (S_5- 13.94, 13.27 and 11.37 µ mol $CO_2m^{-2}s^{-1}$at 40, 60 and 80 DAS, respectively) during 2020-21.

Among all the sub treatments, control (S_0- no mycorrhizal application) recorded lower net photosynthetic rate of 10.62, 9.31 and 9.50µ mol $CO_2m^{-2}s^{-1}$ at 40, 60 and 80 DAS, respectively during 2019-20 and 6.34, 9.15 and 7.44µ mol $CO_2m^{-2}s^{-1}$ at 40, 60 and 80 DAS, respectively during 2020-21. It was found to be at par with the treatment that received the soil application of *Acaulospora* sps. @ 12.5 kg ha^{-1} (S_6- 11.62, 10.88 and 10.43µ mol $CO_2m^{-2}s^{-1}$ during 2019-20 and 6.67, 9.72 and 8.19 µ mol $CO_2m^{-2}s^{-1}$ during 2020-21) at all the stages of growth. In the present investigation, soil application of *Glomus mosseae* @ 12.5 kg ha^{-1} (S_3) recorded 51.9 and 46.2% higher net photosynthetic rate over control at 60DAS, followed by the soil application of *Gigaspora* sps. @ 12.5 kg ha^{-1} (S_5) which recorded 50.5 and 45.0% higher net photosynthetic rate over control during 2019-20 and 2020-21, respectively.

Higher net photosynthetic rate is attributed to the higher levels of chlorophyll (Davies *et al.,* 1994) and specific leaf weight of the plants. Salam *et al*., (2018) also reported that significant differences were noticed among the mycorrhizal treatments for photosynthetic rate of damask rose, and the control plants recorded the lowest photosynthetic rate compared to the mycorrhizal rose plants. *Glomus mosseae* inoculated plants enhanced the photosynthetic ability of groundnut plant (Pawar *et al.,* 2018).

Among the interactions, soil application of *Gigaspora* sps. @ 12.5 kg ha^{-1} recorded higher net photosynthetic rate under irrigated conditions (M_0S_5-17.71 and 17.79 µ mol CO_2 $m^{-2}s^{-1}$) and soil application of *Glomus mosseae* @12.5 kg ha^{-1} recorded higher net photosynthetic rate (M_1S_3- 10.85 and 9.81 µ mol CO_2 $m^{-2}s^{-1}$) under water stress conditions. Control without mycorrhizal treatment recorded lower net photosynthetic rate compared to all other treatments under irrigated (M_0S_0- 12.11 and 11.42 µ mol $CO_2m^{-2}s^{-1}$) as well as water stress conditions (M_1S_0- 6.50 and 6.88 µ mol CO_2 $m^{-2}s^{-1}$) at 60DAS. Similar trend was observed among the interactions at 80DAS. The net photosynthetic rate recorded with the soil application of *Glomus mosseae* @ 12.5 kg ha^{-1} (M_1S_3) was 1.7 and 1.4- folds higher than the non-AM plants (M_1S_0) under drought stress followed by *Gigaspora* sps. @ 12.5 kg ha^{-1} (M_1S_5) which recorded 1.6 and 1.3- folds higher net photosynthetic rate under drought stress in both the years respectively at 60 DAS.

The net photosynthetic rate of M_1S_3 was 1.2- fold higher than the control plants (non-AM plants) under irrigation (M_0S_0) during 2019-20, and it was comparable to the control under irrigation (M_0S_0- 9.37 µ mol $CO_2m^{-2}s^{-1}$) during 2020-21, at 80DAS, which indicated that the groundnut plants inoculated with these mycorrhizal species under drought stress maintained higher photosynthetic rate and was found to be comparable to that of irrigated control without mycorrhizal application. Salam *et al.,* (2018) reported that the higher photosynthetic rate was maintained by the mycorrhizal treatments in damask rose under irrigated and stress conditions. Khalvati *et al.,* (2005) reported that the net photosynthetic rate of mycorrhizal barley plants was significantly higher than uninoculated plants under drought stress. The reduction of chlorophyll content may cause a damaging effect on the quantum yield of PS II which is lesser in AMF plants as compared to non-AMF plants, indicating that mycorrhizal association is involved in the alleviation of drought stress induced reduction of photosynthetic efficiency.

B. Stomatal conductance

The data pertaining to the stomatal conductance of groundnut as influenced by AM species under drought stress during 2019-20 and 2020-21 were furnished in the Tables 3 and 4, respectively.

Table 3: Influence of arbuscular mycorrhizal species on stomatal conductance (µ mol H_2O $m^{-2}s^{-1}$) of groundnut during *rabi* 2019-20.

Treatments	Stomatal conductance (µ mol H_2O $m^{-2}s^{-1}$)											
Sub treatments	20DAS			40DAS			60DAS			80DAS		
	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean
S_0-No application of mycorrhiza	34.51	33.09	33.80	87.43	75.39	81.41	122.73	79.50	101.12	72.74	63.86	68.30
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	33.54	32.72	33.13	83.34	85.36	84.35	136.75	92.49	114.62	86.18	81.31	83.74
S_2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	33.22	32.51	32.86	84.97	82.89	83.93	131.28	92.22	111.75	83.29	77.51	80.40
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	37.71	34.91	36.31	95.54	88.44	91.99	165.06	121.70	143.38	90.86	90.03	90.45
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	36.26	34.58	35.42	91.86	87.62	89.74	146.04	118.08	132.06	86.84	83.51	85.18
S_5- Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}	37.58	37.54	37.56	102.81	95.11	98.96	173.63	120.84	147.24	96.78	88.20	92.49
S_6- Soil application of *Acaulospora* sps @12.5 kg ha^{-1}	32.90	33.70	33.30	80.78	82.35	81.56	125.53	90.92	108.22	81.81	77.38	79.60
Mean	35.10	34.15		89.53	85.31		143.00	102.25		85.50	80.26	

	20DAS			40DAS			60DAS			80DAS		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm±	0.67	1.17	1.66	1.25	2.85	4.02	1.99	2.16	3.05	0.77	2.36	3.34
CD (P=0.05)	NS	NS	NS	NS	8.31	NS	12.11	6.30	8.91	4.69	6.89	9.74
CV (%)	8.93	8.31		6.53	7.97		7.46	4.33		4.26	6.97	

Table 4: Influence of arbuscular mycorrhizal species on stomatal conductance (µ mol H_2O $m^{-2}s^{-1}$) of groundnut during *rabi* 2020-21.

Treatments	Stomatal conductance (µ mol H_2O $m^{-2}s^{-1}$)											
Sub treatments	20DAS			40DAS			60DAS			80DAS		
	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean
S_0-No application of mycorrhiza	36.83	37.93	37.38	70.58	71.11	70.84	111.74	59.99	85.86	102.65	72.26	87.46
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	36.88	38.87	37.87	104.46	104.77	104.62	123.23	88.91	106.07	116.34	98.71	107.53
S_2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	37.16	37.30	37.23	81.53	85.81	83.67	120.34	82.31	101.32	111.93	92.37	102.15
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	42.54	41.42	41.98	109.34	107.45	108.39	125.74	101.47	113.61	129.01	110.09	119.55
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	42.98	42.65	42.82	93.62	93.01	93.32	123.99	92.17	108.08	118.73	101.59	110.16
S_5- Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}	40.23	40.71	40.47	116.21	110.96	113.58	135.48	100.54	118.01	134.58	104.99	119.79
S_6- Soil application of *Acaulospora* sps @12.5 kg ha^{-1}	37.95	39.32	38.64	70.28	72.58	71.43	115.88	77.01	96.45	109.20	77.82	93.51
Mean	39.22	39.74		92.29	92.24		122.34	86.06		117.49	93.98	

	20DAS			40DAS			60DAS			80DAS		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm±	1.12	2.54	3.60	1.53	2.30	3.26	1.41	2.62	3.70	1.98	2.35	3.33
CD (P=0.05)	NS	NS	NS	NS	6.72	NS	8.60	7.65	10.81	12.06	6.87	9.72
CV (%)	7.70	9.28		7.58	6.11		6.22	6.16		8.59	5.45	

Stomatal conductance differed significantly among the irrigated and stress treatments after imposition of drought stress. Among the main treatments, water stress treatment recorded lower stomatal conductance (M_1 - 102.25 and 86.06 µ mol H_2O $m^{-2}s^{-1}$) than irrigation treatment (M_0- 143.00 and 122.34µ mol H_2O $m^{-2}s^{-1}$) during 2019-20 and 2020-21, respectively at 60DAS. Similarly, at 80DAS lower stomatal conductance was recorded in the water stress treatment (M_1- 80.26 and 93.98 µ mol H_2O $m^{-2}s^{-1}$) compared to the irrigation treatment (M_0- 85.5 and 117.49 µ mol H_2O $m^{-2}s^{-1}$). Water stress treatment decreased the stomatal conductance of groundnut plants by 28.5 and 29.7 per cent than the irrigation treatment at 60DAS and by 6.1 and 20.0 per cent at 80 DAS in both the years, respectively. The reduction in stomatal conductance under drought stress in groundnut was reported by Songsri *et al.,* (2013); Vaidya *et al.,* (2015).

The reduction of stomatal conductance under drought stress might be attributed to the accumulation of ABA under drought stress which induces partial stomatal closure (Selmar and Kleinwächter, 2013).

Significant differences among the mycorrhizal treatments were observed from 40 to 80DAS. At 40, 60 and 80 DAS, higher stomatal conductance was recorded with the soil application of *Gigaspora* sps. @ 12.5 kg ha^{-1} (S_5- 98.96, 147.24 and 92.49 µ mol H_2O $m^{-2}s^{-1}$, respectively during 2019-20 and 113.58, 118.01and 119.79 µ mol H_2O $m^{-2}s^{-1}$, respectively during 20202-21) which was at par with the treatment that received the soil application of *Glomus mosseae* @ 12.5 kg ha^{-1} (S_3-91.99, 143.38 and 90.45, µ mol H_2O $m^{-2}s^{-1}$, respectively during 2019-20 and 108.39, 113.61and 119.55 µ mol H_2O $m^{-2}s^{-1}$, respectively during 2020-21) in both the years.

Lower stomatal conductance was recorded with control (S_0- 81.41 and 70.84µ mol H_2O $m^{-2}s^{-1}$ at 40DAS; 101.12 and 85.86 µ mol H_2O $m^{-2}s^{-1}$ at 60DAS and 68.30 and 87.46 µ mol H_2O $m^{-2}s^{-1}$ at 80DAS during 2019-20 and 2020-21, respectively). Stomatal conductance of the treatment that received *Gigaspora* sps. @ 12.5 kg ha^{-1}(S_5) was 45.6 and 37.4 % higher than non-mycorrhizal plants (S_0) at 60DAS and *Glomus mosseae*@ 12.5 kg ha^{-1}(S_3) was 41.8 and 32.3 % higher at 60DAS in both the years, respectively. Green *et al.*, (1998) reported that VAM colonization significantly enhanced the stomatal conductance of intact leaves of adequately watered cowpea plants. The increase in stomatal conductance is attributed to the down regulation of SINCED, an ABA biosynthetic gene in mycorrhizal plants (Duc *et al.*, 2018).

At 60DAS, among the interactions, higher stomatal conductance under irrigated conditions was recorded with the soil application of *Gigaspora* sps. @ 12.5 kg ha^{-1} (M_0S_5- 173.63 and 135.48 µ mol H_2O $m^{-2}s^{-1}$) in both the years and it was at par with the soil application of *Glomus mosseae* @ 12.5 kg ha^{-1} (M_0S_3- 165.06 and 125.74 µ mol H_2O $m^{-2}s^{-1}$), whereas under drought stress, soil application of *Glomus mosseae* @ 12.5 kg ha^{-1} recorded higher stomatal conductance (M_1S_3- 121.70 and 101.47 µ mol H_2O m^{-2} s^{-1}) and it was at par with the soil application of *Gigaspora* sps. @ 12.5 kg ha^{-1} (M_1S_5- 120.84 and 100.54 µ mol H_2O $m^{-2}s^{-1}$) in both the years, respectively. Lower stomatal conductance was recorded with control under irrigation (M_0S_0- 122.73 and 111.74 µ mol H_2O $m^{-2}s^{-1}$) and water stress conditions (M_1S_0- 79.50 and 59.99 µ mol H_2O $m^{-2}s^{-1}$). Similar trend among the interactions was observed at 80DAS.

The stomatal conductance of the treatment that received the soil application of *Glomus mosseae* @ 12.5 kg ha^{-1} under drought stress (M_1S_3-121.70 and 101.47 µ mol H_2O $m^{-2}s^{-1}$) and the soil application of *Gigaspora* sps. @ 12.5 kg ha^{-1} (M_1S_5- 120.84 and 100.54 µ mol H_2O $m^{-2}s^{-1}$) were found to be at par with the treatment without mycorrhizal inoculation under irrigated conditions (M_0S_0- 122.73 and 111.74 µ mol H_2O $m^{-2}s^{-1}$) at 60DAS during 2019-20 and 2020-21, respectively, which implies that the crops inoculated with these mycorrhizal species under drought stress are capable of maintaining stomatal conductance nearly equal to that of control (without mycorrhiza) under irrigation. In the present investigation, at 60DAS, soil application of *Glomus mosseae* and *Gigaspora* sps. @ 12.5 kg ha^{-1} to the water stressed groundnut plants increased the stomatal conductance by 53.1 and 52.0 % during 2019-20 and by 69.1 and 67.6 % during 2020-21, respectively, over the non-mycorrhizal plants under water stress. The obtained results are in agreement with those obtained by Ruiz-Sánchez *et al.,* (2010) in rice and Khalvati *et al.,* (2005) in barley.

C. Transpiration rate

The data regarding the transpiration rate of groundnut as influenced by AM species under water stress during 2019-20 and 2020-21 were presented in the Tables 5 and 6, respectively.

Table 5: Influence of arbuscular mycorrhizal species on transpiration rate (µ mol H_2O $m^{-2}s^{-1}$) of groundnut during *rabi* 2019-20.

Treatments	Transpiration rate (µ mol H_2O $m^{-2}s^{-1}$)											
Sub treatments	20DAS			40DAS			60DAS			80DAS		
	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean
S_0-No application of mycorrhiza	0.81	0.89	0.85	1.86	1.66	1.76	1.87	1.03	1.45	1.00	1.19	1.10
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	0.84	0.78	0.81	1.90	2.00	1.95	2.39	1.84	2.12	1.45	1.36	1.40
S_2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	0.84	0.80	0.82	2.06	1.78	1.92	2.22	1.50	1.86	1.31	1.34	1.32
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	0.91	0.84	0.87	2.13	2.09	2.11	2.56	2.14	2.35	1.48	1.60	1.54
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	0.93	0.92	0.92	1.97	1.88	1.92	2.45	1.86	2.15	1.47	1.49	1.48
S_5- Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}	0.91	0.85	0.88	2.17	2.19	2.18	2.63	1.90	2.26	1.59	1.50	1.55
S_6- Soil application of *Acaulospora sps* @12.5 kg ha^{-1}	0.81	0.79	0.80	1.79	1.73	1.76	2.21	1.37	1.79	1.22	1.22	1.22
Mean	0.86	0.84		2.00	1.90		2.33	1.66		1.36	1.39	

	20DAS			40DAS			60DAS			80DAS		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm±	0.01	0.03	0.05	0.03	0.07	0.10	0.04	0.09	0.13	0.02	0.04	0.05
CD (P=0.05)	NS	NS	NS	NS	0.22	NS	0.24	0.27	NS	NS	0.10	NS
CV (%)	6.17	9.58		6.07	9.33		9.08	11.37		8.13	6.26	

There was significant difference among the main plot treatments at 60DAS. Water stress treatment recorded significantly lowest transpiration rate (1.66 and 1.71µ mol H_2O $m^{-2}s^{-1}$) compared to irrigation treatment (2.33 and 2.50 µ mol H_2O $m^{-2}s^{-1}$) in both the years. The transpiration rate of groundnut was 40.4 and 46.2 % lower in stressed treatment compared to the irrigated treatment at 60DAS during 2019-20 and 2020-21, respectively. First response to drought stress is closing of stomata which prevents the rate of water loss with reduced stomatal conductance and transpiration rate. Similar reduction in transpiration rate was observed by Vaidya *et al.,* (2015) in drought stressed groundnut plants compared to control plants.

Table 6: Influence of arbuscular mycorrhizal species on transpiration rate (µ mol H_2O $m^{-2}s^{-1}$) of groundnut during *rabi* 2020-21.

Treatments	Transpiration rate (µ mol H_2O $m^{-2}s^{-1}$)											
Sub treatments	20DAS			40DAS			60DAS			80DAS		
	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean
S_0-No application of mycorrhiza	1.10	1.03	1.07	1.21	1.24	1.22	2.28	1.13	1.71	0.78	0.95	0.87
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	1.00	0.95	0.98	1.47	1.58	1.52	2.44	1.77	2.11	1.18	1.11	1.15
S_2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	0.93	1.00	0.97	1.43	1.41	1.42	2.39	1.70	2.05	1.07	1.09	1.08
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	1.04	1.12	1.08	1.76	1.71	1.74	2.75	1.95	2.35	1.40	1.49	1.45
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	1.16	1.15	1.16	1.33	1.34	1.33	2.50	1.89	2.20	1.20	1.17	1.19
S_5- Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}	1.03	1.02	1.03	1.82	1.86	1.84	2.76	1.92	2.34	1.53	1.41	1.47
S_6- Soil application of *Acaulospora* sps @12.5 kg ha^{-1}	1.12	1.10	1.11	1.16	1.19	1.17	2.36	1.59	1.98	0.98	0.96	0.97
Mean	1.05	1.05		1.45	1.48		2.50	1.71		1.16	1.17	

	20DAS			40DAS			60DAS			80DAS		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm±	0.02	0.04	0.06	0.03	0.05	0.10	0.04	0.04	0.06	0.02	0.03	0.05
CD (P=0.05)	NS	NS	NS	NS	0.14	NS	0.25	0.12	0.17	NS	0.10	NS
CV (%)	8.20	10.34		9.69	7.85		8.94	4.88		10.22	6.90	

Significant differences among the mycorrhizal treatments were observed at 40, 60 and 80DAS. Among the sub treatments, at 40DAS, higher transpiration rate was recorded with the soil application of *Gigaspora* sps. @ 12.5 kg ha^{-1} (S_5- 2.18 and 1.84 µ mol H_2O $m^{-2}s^{-1}$) which was at par with the treatment that received the soil application of *Glomus mosseae* @ 12.5 kg ha^{-1} (S_3- 2.11 and 1.74 µ mol H_2O $m^{-2}s^{-1}$) whereas, control recorded significantly lower transpiration rate (S_0- 1.76 and 1.22 µ mol H_2O $m^{-2}s^{-1}$) which was at par with the soil application of *Acaulospora* sps. @ 12.5 kg ha^{-1} (1.76 and 1.17 µ mol H_2O $m^{-2}s^{-1}$) in both the years. At 60DAS, soil application of *Glomus mosseae* @ 12.5 kg ha^{-1} recorded higher transpiration rate (S_3- 2.35 and 2.35 µ mol H_2O $m^{-2}s^{-1}$) compared to the other treatments and was found to be at par with the soil application of *Gigaspora* sps. @ 12.5 kg ha^{-1} (S_5- 2.26 and 2.34 µ mol H_2O $m^{-2}s^{-1}$), and lower transpiration rate was observed in control without mycorrhizal application (S_0- 1.45 and 1.71 µ mol H_2O $m^{-2}s^{-1}$), followed by the soil application of *Acaulospora* sps. (S_6- 1.79 and 1.98 µ mol H_2O $m^{-2}s^{-1}$) during 2019-20 and 2020-21, respectively. Same trend was followed at 80DAS in both the years of study. Green *et al.,* (1998) reported that AM colonization significantly enhanced the transpiration rate of cowpea plants under well-watered conditions. A higher transpiration rate in leaves of AM plants would be consistent with the higher rates of stomatal conductance that often accompany the mycorrhizal symbiosis, and are supposed to be necessary to supply carbon needs for the fungal symbiont (Auge, 2001).

Significant interaction effect was observed at 60DAS only during 2020-21. Among the interactions, higher transpiration rate was observed with the soil application of *Glomus mosseae* @ 12.5 kg ha^{-1} under drought conditions (M_1S_3-1.95 µ mol H_2O $m^{-2}s^{-1}$) and soil application of *Gigaspora* sps. @ 12.5 kg ha^{-1} under irrigated conditions (M_0S_5- 2.76 µ mol H_2O $m^{-2}s^{-1}$) during 2020-21. Whereas, lower transpiration rate was recorded in control under both irrigated (M_0S_0- 2.28 µ mol H_2O $m^{-2}s^{-1}$) and drought stress conditions (M_1S_0 - 1.13 µ mol H_2O $m^{-2}s^{-1}$). The transpiration rate of groundnut supplied with the soil application of *Glomus mosseae* (M_1S_3) and *Gigaspora* sps. @ 12.5 kg ha^{-1} (M_1S_5) was 72.6 and 69.9 % higher over control under water stress (M_1S_0), respectively at 60DAS during 2020-21. The obtained data is in agreement with the results of Auge *et al.*, (2008) in squash, and Salam *et al.* (2018) in rose who reported an increase in transpiration rate and stomatal conductance in mycorrhizal plants grown under water stress.

CONCLUSION

Photosynthesis and transpiration are the two important determinants of the crop growth and yield. In the present investigation, water stress substantially reduced the net photosynthetic rate, stomatal conductance and transpiration rate of groundnut. The mycorrhizal plants under water stress were recorded with higher net photosynthetic rate, stomatal conductance and transpiration rate compared to the non-mycorrhizal plants subjected to water stress. Among the mycorrhizal treatments, soil application of *Glomus mosseae* and *Gigaspora* sps. @ 12.5 kg ha^{-1} recorded superior performance in enhancing the net photosynthetic rate, stomatal conductance and transpiration rate of groundnut under water stress and were found to perform comparably to that of non-mycorrhizal plants under irrigation.

FUTURE SCOPE

Subsequent research should further investigate the effectiveness of AM fungi under combined abiotic stresses with different water management strategies.

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Conflict of interest. The authors declare that there is no conflict of interest.

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