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Influence of arbuscular mycorrhizal species on total dry matter accumulation, yield and its attributes of groundnut under water stress

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Abstract
Two field experiments were conducted at Agricultural College Farm, Bapatla to assess the effect of different arbuscular mycorrhizal species on growth, yield and its attributes of groundnut under water stress during *rabi* 2019-20 and 2020-21. The experimental results indicated that water stress significantly reduced the total dry matter accumulation, mean number of pods per plant, peg to pod ratio, pod yield, and harvest index in both the years. Among the mycorrhizal treatments, soil application of *Glomus mosseae* and *Gigaspora* sps. @ 12.5 Kg ha^{-1} exhibited superior performance in enhancing the total dry matter accumulation and yield of groundnut. Especially under drought stress, soil application of *Glomus mosseae* and *Gigaspora* sps. @ 12.5 Kg ha^{-1} increased the total dry matter accumulation 96.2 and 75.7 per cent during 2019-20 and 68.7 and 57.6 per cent during 2020-21 over control under drought stress. Higher number of pods per plant and pod yield under water stress were recorded by the treatments that received *Glomus mosseae* (14.36 and 1011.75 Kg ha^{-1} during 2019-20 and and 1087.62 Kg ha^{-1} during 2020-21, respectively) followed by *Gigaspora* sps. (13.82 and 974.04 Kg ha^{-1} during 2019-20 and 12.00 and 997.05 Kg ha^{-1} during 2020-21, respectively). Significantly poor performance with respect to total dry matter accumulation, yield and its attributes of groundnut was exhibited by control plants without mycorrhizal application and the plants that received *Acaulospora* sps. under both irrigated as well as water stress conditions.

Keywords: Drought, dry matter, groundnut, mycorrhiza, yield

Introduction
Groundnut (*Arachis hypogaea* L) is an important oilseed crop which accounts for 45% of total area under oil seed crops and 55 % of total oil seed production (Vijay Kumar *et al.*, 2021) [34]. Eighty percent of global peanut production takes place in environments prone to water deficit during the crop cycle (Wright and Nageswara Rao, 1994) [37]. Water stress limits crop production throughout the world (Kramer and Boyer, 1995) [16]. In groundnut, when water deficit takes place during pegging and pod formation stages, reductions in seed yield are mostly linked to decreased pod set, and seed weight (Boote *et al.*, 1976; Haro *et al.*, 2008; Ono *et al.*, 1974; Pallas *et al.*, 1979; Skelton and Shear, 1971 and Wright, 1989) [1, 13, 19, 20, 29, 38]. Lack of rainfall during this stage promotes increased surface soil strength, which impairs pegging and represents an additional factor limiting pod set and final seed numbers (Haro *et al.*, 2008) [13]. Pegs that started elongation before or during drought arrest their growth due to the restriction imposed by increased soil strength (Chapman *et al.*, 1993) [4], and many others remain above the soil surface until a new rainfall event or irrigation is provided which removes this limitation and allows their penetration into the soil (Haro *et al.*, 2008) [13]. Crop management practices that could enhance drought resistance, plant water-use efficiency and plant growth under drought stress are particularly beneficial (Egilla *et al.*, 2001) [7].
Mycorrhizal fungi were proved to enhance the water use efficiency of crop plants (Bryla and Duniway, 1997) [2] by directly enhancing the root water uptake providing adequate water to preserve physiological activity in plants, especially under severe drought conditions (Faber et al., 1991; Smith and Read, 1997) [30, 8]. Mycorrhizal inoculation also improves root P uptake, particularly under dry soil conditions (Jakobsen, 1995) [15].

Therefore, a strategy for management of drought through improvement of nutrient uptake would be to inoculate soils with appropriate AM fungi. Identification of AM fungi that is drought tolerant and adopted to a particular environment is a major challenge ahead. Hence, the present investigation is taken up to study the influence of arbuscular mycorrhizal species on growth and yield of groundnut under water stress.

Materials and methods

The experiment was carried out in a split plot design with 2 main treatments and seven sub treatments replicated thrice. The treatments include

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} S2: 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}

FYM was applied before 15 days of the crop for proper mixing and decomposition of the manure. Nitrogen, phosphorus and potassium were supplied through urea, single super phosphate (SSP) and muriate of potash (MOP). 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. 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. Mycorrhizal species were applied each @ 12.5 Kg ha^{-1} at the time of sowing. The required amount of mycorrhiza for 12m2 plot (15.0 g) was weighed and 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.

For estimation of total dry matter accumation, plant samples were collected by uprooting whole plant by soil excavation at harvesting periods. After excavation, the samples were slaked by dipping it into water and washed by gently flowing water. For dry biomass, the collected plant samples were oven dried at 80oC for 48 h till constant weight of the samples was observed. Computed total dry matter was expressed as g $plant^{-1}$.

The number of pegs and pods from 5 plants of destructive samples of a plot was counted and mean number of pegs and pods per plant was computed. Peg to pod ratio at harvest was calculated by using the following formula,

$$\text{Peg to pod ratio} = \frac{\text{Number of pods plant}^{-1}}{\text{Number of pegs plant}^{-1}}$$

To measure the shelling percentage, the pods were shelled and weight was recorded. The shelling % was calculated by using the following formula

$$\text{Shelling percentage} = \frac{\text{Weight of kernels}}{\text{Weight of pods}} \times 100$$

To obtain the total pod yield of groundnut, the sun-dried pods from the net plot area were cleaned and weight of the pods was recorded as pod yield per net plot. The yield obtained from five plants taken as destructive samples was also added and final pod yield per plot was calculated and expressed as Kg ha^{-1}. The harvest index of groundnut was worked out by using the following formula.

$$\text{Harvest Index} = E\frac{\text{[illegible]}}{\text{[illegible]}} \times 100$$

1. Results and Discussion

Influence of arbuscular mycorrhizal species on total dry matter accumulation of groundnut

The data pertaining to the total dry weight of groundnut as influenced by AM species under drought stress during 2019-20 and 2020-21 were presented in Tables 4.1 and 4.2 respectively. Total dry weight of groundnut was significantly influenced by mycorrhizal species and drought stress.

Significant difference among the main treatments was recorded only after 40DAS. Significant difference among the mycorrhizal treatments was observed from 40DAS till harvest. Among the main treatments, the highest total dry weight of 20.51 and 19.61 g plant- 1 was recorded in control without stress (M_0) compared to stressed treatment (M_1- 15.40 and 14.81 g $plant^{-1}$) during 2019-20 and 2020-21, respectively at 60DAS. At 80DAS, irrigation treatment recorded higher total dry weight (M_0- 30.39 and 27.33 g $plant^{-1}$) compared to the water stress treatment (M_1- 19.58 and 17.88 g $plant^{-1}$) in both the years. At harvest, water stress treatment (M_1-22.23 and 19.25 g $plant^{-1}$) recorded the lowest dry matter yield compared to irrigation treatment (M_0- 33.10 and 28.58 g $plant^{-1}$).

Water stress (M_1) decreased the total dry matter of groundnut by 32.8 and 32.6 per cent, during 2019-20 and 2020-21, respectively, over irrigation treatment (M_0), at harvest. The obtained results are in conformity with those obtained by Clavel *et al.* (2005) [6] who reported that the dry weight of groundnut was reduced under drought stress compared to the irrigated conditions. Similar results were recorded by Salam *et al.* (2018) in rose plants under water stress.

At 40 DAS, among the mycorrhizal treatments, higher dry matter yield was recorded with the soil application of *Gigaspora* sps. @ 12.5 Kg ha^{-1} (S_5- 7.45 and 7.27 g $plant^{-1}$) which was at par with the treatment that received the soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} (S_3- 7.44 and 7.20 g $plant^{-1}$) during 2019-20 and 2020-21, respectively. Lower total dry weight was recorded in control, without mycorrhizal application (S_0- 4.91 and 4.17 g $plant^{-1}$), which was at par with the soil application of *Acaulospora* sps. @12.5 Kg ha^{-1} (S_6- 5.06 and 4.24 g $plant^{-1}$).

At 60 DAS, soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} recorded significantly higher dry weight of 22.13 and was found to be statistically on a par with the soil application of *Gigaspora* sps. @12.5 Kg ha^{-1} (S_5- 21.44 g $plant^{-1}$) during 2019-20. During 2020-21, soil application of *Gigaspora* sps. @12.5 Kg ha^{-1} recorded higher total dry matter (S_5- 21.00 g $plant^{-1}$) and it was at par with *Glomus mosseae* @ 12.5 Kg ha^{-1} (S_3- 20.43 g plant-1). Lower dry weight was recorded in control (S_0- 13.62 and 13.67 g $plant^{-1}$) compared to all other treatments, and it was followed by the soil application of *Acaulospora* sps. @ 12.5 Kg ha^{-1} (S_6- 15.22 and 14.53 g $plant^{-1}$) during both the years. Other treatments (S_1, S2 and S_4) were found to be superior over control and inferior over S_3 and S_5.

At 80DAS, soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} (S_3) recorded the maximum dry weight of 31.46 and 26.58 g plant^{-1}, and it was on a par with the soil application of *Gigaspora* sps. @ 12.5 Kg ha^{-1} (S_5- 30.40 and 26.32 g plant^{-1}). The treatment without mycorrhizal application (S_0) recorded the minimum dry weight of 18.52 and 18.66 g plant^{-1} during 2019-20 and 2020-21, respectively. Similar trend was observed with regards to total dry weight at harvest. Soil application of *Glomus mosseae* (S_3) and *Gigaspora* sps. (S_5) @ 12.5 Kg ha^{-1} recorded 56.0 and 53.4 per cent increase in total dry matter, respectively, during 2019-20 and 39.5 and 38.4 per cent increase, respectively, during 2020-21, over control (S_0), at harvest. The remaining treatments (S_1, S2, S_4 and S_6) recorded higher dry weight than control and lower dry weight than S_3 and S_5. Enhancement of plant growth might be due to phytohormones such as Indole Acetic Acid (IAA) and cytokinins secreted by AM fungi which also help in increasing carbohydrate and protein content in the plants (Frankenberger and Arshad, 1995) [11]. Similar results were reported by Pawar *et al.* (2018) [21] in groundnut and Salam *et al.* (2018) [25] in sunflower.

Significant interaction effect between main treatments and mycorrhizal treatments was recorded at 60 DAS only. At 60 DAS, higher total dry weight was recorded with the treatment M_0S_5 (24.12 and 24.27 g plant^{-1}) during 2019-20 and 2020-21, respectively, which was at par with the soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} (M_0S_3-23.32 g plant^{-1}) during 2019-20, and lower total dry weight was recorded in control (M_1S_0- 10.68 and 11.25 g plant^{-1}) under drought stress. Under drought stress, M_1S_3 (20.95 and 18.98 g plant^{-1}) recorded higher dry matter yield followed by M_1S_5 with total dry weight of 18.77 and 17.73 g plant^{-1}. In the current study, under water stress condition, soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} increased the total dry matter by 96.2 and 68.7 per cent during 2019- 20 and 2020-21, respectively, followed by *Gigaspora* sps. @ 12.5 Kg ha^{-1} (75.7 per cent increase in 2019-20 and 57.6 per cent increase in 2020-21).

Table 1: Influence of arbuscular mycorrhizal species on total dry weight (g plant^{-1}) of groundnut during *rabi* 2019-20

Treatments	Total dry weight (g plant^{-1})														
Sub treatments	20 DAS			40 DAS			60 DAS			80 DAS			At harvest		
	M_0	M_1	Mean	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	1.40	1.29	1.34	4.82	5.00	4.91	16.56	10.68	13.62	23.67	13.37	18.52	26.18	16.73	21.46
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	1.30	1.25	1.27	5.99	6.30	6.14	21.53	15.12	18.33	30.65	19.15	24.90	34.36	22.25	28.31
S2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	1.33	1.30	1.31	6.62	6.55	6.59	20.65	14.13	17.39	27.83	17.83	22.83	31.40	21.44	26.42
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	1.35	1.33	1.34	7.54	7.34	7.44	23.32	20.95	22.13	36.44	26.48	31.46	38.77	28.18	33.48
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	1.42	1.40	1.41	6.10	5.90	6.00	19.52	15.57	17.55	31.06	19.83	25.44	33.32	22.43	27.87
S_5- Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}	1.45	1.40	1.42	7.76	7.15	7.45	24.12	18.77	21.44	36.94	23.86	30.40	40.61	25.21	32.91
S_6- Soil application of *Acaulospora* sps @12.5 kg ha^{-1}	1.32	1.39	1.35	5.26	4.86	5.06	17.87	12.57	15.22	26.16	16.54	21.35	27.06	19.36	23.21
Mean	1.37	1.34		6.30	6.16		20.51	15.40		30.39	19.58		33.10	22.23	

	20DAS			40DAS			60DAS			80DAS			At harvest		
	Main plots	Sub plots	Interaction	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	0.05	0.10	0.15	0.21	0.29	0.42	0.60	0.47	0.44	0.62	0.27	0.77	1.09
CD (P=0.05)	NS	NS	NS	NS	0.44	NS	1.78	1.23	1.74	2.86	1.29	NS	1.63	2.26	NS
CV (%)	6.69	6.67		7.19	5.90		7.45	5.75		8.63	4.32		4.44	6.85	

M_0- No stress (irrigation will be given as per irrigation schedule)
M_1- Moisture stress at pegging and pod formation stage (*i.e.*, 40-60 DAS)

Table 2: Influence of arbuscular mycorrhizal species on total dry weight (g plant^{-1}) of groundnut during *rabi* 2020-21

Treatments	Total dry weight (g plant^{-1})														
Sub treatments	20 DAS			40 DAS			60 DAS			80 DAS			At harvest		
	M_0	M_1	Mean	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	1.19	1.05	1.12	4.01	4.33	4.17	16.08	11.25	13.67	23.28	14.03	18.66	24.52	15.24	19.88
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	1.10	1.15	1.12	5.22	5.73	5.47	20.77	15.39	18.08	29.34	18.19	23.77	30.82	19.69	25.26
S2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	1.02	1.01	1.01	6.08	4.69	5.38	18.12	13.42	15.77	25.61	16.82	21.22	26.59	18.19	22.39
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	1.28	1.31	1.30	7.28	7.12	7.20	21.88	18.98	20.43	30.81	22.34	26.58	32.15	23.32	27.74
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	1.31	1.12	1.21	4.41	5.30	4.86	19.61	14.36	16.98	26.73	17.33	22.03	27.89	19.34	23.62
S_5- Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}	1.34	1.28	1.31	7.52	7.03	7.27	24.27	17.73	21.00	31.75	20.90	26.32	32.89	22.12	27.51
S_6- Soil application of *Acaulospora* sps @12.5 kg ha^{-1}	1.14	1.22	1.18	3.92	4.56	4.24	16.53	12.54	14.53	23.76	15.54	19.65	25.21	16.83	21.02
Mean	1.20	1.16		5.49	5.54		19.61	14.81		27.33	17.88		28.58	19.25	

	20DAS			40DAS			60DAS			80DAS			At harvest		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm±	0.02	0.07	0.10	0.05	0.25	0.36	0.21	0.36	0.51	0.27	0.48	0.67	0.27	0.82	1.17
CD (P=0.05)	NS	NS	NS	NS	0.74	NS	1.26	1.04	1.47	1.67	1.39	NS	1.65	2.41	NS
CV (%)	8.94	14.26		4.27	11.20		5.52	5.08		5.57	5.17		5.19	8.44	

M_0- No stress (irrigation will be given as per irrigation schedule)
M_1- Moisture stress at pegging and pod formation stage (*i.e.*, 40-60 DAS)

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The enhanced growth effects of mycorrhizal plants are often related to the AMF symbiosis, which could help plants to cope with the adverse effects of drought stress directly or indirectly through enhancing plant functionality both above- and below-ground (Rapparini and Peñuelas, 2014) [24]. In the present investigation, both under irrigated as well as water stressed condition, soil application of *Glomus mosseae* and *Gigaspora* sps. @ 12.5 Kg ha^{-1} improved the total dry matter of the groundnut crop.

Influence of arbuscular mycorrhizal species on yield attributes of groundnut

Number of pegs plant^{-1}

The data on variation in number of pegs $plant^{-1}$ as affected by water stress and mycorrhizal treatments in groundnut were presented in Tables 4.3(a) and 4.4(a). Number of pegs per plant measured at harvest ranged from 25.69 to 31.09 during 2019-20 and from 25.86 to 34.52 during 2020-21. There was no significant difference between main treatments, mycorrhizal treatments and their interactions in both the years. The obtained results were in contradictory to those obtained by Songsri *et al.* (2009) [31] who observed that number of pegs per plant were significantly reduced under water stress conditions in groundnut.

Number of pods plant $^{-1}$

The data pertaining to the number of pods per plant at harvest as affected by water stress and mycorrhizal treatments in groundnut were presented in Tables 4.3 (a) and 4.4 (a).

Significant differences were observed between the main treatments, mycorrhizal treatments and their interactions in both the years. The mean number of pods per plant are significantly lower under water stress (M_0- 19.24 and 19.47) compared to irrigated condition (M_1- 12.08 and 10.91) in both the years (2019-20 and 2020-21, respectively). Groundnut crop grown under water stress condition recorded 37.2 and 39.5 per cent reduction in mean number of pods per plant compared to irrigated condition in both the years of study. Similar results were reported by Carvalho *et al.* (2017) [3] who reported that the number of pods per plant were significantly reduced in groundnut plants exposed to terminal drought stress.

Among the mycorrhizal treatments tested, soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} recorded the highest mean number of pods per plant (S_3- 17.35 and 17.34) which was at par with the soil application of *Gigaspora* sps. @ 12.5 Kg ha^{-1} (S_5- 17.34 and 16.86) during 2019-20 and 2020-21, respectively. Control without mycorrhizal inoculation recorded lower mean number of pods per plant (S_0- 14.11) which was at par with the soil application of *Acaulospora* sps. @ 12.5 Kg ha^{-1} (S_6- 14.29) and *Glomus aggregatum* @ 12.5 Kg ha^{-1} (S2- 14.86) during 2019-20. During 2020-21, the lowest mean number of pods per plant were recorded by the control (S_0- 13.00). Similar significant differences between mycorrhizal treatments were detected in groundnut for number of pods per plant by Uko *et al.* (2019) [33] and Pawar *et al.* (2018) [21]. In the current study, soil application of *Glomus mosseae* and *Gigaspora* sps. @ 12.5 Kg ha^{-1} recorded 23.0 and 22.9 per cent increase in number of pods per plant respectively during 2019-20 and 33.4 and 29.7 per cent, respectively during 2020-21, over control plants. Similarly, the highest number of fruits per plant were observed in mycorrhizal red pepper plants compared to non-mycorrhizal plants (Selvakumar *et al.*, 2018) [26]. The remaining treatments (S_1 and S_4 during 2019-20 and S_1, S2, S_4 and S_6 during 2020-21) were significantly higher than control and lower than S_3 and S_5.

Among the interactions, under irrigated conditions, significantly higher number of pods per plant was noticed with the soil application of *Gigaspora* sps. @ 12.5 Kg ha^{-1} (M_0S_5-20.85 and 21.72) and it was on a par with the soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} (M_0S_3- 20.24 and 21.10) in both the years of 2019-20 and 2020-21 respectively, whereas control recorded lower number of pods per plant (M_0S_0- 18.42 and 16.72) which was at par with the soil application of *Acaulospora* sps. @ 12.5 Kg ha^{-1} (M_0S_6- 18.51 and 18.25) and *Glomus aggregatum* @ 12.5 Kg ha^{-1} (M_0S_2- 18.65 and 18.40) during 2019-20 and 2020-21, respectively.

Under water stress conditions, highest number of pods per plant was recorded in M_1S_3 treatment (14.46 and 13.57) followed by M_1S_5 (13.82 and 12.00) and M_1S_1(13.20 and 11.18) in both the years, respectively, and control was recorded with lesser number of pods per plant (M_1S_0- 9.80 and 9.27) and it was found to be on a par with M_1S_6 (10.07 and 9.53). The number of pods per plant in the treatment that received the soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} (M_1S_3) and *Gigaspora* sps. @ 12.5 Kg ha^{-1} (M_1S_5) was 47.5 and 46.4 per cent higher than the control under drought stress, respectively during 2019-20, and 38.5 and 29.4 per cent higher over control (M_1S_0) during 2020-21, respectively. Higher pod yield and pod number can be positively correlated to the higher nitrogen accumulation in AM fungi treated plants (Singh, 1999) [28]. Quilambo *et al.* (2005) [23] also reported significantly higher number of pegs and pods in mycorrhizal groundnut plants under water stress compared to non- mycorrhizal plants.

Peg to pod ratio

The data pertaining to the peg to pod ratio of groundnut as affected by the mycorrhizal inoculation under drought stress were furnished in Tables 4.3 (a) and 4.4 (a).

There was significant difference between the main treatments, mycorrhizal treatments and their interactions with regards to peg to pod ratio of groundnut except among the interactions during 2019-20. Similar significant differences were observed in groundnut by Songsri *et al.* (2009) [31].

Peg to pod ratio of groundnut was significantly lower under water stress condition in both the years of study. The highest peg to pod ratio was recorded in the groundnut plants under irrigation (0.68 and 0.66) compared to the plants exposed to drought stress (0.41 and 0.41). Groundnut plants subjected to water stress recorded 39.7 and 32.8 per cent reduction in peg to pod ratio compared to irrigated treatment during 2019-20 and 2020-21, respectively. Water deficit stress reduced the peg to pod ratio. The decrease in peg to pod ratio might be attributed to the reduction in time for conversion of pegs to pods as the water deficit stress was imposed at pegging stage which hindered and delayed the peg formation. Similar decrease in peg to pod ratio was observed with increasing water stress in groundnut (Songsri *et al.*, 2009) [31].

Among the different mycorrhiza tested, soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} recorded the highest peg to pod ratio (S_3-0.65 and 0.64) in both the years, respectively, and it was at par with the soil application of *Gigaspora* sps. @ 12.5 Kg ha^{-1} (S_5- 0.59 and 0.62) and was followed by *Glomus fasciculatum* @ 12.5 Kg ha^{-1} (S_1- 0.57 and 0.58) in both the years respectively, whereas, control recorded significantly lower peg to pod ratio (S_0- 0.47 and 0.42) in both the years respectively, and it was on a par with the soil application of *Acaulospora* sps.@ 12.5 Kg ha^{-1} (S_6- 0.48 and 0.45) followed by *Glomus aggregatum* @ 12.5 Kg ha^{-1} (S2- 0.52 and 0.48) in both the years, respectively.

Among the interactions, soil application of *Glomus mosseae* @

12.5 Kg ha^{-1} to the irrigated groundnut plants recorded higher peg to pod ratio (M_0S_3- 0.78) compared to other treatments, and it was at par with the application of *Gigaspora* sps. @ 12.5 Kg ha^{-1} under irrigated conditions (M_0S_5- 0.77). Lower peg to pod ratio was obtained with non-inoculated plants under water stress condition (M_1S_0- 0.35) compared to other treatments. In the present study, under water stress, soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} recorded higher peg to pod ratio (M_1S_3- 0.49) which was on a par with *Gigaspora* sps. @ 12.5 Kg ha^{-1} (M_1S_5- 0.47), whereas lesser peg to pod ratio was recorded with the plants not inoculated with mycorrhiza under drought stress (M_1S_0- 0.35) which was at par with *Acaulospora* sps. @ 12.5 Kg ha^{-1} (M_1S_6- 0.36), during 2020-21**.** In the present study, soil application of *Glomus mosseae* and *Gigaspora* sps. each @ 12.5 Kg ha^{-1} were recorded with highest peg to pod ratio compared to other mycorrhizal treatments which might be attributed to the maintenance of relatively higher water and nutrient uptake due to vast network of extra-radical hyphae with a very large surface area, that might helped the groundnut plants for higher peg to pod ratio in the plants during pegging and pod development even under stress conditions.

Shelling percentage

The data on the shelling percentage of groundnut as affected by AM species under drought stress in groundnut were furnished in Tables 4.3 (b) and 4.4 (b).

Shelling percentage of groundnut ranged from 60.87 to 71.04 during 2019-20 and 67.41 to 76.06 during 2020-21. No significant differences with respect to shelling percentage of groundnut among the main treatments, mycorrhizal treatments and their interactions were observed in both the years of study.

Pod yield

The data pertaining to the pod yield of groundnut as affected by moisture stress and mycorrhizal application were furnished in Tables 4.3 (b) and 4.4 (b).

Significant differences were observed between the main, mycorrhizal treatments and their interactions with regards to the pod yield of groundnut in both the years. The pod yield was significantly low under drought stress (M_1- 866.77 and 904.19 Kg ha^{-1}) compared to irrigated condition (M_0- 1274.14 and 1359.41 Kg ha^{-1}) in both the years, respectively. Groundnut crop under water stress recorded 32.0 and 33.5 per cent reduction in pod yield compared to irrigation treatment in both the years respectively. According to Carvalho *et al*. (2017) [3], the pod yield of groundnut reduced due to water stress in groundnut. Water stress is the most important factor limiting crop productivity and adversely affects most of the physiological processes. Drought induced reduction in the yield might be due to various factors such as decreased rate of photosynthesis (Flexas *et al.*, 2004) [10], disturbed assimilate partitioning (Farooq *et al.*, 2009) [9] and inadequate resource availability.

Among the mycorrhizal treatments, pod yield of groundnut ranged from 946.05 to 1195.53 Kg ha^{-1} during 2019-20 and 994.37 to 1282.22 Kg ha^{-1} during 2020-21. Soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} recorded the highest pod yield (S_3- 1195.53 and 1282.22 Kg ha^{-1}) which was at par with the soil application of *Gigaspora* sps. (S_5- 1184.91 and 1248.13 Kg ha^{-1}), whereas control without mycorrhizal application (S_0) recorded the lowest pod yield of 946.05 and 994.37 Kg ha^{-1}.

The treatment that received the soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} (S_3) and *Gigaspora* sps.@ 12.5 Kg ha^{-1} (S_5) recorded 26.4 and 25.2 per cent higher pod yield over control during 2019-20, and 28.9 and 25.5 per cent increase in pod yield, respectively over control during 2020-21. In the present study, the higher pod yield with the soil application of *Glomus mosseae* and *Gigaspora* sps. @ 12.5 Kg ha^{-1} might be due to higher net photosynthetic rate, higher pod number, pod weight and increased nutrient uptake (Murmu *et al.*, 2008) [17].

Among the interactions, under irrigated condition, the treatment that received the soil application of *Gigaspora* sps. @ 12.5 Kg ha^{-1} (M_0S_5- 1395.79 and 1499.21 Kg ha^{-1}) recorded higher pod yield and was found to be on a par with the soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} (M_0S_3- 1379.30 and 1476.83 Kg ha^{-1}), and under drought stress, soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} recorded higher pod yield (M_1S_3- 1011.75 and 1087.62 Kg ha^{-1}) and was followed by *Gigaspora* sps. @ 12.5 Kg ha^{-1} (M_1S_5- 974.04 and 997.05 Kg ha^{-1}) in both the years, respectively. Soil application of *Gigaspora* sps. and *Glomus mosseae* recorded 17.2 and 15.8 per cent increase during 2019-20 and 23.2 and 21.4 per cent increase in pod yield over non-mycorrhizal plants under irrigation during 2020-21. In the present investigation, soil application of *Gigaspora* sps. and *Glomus mosseae* @ 12.5 Kg ha^{-1} under irrigation recorded 43.3 and 36.3 per cent higher pod yield during 2019-20 and 50.4 and 35.8 per cent higher pod yield during 2020-21 than the soil application of *Gigaspora* sps. and *Glomus mosseae* under water stress condition, which indicated that the mycorrhizal efficiency was enhanced under irrigated condition than the drought stress, and thus has an added advantage in increasing the pod yield of groundnut under irrigation. It was also observed that the soil application of *Glomus mosseae* (M_1S_3- 1011.75 and 1087.62 Kg ha^{-1}) and *Gigaspora* sps. @ 12.5 Kg ha^{-1} (M_1S_5- 974.04 and 997.05 Kg ha^{-1}) under water stress were recorded the pod yield comparable to that of the control under irrigation (M_0S_0- 1191.05 and 1216.82 Kg ha^{-1}).

The lower pod yield under irrigation was recorded in control (M_0S_0- 1191.05 and 1216.82 Kg ha^{-1}) and it was found to be on a par with the soil application of *Acaulospora* sps @ 12.5 Kg ha^{-1} (M_0S_6- 1214.21 and 1259.68 Kg ha^{-1}) and *Glomus aggregatum* @ 12.5 Kg ha^{-1} (M_0S2-1225.44 and 1264.45 Kg ha^{-1}) in both the years. Under drought stress, control (M_1S_0) recorded lower pod yield of 701.05 and 771.91 Kg ha^{-1}, and it was followed by the soil application of *Acaulospora* sps. (M_1S_6- 755.44 and 819.05 Kg ha^{-1}) and *Glomus aggregatum* @ 12.5 Kg ha^{-1} (M_1S2- 812.28 and 835.72 Kg ha^{-1}) during 2019-20 and 2020-21, respectively. In the current study, soil application of *Glomus mosseae* and *Gigaspora* sps. @ 12.5 Kg ha^{-1} under drought stress recorded 44.3 and 38.9 per cent higher pod yield, respectively during 2019-20 and 40.9 and 29.2 per cent higher pod yield, respectively, during 2020-21, over the non-mycorrhizal plants under water stress condition (M_1S_0). The obtained results are in agreement with those obtained by Gholamhoseini *et al*. (2013) [12] who reported that the mycorrhizal inoculation significantly enhanced the seed yield of sunflower under water stress. Similar results were reported by Subramanian *et al*. (2006) [32] in tomato and Chareesri *et al*. (2020) [5] in rice.

In the present study, groundnut plants inoculated with *Glomus mosseae* and *Gigaspora* sps. exhibited superior performance and improved the pod yield of groundnut both under irrigated as well as under water stress conditions. This might be due to higher root colonization of these two species with the host plant which improved the growth of groundnut plants and drought tolerance capacity through improvement in leaf water potential and relative water content that attributed to the improved nitrogen, phosphorus and other essential nutrients uptake, resulted in higher pod yield in groundnut. Hence, inoculation of these mycorrhizal treatments could enhance the yield of groundnut compared to non-mycorrhizal plants. Singh (1999) [28] also reported significantly higher groundnut yield in AM fungi plants which was attributed to higher moisture content, increasing nutrient supply and higher nitrogen and phosphorus accumulation in AM fungi treated plants compared to non-AM plants. Similar increase in seed yield in mycorrhiza inoculated plants was reported in chickpea (Weber *et al.*, 1993) [35].

Harvest index

The data on harvest index of groundnut as affected by moisture stress and mycorrhizal treatments were presented in Tables 4.3 (b) and 4.4 (b). Significant differences were observed between the main treatments and mycorrhizal treatments in both the years. Interaction between main and mycorrhizal treatments was not significant in both the years. Similar significant differences were also reported in groundnut by Shinde *et al.* (2010).

The harvest index of groundnut was significantly low under drought stress compared to irrigated condition in both the years. The highest harvest index was recorded in the groundnut plants grown under irrigation (M_0- 51.58 and 60.75 %) compared to those exposed to water stress (M_1- 46.42 and 49.58 %). Groundnut crop grown under water stress recorded 5.2 and 11.2 per cent lower harvest index over irrigated treatment in both the years, respectively. The lower harvest index under water stress is due to reduced moisture which affects the yield components and yield. Shinde *et al.* (2010) reported that harvest index of groundnut was negatively affected by water stress. Similar reduction in harvest index under water stress was recorded by Pour-Aboughadareh (2020) in wheat genotypes.

Among the different mycorrhizae applied, soil application of *Glomus mosseae* @ 12.5 Kg ha^{-1} recorded higher harvest index (S_3- 58.26 and 58.41 %) which was at par with the soil application of *Gigaspora* sps. @ 12.5 Kg ha^{-1} (S_5- 54.58 and 57.87 %) followed by *Glomus fasciculatum* @ 12.5 Kg ha^{-1} (S_1- 50.86 and 57.23 %) and *Glomus intraradices* @ 12.5 Kg ha^{-1} (S_4- 49.97 and 55.65 %) in both the years, respectively. Whereas, lower harvest index was recorded by control (S_0- 40.35 and 50.98) which was statistically on a par with the soil application of *Acaulospora* sps. @ 12.5 Kg ha^{-1} (S_6- 42.60 and 52.50 %) followed by *Glomus aggregatum* @ 12.5 Kg ha^{-1} (S2- 46.41 and 53.52 %). The interaction effect between main and mycorrhizal treatments with regards to the harvest index of groundnut was found to be non-significant during both the years.

Harvest index is frequently used as an indicator of yield efficiency and consequently as a selection criterion for crop breeding. In the present study, soil application of *Glomus mosseae* and *Gigaspora* sps. @ 12.5 Kg ha^{-1} were recorded with higher harvest index over other treatments and control *i.e.*, without mycorrhiza. The obtained results are in agreement with those obtained by Uko *et al*. (2019) [33] who reported that the mycorrhiza colonized groundnut plants were recorded with higher harvest index over non-mycorrhizal plants. Similar results were reported by Jakobsen (1987) [14] in pea and Noori *et al.* (2014) [18] in wheat.

Table 3(a): Influence of arbuscular mycorrhizal species on yield attributes of groundnut during *rabi* 2019-20

Treatments					Yield attributes				
Sub treatments	-1				-1			Peg to pod ratio	
	M_0	M_1	Mean	M_0	M_1	Mean	M_0	M_1	Mean
S_0-No application of mycorrhiza	30.65	29.62	30.13	18.42	9.80	14.11	0.60	0.33	0.47
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	28.17	29.77	28.97	19.23	13.20	16.22	0.69	0.45	0.57
S2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	27.97	29.68	28.83	18.65	11.07	14.86	0.67	0.38	0.52
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	25.69	28.40	27.04	20.24	14.46	17.35	0.79	0.51	0.65
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	27.96	28.34	28.15	18.77	12.11	15.44	0.67	0.43	0.55
S_5- Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}	28.67	31.09	29.88	20.85	13.82	17.34	0.73	0.45	0.59
S_6- Soil application of *Acaulospora* sps @12.5 kg ha^{-1}	30.82	28.47	29.64	18.51	10.07	14.29	0.61	0.35	0.48
Mean	28.56	29.34		19.24	12.08		0.68	0.41	

	Number of pegs plant^{-1}			Number of pods plant^{-1}			Peg to pod ratio		
	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction	Main plots	Sub plots	Interaction
SEm±	0.51	1.41	1.99	0.33	0.33	0.46	0.01	0.02	0.03
CD (P=0.05)	NS	NS	NS	1.99	0.96	1.35	0.09	0.06	NS
CV (%)	8.01	11.90		9.58	5.13		12.41	8.68	

M_0- No stress (irrigation will be given as per irrigation schedule)

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

Table 3(b): Influence of arbuscular mycorrhizal species on yield and yield attributes of groundnut during *rabi* 2019-20

Treatments				Yield and yield attributes					
Sub treatments		Pod yield (Kg ha^{-1})		Shelling percent			Harvest index		
	M_0	M_1	Mean	M	M	Mean	M	M	Mean
S_0-No application of mycorrhiza	1191.05	701.05	946.05	65.24	66.80	66.02	42.67	38.03	40.35
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	1268.07	923.51	1095.79	71.04	63.53	67.28	54.56	47.15	50.86
S2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	1225.44	812.28	1018.86	64.89	65.92	65.41	49.18	43.64	46.41
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	1379.30	1011.75	1195.53	68.76	60.87	64.82	60.18	56.34	58.26
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	1245.09	889.30	1067.19	65.11	62.30	63.71	54.38	45.56	49.97
S_5- Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}	1395.79	974.04	1184.91	67.89	69.04	68.46	56.12	53.04	54.58
S_6- Soil application of *Acaulospora* sps @12.5 kg ha^{-1}	1214.21	755.44	984.82	65.27	68.12	66.69	43.98	41.21	42.60
Mean	1274.14	866.77		66.89	65.22		51.58	46.42	

	Pod yield			Shelling percent			Harvest index		
	Main plots	**Sub plots**	**Interaction**	**Main plots**	**Sub plots**	**Interaction**	**Main plots**	**Sub plots**	**Interaction**
SEm±	15.74	17.01	24.06	0.91	1.43	2.02	0.68	1.99	2.81
CD (P=0.05)	95.76	49.66	70.22	NS	NS	NS	4.14	5.80	NS
CV (%)	6.74	3.89		6.30	5.29		6.37	9.94	

M_0- No stress (irrigation will be given as per irrigation schedule)
M_1- Moisture stress at pegging and pod formation stage (*i.e.,* 40-60 DAS)

Table 3(c): Influence of arbuscular mycorrhizal species on yield attributes of groundnut during *rabi* 2020-21

Treatments	Yield attributes								
Sub treatments	**Number of pegs plant^{-1}**			**Number of pods plant^{-1}**			**Peg to pod ratio**		
	M_0	**M_1**	**Mean**	**M_0**	**M_1**	**Mean**	**M_0**	**M_1**	**Mean**
S_0-No application of mycorrhiza	34.52	26.85	30.69	16.72	9.27	13.00	0.48	0.35	0.42
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	27.42	26.37	26.89	20.12	11.18	15.65	0.73	0.43	0.58
S2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	32.21	26.35	29.28	18.40	10.27	14.34	0.57	0.39	0.48
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	26.95	28.29	27.62	21.10	13.57	17.34	0.78	0.49	0.64
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	28.35	26.01	27.18	19.97	10.55	15.26	0.71	0.41	0.56
S_5- Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}	28.29	25.86	27.07	21.72	12.00	16.86	0.77	0.47	0.62
S_6- Soil application of *Acaulospora* sps @12.5 kg ha^{-1}	33.49	26.36	29.93	18.25	9.53	13.89	0.55	0.36	0.45
Mean	30.18	26.59		19.47	10.91		0.66	0.41	

	Number of pegs plant^{-1}			Number of pods plant^{-1}			Peg to pod ratio		
	Main plots	**Sub plots**	**Interaction**	**Main plots**	**Sub plots**	**Interaction**	**Main plots**	**Sub plots**	**Interaction**
SEm±	0.74	1.20	1.69	0.35	0.26	0.37	0.01	0.02	0.02
CD (P=0.05)	NS	NS	NS	2.12	0.76	1.07	0.04	0.05	0.07
CV (%)	11.97	10.34		10.53	4.19		5.98	7.72	

M_0- No stress (irrigation will be given as per irrigation schedule)
M_1- Moisture stress at pegging and pod formation stage (*i.e.,* 40-60 DAS)

Table 3(d): Influence of arbuscular mycorrhizal species on yield attributes of groundnut during *rabi* 2020-21

Treatments	Yield and yield attributes								
Sub treatments	**Pod yield (Kg ha^{-1})**			**Shelling percent**			**Harvest index**		
	M_0	**M_1**	**Mean**	**M**	**M**	**Mean**	**M**	**M**	**Mean**
S_0-No application of mycorrhiza	1216.82	771.91	994.37	73.17	72.27	72.72	55.46	46.49	50.98
S_1- Soil application of *Glomus fasciculatum* @12.5 kg ha^{-1}	1427.30	910.38	1168.84	69.52	71.45	70.49	63.21	51.25	57.23
S2- Soil application of *Glomus aggregatum* @12.5 kg ha^{-1}	1264.45	835.72	1050.08	73.28	71.75	72.52	58.64	48.39	53.52
S_3- Soil application of *Glomus mosseae* @12.5 kg ha^{-1}	1476.83	1087.62	1282.22	67.96	76.06	72.01	65.30	51.51	58.41
S_4- Soil application of *Glomus intraradices* @12.5 kg ha^{-1}	1371.59	907.62	1139.60	67.41	71.75	69.58	60.49	50.81	55.65
S_5- Soil application of *Gigaspora* sps. @12.5 kg ha^{-1}	1499.21	997.05	1248.13	70.36	71.72	71.04	64.24	51.50	57.87
S_6- Soil application of *Acaulospora* sps @12.5 kg ha^{-1}	1259.68	819.05	1039.37	73.62	70.73	72.18	57.88	47.11	52.50
Mean	1359.41	904.19		70.76	72.25		60.75	49.58	

	Pod yield			Shelling percent			Harvest index		
	Main plots	**Sub plots**	**Interaction**	**Main plots**	**Sub plots**	**Interaction**	**Main plots**	**Sub plots**	**Interaction**
SEm±	20.69	13.11	18.54	0.94	1.68	2.38	1.04	1.56	2.21
CD (P=0.05)	125.91	38.26	54.11	NS	NS	NS	6.31	4.56	NS
CV (%)	8.38	3.84		6.04	5.76		8.61	6.94	

M_0- No stress (irrigation will be given as per irrigation schedule)
M_1- Moisture stress at pegging and pod formation stage (*i.e.,* 40-60 DAS)

Conclusion

In the present investigation, water stress decreased the total dry matter, pod number, pod yield and harvest index of groundnut significantly in both the years compared to the irrigation treatment. Among all the mycorrhizal treatments, soil application of *Glomus mosseae* and *Gigaspora* sps. @ 12.5 Kg ha^{-1} exhibited superior performance in enhancing the total dry matter accumulation, yield and yield attributes of groundnut under both irrigated as well as water stress conditions. While, non-mycorrhizal plants and plants that received *Acaulospora* sps. exhibited poor performance compared to all other mycorrhizal treatments especially under water stress conditions.

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