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Influence of plant growth promoting rhizo microorganisms on yield attributes and grain yield of maize (*Zea mays* L.) under water stress in Krishna Zone of Andhra Pradesh

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Abstract
A field experiment was carried out during *rabi* season of 2021-22 on a sandy clay loam soil at the Agricultural College Farm, Bapatla to study the effect of plant growth promoting rhizo microorganisms on yield attributes and grain yield of maize (*Zea mays* L.) under water stress. The experiment was laid out in split-plot design with three water stress treatments (M_1- Irrigated crop (*i.e.,* no stress was given), M_2- water stress at knee high stage and M_3- water stress at reproductive stage) as main plot and six bio-inoculant treatments (S_0: Control, S_1: VAM @ 12.5 kg ha^{-1}, S_2: PSB @ 5 kg ha^{-1}, S_3: *Bacillus* spp @ 5 kg ha^{-1}, S_4: *Azotobacter* @ 5 kg ha^{-1} and S_5: *Azospirillum* @ 5 kg ha^{-1}) as sub-plot treatments. Mean values for number of kernels per cob, cob length, cob girth and grain yield were highest with M_1 (no water stress) followed by M_2 (water stress at knee high stage) which were comparable with each other. With regard to bio-inoculant, mean values for number of kernels per cob, cob length, cob girth and grain yield were maximum with S_1 treatment (VAM @ 12 kg ha^{-1}). Hence, it can be concluded that water stress at knee high stage and application of VAM @ 12 kg ha^{-1} is an effective and sustainable way to enhance the yield attributes and grain yield of maize and the negative effects of drought stress can be mitigated.

Keywords: Water stress, cob length, test weight, cob girth, grain yield and maize

Introduction
Maize (*Zea mays* L.) is an important cereal crop after rice and wheat. Maize or corn (*Zea mays*) called as "queen of cereals" is a versatile plant belonging to the family of grasses (*Poaceae*). It is a multi purpose crop being used as food, feed and fodder in India. Maize is cultivated in India on an area of 9.70 m.ha with the production of 30 million metric tonnes and the productivity of 3.09 metric tonnes ha^{-1} (USDA, 2021) [16]. *Rabi* maize is an excellent choice as the second crop in rainfed agriculture. In Andhra Pradesh, 62% of maize growing area is unirrigated. By 2050, demand for maize in developing countries is expected to exceed 160 mts and will surpass the demand of both wheat and rice.

Drought being the most important environmental abiotic stress, severely impairs plant growth and development, limits plant performance and productivity, more than any other environmental factor (Shao *et al.*, 2009) [14]. Maize is highly demanding plant in terms of water (Gong *et al.*, 1997) [7]. It's productivity under unirrigated conditions is getting declined compared to irrigated maize as it experiences water stress at key growth stages. Maize, when grown as the second crop, constantly expose to drought stress and it is highly sensitive to drought, specifically at two weeks prior and post silking (Tollenaar and Lee, 2011) [15].

Water stress seriously hindered the growth and development of maize through reduction in leaf area and plant biomass. Leaf growth is very sensitive to water stress and may be inhibited by a slight reduction of water potential in the tissue (Hsiau and Xu, 2000) [10]. At severe drought, Anthesis and silking interval also increased by decrease in silk growth and development rate. Severe stress at tasseling stage reduced the yield by affecting the yield attributes and grain yield per plant (Aslam *et al.*, 2015) [1].

Plant growth promoting rhizobacteria (PGPR) and arbuscular mycorhizal fungi (AMF) that colonize the rhizosphere and interact with plants, helping them to grow in both direct and indirect ways. PGPR and AMF produce active metabolites that can be used by plants as growth regulators such as auxins, gibberellins, and cytokinins and also influence the biological fixation of nitrogen and nitrate assimilation.

Mitigate the impact of drought on plants through a process called Induced Systemic Tolerance (IST), which includes the production of hormones, antioxidants, osmolytes and decreased electrolyte leakage (Milosevic *et al.*, 2012) [11]. However, little is known about the processes involved in the interaction of plants with bacteria and fungi under drought conditions. Considering the above facts on maize growth during water stress and bio-inoculant action, the present investigation was taken to study the Influence of plant growth promoting rhizo microorganisms on yield attributes and grain yield of maize (*Zea mays* L.) under water stress in Krishna Zone of Andhra Pradesh.

Materials and Methods

An experiment was conducted with three water stress treatments (M_1- Irrigated crop (*i.e.,* no stress was given), M_2- water stress at knee high stage and M_3- water stress at reproductive stage) as main plot and six bio-inoculant treatments (S_0: Control, S_1: VAM @ 12.5 kg ha^{-1}, S_2: PSB @ 5 kg ha^{-1}, S_3: *Bacillus spp* @ 5 kg ha^{-1}, S_4: *Azotobacter*@ 5 kg ha^{-1} and S_5: *Azospirillum* @ 5 kg ha^{-1}) as sub-plot treatments. The experiment was conducted on a sandy clay loam soil during *rabi* seasons of 2021-22 at the Agricultural College Farm, Bapatla. This trial was laid in a split plot with three replications. The experimental soil was slightly alkaline in reaction; E.C was non-saline in nature and below the critical point, low in organic carbon, low in available nitrogen, medium in available phosphorus and high in available potassium. The average maximum and minimum temperatures were 31.7 °C and 19.8 °C during *rabi*, 2021-22. A total rainfall of 60.3 mm received during *rabi* season of 2021-22. The test variety used for sowing was Lakshmi 2277 and crop was sown at 60 cm and 20 cm inter and intra row distance, respectively and adopted all the standard package of practices. Water stress was imposed by manipulating irrigation (*i.e.,* skipping of irrigation) in such a way that the key stages, particularly knee high stage and reproductive growth stages were exposed to water stress. M_1- Fully irrigated crop (*i.e.,* no stress was given) M_2- with holded irrigation for 15 days at knee high stage (30-45 DAS) followed by rewatering, and M_3- with holded irrigation for 15 days at reproductive stage. (*i.e.,* 50-65 DAS) followed by rewatering. Three days before sowing, the bio-inoculants were applied to the selected plots for treatment imposition by mixing with vermi compost to facilitate even distribution in plots. Application of nutrients was done as per the treatments in the form of urea, single super phosphate and muriate of potash respectively. Nitrogen was applied in 3 equal split doses *viz.,* at basal, knee-high and tasseling stage. During the experimentation, the entire prescribed dose of phosphorus and potassium was applied at the time of sowing in the form of single super phosphate and muriate of potash, respectively. Recommended fertilizer dose of maize for Krishna zone of Andhra Pradesh is 240-80-80 kg NPK ha^{-1}. The data on yield attributes and grain yield were recorded as per standard procedures. All data are statistically analysed using the analysis of variance technique for split plot design as described by Panse and Shukhatme (1978) [12]. Statistical significance was tested by applying F-test at 0.05 level of probability.

Results and Discussion

Effect of plant growth promoting rhizo microorganisms on yield attributes and grain yield of maize (Zea mays L.) under water stress

1. Cob length and cob girth (cm)

The cob length and cob girth in *rabi* maize was noticeably influenced by water stress treatments and bio-inoculants. However, the interaction between them could not reach level of significance (Table 1).

The cob length and cob girth in *rabi* maize was significantly higher in no water stress (M_1). These treatments were followed by M_2 and M_3 which were comparable with each other. The treatment M_3 treatment registered statistically lower cob length and girth in maize during the study. Among the various graded doses of bio-inoculants applied to maize, application of Vesicular Arbiscular Mychorrizae @ 12.5 kg ha^{-1} (S_1) resulted in increased cob length and cob girth in maize and was significantly superior to other treatments except with S_3 treatment. The treatment control (S_0) resulted in lower values of cob length and cob girth. The probable reasons for increase in yield traits were extension of root system with fungal mycelium and increase in uptake of phosphorus, nitrogen and other nutrients. It resulted in enhanced nitrogen fixation and also increased plant growth and yield parameters by dissolving insoluble phosphate thus increasing the amount of available phosphorus due to mycorrhizal association (Garshasbi *et al.* 2014) [5].

2. Test weight (g)

Data analyzed for test weight (g) of maize presented in Table 1 revealed that the water stress treatments and bio-inoculants given to maize did not influence the test weight of maize. Their interaction was also found to be non-significant.

3. Number of kernels per cob

The highest number of kernels per cob was noticed in the M_1 treatment and it was significantly superior to M_2 treatment. However, it was on par with M_2 treatment. Among the various bio inoculants, application of VAM @ 12.5 kg ha^{-1} recorded the maximum and which was statistically superior to other treatments except S_2 treatment. The lowest number of kernels per cob noticed with S_0 treatment and it was statistically inferior to all treatments. According to Sajedi and Madani, (2006) [13], consumption of mycorrhizal increased yield components of maize both in condition of optimum irrigation and in condition of water deficit than treatment of without mycorrhizal consumption. Hajilou *et al.* (2010) [8] showed that mycorrhizal consumption has significant effect in probability level of 5% on the number of seed per fruit.

4. Grain yield (kg ha^{-1})

Data pertaining to grain yield of maize as influenced by maize crop residue management practices and fertility levels given to preceding rice and graded levels of fertilizers applied to maize are presented in Table 2.

Computation and analysis of the data related to grain yield of maize with respect to water stress treatments, indicated that grain yield of maize was registered with Irrigated (M_1) and it was found statistically superior to water stress at reproductive stage (M_3) treatment. However, it was statistically on par with water stress at knee high stage (M_2) treatment. The percentage increase in yield with Irrigated treatment was 18.04% over water stress at reproductive stage (M_3). 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) [4], disturbed assimilate partitioning (Farooq *et al.*, 2009) [3] and inadequate resource availability.

With respect to bio-inoculants given to maize crop, application of VAM @ 12.5 kg ha^{-1} (S_1) recorded highest grain yield of maize which was remarkably superior to other treatments. However, it was statistically comparable with S_2 & S_3 treatment. The lowest grain yield was noticed in the treatment control (S_0) and it was significantly inferior to all other treatments. This might be under conditions of water stress in maize by adding arbuscular mycorrhiza to the soil, maize yield increased significantly compared to the control that did not have these microorganisms. The coexistence of microorganisms with the roots of crops increases absorption and transfer of moving elements such as mineral nitrogen, especially under conditions of water stress. As the motility of nutrients is low under water stress conditions, arbuscular mycorrhizae can have a significant effect on the growth and development of all plant organs under water stress conditions compared to normal irrigation conditions The obtained results are in agreement with those obtained by Ghorchiani *et al.* (2012) [6] and Boomsma and Vyn, (2008) [2]

Table 1: Cob length (cm), cob girth (cm), number of kernals per cob, test weight (g) and grain yield (kg ha^{-1}) of maize as influenced by water stress and bio inoculants during *rabi*, 2021-22.

Treatments	Cob length (cm)	Cob girth (cm)	Test weight (g)	Number of kernels per cob	Grain yield (kg ha^{-1})
Water stress					
M_1	16.06	14.27	25.69	389.56	7843
M_2	14.14	13.18	24.23	368.56	7364
M_3	13.18	12.24	22.93	335.22	6644
S.Em	0.43	0.27	0.74	6.43	138.3
C.D (p=0.05)	1.69	1.06	NS	25.27	543
CV(%)	12.88	8.67	13.11	7.49	8.1
Bio-inoculants					
S_O	12.47	11.20	22.67	270.22	6571
S_1	16.60	15.31	26.12	434.11	7998
S_2	15.43	14.26	25.30	401.22	7709
S_3	14.60	13.44	24.52	390.00	7339
S_4	13.69	12.43	23.50	338.39	6910
S_5	13.99	12.72	23.59	352.22	7173
S.Em	0.68	0.30	0.85	19.11	166.3
C.D (p=0.05)	1.96	0.87	NS	55.20	480
CV (%)	14.37	6.86	10.7	12.73	6.8
Interaction					
M X S	N.S				
S X M	N.S				

M_1 – No water stress (control), M_2 – Water stress at knee high stage, M_3 – Water stress at reproductive stage ; S_O – VAM (Vesicular arbuscular mycorrhizae fungi), S_1-PSB (Phosporous solubilizing bacteria), S_3- *Bacillus spp*., S_4-*Azotobacter*, S_5-*Azospirillu*

Conclusion

Based on the above results and discussion, it can be concluded that under normal irrigation conditions, as well as water stress conditions at knee high and reproductive stage, and inoculation with Mycorrhiza had the best effect on the measured characteristics and increased yield attributes and grain yield. The use of biological fertilizers also modulated the effect of drought stress and reduced its negative effects. Thus, it is suggested that in case of drought stress, using Mycorrhiza biofertilizers, grain yield of maize can be enhanced and the negative effects of drought stress can be mitigated.

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Conflict of Interest. None.

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