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Original Article

Impact Of Organic Fertilizers and Microbial Inoculation on Soil Structure, Root Development and Maize Yield

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ABSTRACT

Background: *Zea mays* L., commonly known as maize, is a crucial cereal crop for human consumption and is globally ranked third, following wheat and rice. **Objectives:** This study aimed to investigate the impact of organic fertilizers and microbial inoculation on soil structure, root development, and maize yield. **Methods:** A pot experiment was conducted at the Research Area of the Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad, using a completely randomized design. Three levels of organic amendments (farmyard manure and fly ash) at 0, 5, and 10 Mg ha-1, combined with five different microbial inoculants, were applied. Hybrid maize (Shahenshah) was grown with recommended inorganic fertilizers. Soil physical parameters, plant growth parameters, and maize yield were measured and analyzed. **Results:** The results demonstrated that the combination of organic amendments and microbial inoculation significantly influenced the percentage of water-stable aggregates, indicating improved soil structure. Higher levels of organic matter addition led to increased CO2 emission, microbial activity, and decomposition, resulting in the formation of larger water-stable aggregates (>2.0 mm). The combined application of specific microbial inoculants and organic amendments enhanced microbial activity, promoting soil aggregate stability. Additionally, the study evaluated plant growth parameters, including plant and root fresh and dry weights, plant height, leaf area index (LAI), root length, and root length density (RLD). The combined application of organic fertilizers and microbial inoculants resulted in improved root development, increased plant biomass, and enhanced maize yield. **Conclusion:** Utilization of organic fertilizers and microbial inoculation had a significant positive impact on soil structure, root development, and maize yield. These findings emphasize the importance of incorporating organic amendments and beneficial microbes in agricultural practices to enhance soil quality and promote sustainable crop production.

INTRODUCTION

Zea mays L., commonly known as maize, is a crucial cereal crop for human consumption and is globally ranked third, following wheat and rice. This crop is commonly referred to as "The monarch of cereals" due to its impressive annual yield of 600 million metric tons [1] and its widespread cultivation across 118 million hectares globally. This cereal crop is crucial to the sustenance of millions of individuals globally, providing them with access to fundamental food sources. The primary constituent of maize grain is starch, accounting for 80.8% of its composition. Protein is the second most abundant component, comprising 10.5% of the grain, followed by oil at 2.7%, fiber at 2.8%, sugar at 2%, and ash at 1.2%. Maize cultivation in Pakistan spans across 0.9 million hectares of land and yields an annual production of 1.13 million hectares. This crop contributes 0.4% to the country's gross domestic product and 2.1% to its agricultural value added, as reported by the GOP in 2021. According to a study, the regions of Punjab and KPK hold significant importance in the production of maize in Pakistan, accounting for over 90% of the nation's entire maize yield [2].

Pakistan soils are poor structure with low water retention capability, more compactness and low organic matter because of arid and semi-arid climates in most of the regions. Soil physical health and biochemical properties were degraded due to consistent use of chemical fertilizers and less use of organic amendments. Different organic amendments e.g., crop residues, farm waste, compost, sugarcane bagasse, molasses and manure are used to improve the soil physical health and crop productivity [3]. Organic additives not only improve the soil carbon pool but also reduce the stock of synthetic fertilizer application. More aggregate stability and less risk of erosion was found in the soil treated with organic matter [4].

In Pakistani soils low organic matter so need to improve the organic matter status of the soil though use of biological residues. Organic matter converts to humus. It is a source of nutrient plants and microorganisms get these nutrients directly or indirectly from the soil fulfill the requirement, reducing the leaching losses and evapotranspiration loss from the soil. Organic matter release nutrients very slowly. It plays an important role in enhancing the soil fertility level and improves the soil physical health [5]. Frequently use of chemical fertilizer damaged the soil but organic manure and other sources of manure waste, poultry, and sheep manure slow but build up the organic level and enhance the soil aggregate stability of the soil [6].

Microorganisms help to decompose organic matter and turn the material completely decompose all the material produce C use microbes for decomposition [8]. Microbes in the soil directly connect with roots penetration and elongation [9]. Microbes produce gum like material bind the soil particles and helps producing the nutrient like phosphors and nitrogen in the soil this process was slow to enhance this process combination of microbes and organic matter were addition for improving the soil health, enhance the root penetration, plant growth component microbes only use were slowly reactive but with organic matter this process will speed up.

Microorganisms in the soil rhizosphere producing sticky material which binding the soil mineral particles with each other cohesion forces between the particles enhance and plant expect these chemicals for roots which increasing the microbial activity, biomass and colonies in the soil resulting increasing the aggregation of soil structure. Due to the decomposition of organic carbon in the soil because of increasing the soil nutrient capacity, improving the yield of plant population and growth [10].

In agriculture there was a many system to improving the plant growth and productivity but in organic agriculture feed the soil increasing the soil fertility, improving the soil structure and enhance the nutrient statues of the soil. These all were possible thought the addition of organic material. Active or divers biotic community, plant growth and essential plant nutrients these all provides under the foundation of organic farming increasing the soil fertility and improving the soil health. Organic agriculture feeds the soil, but other agriculture systems feed the plant fully concentrate on plant population and its productivity.

Application of organic manure improves the crop yield and improves the chemical and biological properties. there were different types of organic manure uses like green, cow dung, compost and waste which ultimately increasing the crop productivity. Integrated use of organic and inorganic fertilizers supplies a good amount of plant nutrients and therefore can contribute to crop yields. as compared to chemical fertilizers. Without decline the soil fertility get maximum crop yield and better nutrient availability increasing thought the use of organic manure. Due to intensive cropping system soil safer nutrient depletion [10]. Inorganic fertilizer affects crop yield instantly but temporarily while the effect of organic amendments is for long term [11].

It is essential to increase and maintain crop yield to ensure that soil fertility is preserved through the assimilation of organic matter. A wide variety of chemical, physical, and biological soil parameters are affected, either directly or indirectly, by the presence of soil organic matter (SOM). To increase the fertility of the soil, organic resources (farmyard manure and fly ash) and microbial inoculants are used to improve the soil's physical, chemical, and biological properties.

MATERIAL AND METHODS

A study utilizing a pot experiment was carried out at the Research Area of the Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad, utilizing a completely randomized design (CRD) to evaluate the impact of microbial inoculation and varying levels of organic amendments.

The experiment consisted of three replications and three levels of FM and fly ash 0, 5 and 10 Mg ha^{-1} and five different microbials i.e., M_2, M_3, M_{11}, M_{19}, and M_{22}. Hybrid maize (Shahenshah) was sown and recommended dosage of inorganic fertilizers @ 250: 100: 90 kg ha^{-1} (NPK) was applied to the experimental pots. Before sowing, collect the soil, sample and save it for pre analysis.

Soil Aggregate Extraction: The process of wet sieving through various sizes of sieves (2mm, 1mm, 0.5mm, 250 µm and 100 µm) was employed to fractionate soil aggregates using an aggregate stabilizer, as described by Six et al. [12]. The process of Fractionation was carried out using the Soil Aggregate Analyzer. Collect a sample of the soil. Soil samples weighing 60 grammes and sieved through a 3 mm mesh were subjected to a 24-hour soaking period in de-ionized water at a temperature of 20 ± 20 °C. Following a 24-hour period, the instrument's aggregate stabilizer was operated for one hour. The soaked soil sample was subsequently positioned atop a 2 mm sieve, and a sequence of sieves were interconnected. These sieves were then subjected to automatic vertical oscillations of 3 cm at a rate of 30 oscillations per minute for a duration of one hour. Five distinct categories of aggregated specimens were gathered, subjected to desiccation in an oven at a temperature of 60 ° C, and quantified in terms of their mass.

Soil Bulk Density (ℓb): Bulk density is measured by dividing the mass of oven dry soil per unit volume of soil included pore spaces. Bulk density of the soil measured through using the core sampling. Take the core sampler press in the pot soil for 15 to 30 cm depth completely fill the core. Slowly removing the core from the soil place carefully with the help of knife remove the soil add it in steel cylinder led it and placed in the over 105 ^{o} C for 24 hours. After overnight take the sample and weight it.

Bulk density = (mass of oven dry soil) / (Volume of soil including pore spaces)

Total Porosity (Φ): The total porosity of the soil (Φ) was obtained from its bulk density (ℓb) and particle density (ℓp) by the following formula.

$\Phi = 1 - (\ell b / \ell p) * 100$

Organic Matter concentration of soil: By using the following method described was used to determine the soil organic matter. A 500 mL flask was taken 1g 2mm sieved soil added in which. Take H_2SO_4 concentrated in flask 20ml for digestion and after this 10 ml potassium dichromate were added and allowed to stand for 30 mints until cool it. After 30 mint 200ml distilled water was added and allowed to cool it and then orthophoshoric acid 10ml added and mixed it well. added 5-10 drops of diphenylamine indicator mixed it and titrated against 0.5 M Ferrous ammonium sulfate solution, titrate it until the color is changed from violet blue to green. Blank samples were also prepared without soil, but all other chemicals were added to compare the other readings.

% Oxidizable organic carbon = ((Vblank - Vsample) x 0.3 x M) / (Weight of soil (g))

% Organic matter (w / w) = 1.724 x% Oxidizable organic carbon

Plant and root fresh weight (g): Plants were harvested from each pot and the roots are washed out of soil and weight immediately using an electric weight balance to take the fresh weight.

Plant and root dry weight: Both are placed in oven at 65 ^{o} C for 24 hours weight as dry weight in gram.

Plant Height (cm): At the germination stage plants were harvested before harvesting measured the height of the plant with the help of tape and after measuring take the average for every replication. Measured it plant tip to soil level. Its measuring unit is cm

Leaf Area Index (LAI): The leaf area index (LAI) was measured by formula

Leaf area = L × W × A

Root Length (cm): The roots were subjected to scanning using an HP Scanjet-8200 scanner, and subsequent length measurements were obtained through the use of computerized software.

Root length density (RLD): Subsequently, the root length was quantified and divided by the root volume to obtain the root length density.

RLD = root length / volume of pot

RESULTS AND DISCUSSION

Soil physical parameters: Organic amendments combined with microbial inoculation significantly influence the percentage of water stable aggregates. Due to the presence of cohesion forces between the organic material and mineral particles decreasing the breakdown of aggregates resulting in improving the soil structure as a significantly increasing the water stabile aggregates. It was determined with wet process by aggregates stability analyzer and data were recorded as shown in the (Table 1).

Macro aggregates > 2mm: (Table 1) showed the effect of microbial inoculation and organic amendments on> 2.0 mm water stable aggregates (macro aggregates). When higher amount of organic matter were added to the soils (10 Mg ha-1), a higher rate of CO_2 emission increasing and microbes secreted gam like material and used C present in the stock decompose the organic matter and greater supply of source of energy and nutrients to the plant, combine application of microbes and organic amendments enhance the microbial activity and decomposition resulting attraction between the mineral particles increasing, which stimulates soil Microbial activity resulting improve the aggregate stability of the soil. (17.87%) of the> 2.0 mm water stable aggregates found in (FM2M11) that was 17.84% higher than control, followed by (FM2M22), (FM1M11), (FM2M2), (FM2M3), (FA1M11) and (FA1M19) with their values of> 2.0 mm water stable aggregates were 17.63, 17.36, 16.96, 16.88, 15.25 and 15.13% respectively, these values Were higher than the control. 2.0-1.0mm: (Table 1) also showed the effect of microbial inoculation and organic amendments significantly improve the wet aggregate stability of the soil on 2.0 - 1.0 mm water stable aggregates (macro aggregates). The 2.0-1.0 mm aggregates exhibited a minimum value of 6.83% in the presence of (FA1M22), which was comparatively lower than the control value of 11.46%. Conversely, the maximum value of 19.86% for the 2.0-1.0 mm aggregates was observed in the presence of (FM2M11), which was higher than the control. Microscopic clusters measuring between 1 and 0.5 millimeters in size, commonly referred to as micro aggregates. Progressing towards the microscale, the initial cluster comprises of water stable aggregates measuring 1.0-0.5 mm, as presented in the table. The study observed the effects of microbial inoculation and organic amendments on the 1.0-0.5 mm size (19.26%) of water stable aggregates. The application of these factors under (FA2M22) resulted in a combined impact, which was found to be 13.01% lower than the control group (CTRL). The sample exhibits a water stability of 13.06% for aggregates within the 1.0-0.5 mm size range. The water stability of 1.0-0.5 mm aggregates in specimens (FA1M2), (FM1M3), (FM2M2), (FA1M11) and (FM2M11) were found to be 27.13%, 26.77%, 26.03%, 25.93%, 25.73% and 25.23% respectively. These values were higher than the control. The highest percentage (27.13%) of water-stable aggregates measuring between 1.0-0.5 mm was observed in the (FA1M2) treatment, which was greater than that of the control (CTRL).

Table 1: Effect of microbial inoculation on water stable aggregates under different organic amendments

Treatments	AGR1	AGR2	AGR3	AGR4	AGR5
CTRL	$4.06^{g}\pm.17$	$11.46^{e}\pm.24$	$13.06^{f}\pm.21$	$38.83^{ab}\pm1.26$	$35.58^{a}\pm.75$
FM1M2	$9.87^{ab}\pm.56$	$14.3^{cd}\pm.19$	$17.55^{d}\pm.39$	$34.93^{ab}\pm1.09$	$23.37^{a}\pm.98$
FM1M3	$8.57^{ab}\pm.45$	$14.03^{cd}\pm.34$	$17.703^{c}\pm.51$	$34.96^{ab}\pm1.29$	$24.66^{ab}\pm.64$
FM1M11	$17.36^{ab}\pm.56$	$13.25^{cd}\pm.23$	$17.73^{c}\pm.38$	$34.59^{bc}\pm1.14$	$24.53^{ab}\pm.66$
FM1M19	$10.47^{ab}\pm.23$	$14.34^{cd}\pm.19$	$16.11^{e}\pm.34$	$34.48^{bc}\pm.62$	$24.59^{abc}\pm.54$
FM1M22	$7.33^{abc}\pm.28$	$10.24^{cd}\pm.24$	$21.48^{ab}\pm.31$	$32.54^{cd}\pm1.51$	$28.48^{abc}\pm1.32$
FM2M2	$16.96^{abc}\pm.36$	$19.3^{ab}\pm.27$	$25.93^{ab}\pm.30$	$20.46^{e}\pm.75$	$17.35^{abc}\pm.95$
FM2M3	$16.88^{a}\pm.10$	$19.62^{ab}\pm.28$	$26.03^{ab}\pm.49$	$20.24^{e}\pm.74$	$17.16^{abc}\pm.40$
FM2M11	$17.87^{a}\pm.15$	$19.86^{a}\pm.69$	$25.36^{a}\pm.38$	$37.24^{a}\pm.60$	$18.46^{abc}\pm.66$
FM2M19	$13.57^{a}\pm.30$	$19.71^{ab}\pm.17$	$24.39^{ab}\pm.22$	$20.81^{bc}\pm.18$	$21.54^{abc}\pm1.07$
FM2M22	$17.63^{a}\pm.34$	$9.63^{a}\pm.27$	$22.96^{ab}\pm.32$	$33.18^{e}\pm.32$	$26.86^{abc}\pm1.56$
FA1M2	$14.64^{a}\pm.43$	$19.67^{ab}\pm.10$	$27.13^{a}\pm.25$	18.67e±.34	$16.80^{abc}\pm1.01$
FA1M3	$14.64^{a}\pm.34$	$19.23^{ab}\pm.28$	$26.77^{a}\pm.18$	$18.73^{e}\pm.38$	$17.57^{abc}\pm1.21$
FA1M11	$15.13^{cd}\pm.13$	$19.25^{ab}\pm.13$	$25.73^{ab}\pm.54$	$17.77^{e}\pm.75$	$22.23^{abc}\pm1.20$
FA1M19	$15.25^{de}\pm.21$	$19.05^{bc}\pm.25$	$23.61^{bc}\pm.74$	$20.29^{de}\pm.66$	$21.77^{abc}\pm.88$
FA1M22	$4.02^{bc}\pm.16$	$6.83^{cd}\pm.20$	$10.53^{f}\pm.91$	$35.16^{bc}\pm1.62$	$22.48^{abc}\pm1.53$
FA2M2	$6.25^{fg}\pm.26$	$12.33^{cd}\pm.19$	$12.13^{f}\pm.62$	$39.02^{ab}\pm1.15$	$30.26^{abc}\pm1.96$

FA2M3	7.2^{ef}±.38	11.09^{de}±.60	12.57f±.68	41.83^{ab}±1.46	27.25^{bc}±1.91
FA2M11	6.87^{ef}±.15	11.61^{de}±.19	12.88^{f}±.71	42.06^{ab}±.60	26.56^{bc}±1.48
FA2M19	7.32^{de}±.15	11.19^{de}±1.16	13.12^{f}±1.11	34.92^{ab}±1.44	33.42^{c}±2.61
FA2M22	6.27^{de}±1.09	9.74^{cd}±1.11	13.01^{f}±.52	36.84^{ab}±.74	34.48^{c}±1.58

Table 2 did not show any treatment in the smallest category that had an impact on soil bulk density as a result of microbial inoculation and organic amendments. The emission of CO2 is increasing due to the stimulation of microbial activity as a result of the increase in organic material (10 Mg ha^{-1}). The bulk density of (FM1M2) and (FM1M3) samples were observed to be lower than the control sample (CTRL), with values of 1.29 g cm-3 and 1.37 g cm-3, respectively. Similarly, the bulk density of the sample with a density of 1.36 g cm-3 was also lower than the control sample (CTRL) with a bulk density of 1.47 g cm-3. Soil Organic Matter (SOM) constitutes a crucial component in the assessment of soil well-being. Table 2 presents data indicating that the introduction of microbial inoculation and organic amendments resulted in a statistically significant impact on the soil organic matter (SOM). The application of combine (FM1M2) resulted in a lower SOM value of 0.31 compared to the SOM value of 0.38% observed in the (CTRL) treatment. Another combination of treatments resulted in a positive impact on the soil organic matter (SOM). The combination of FM2M11 with SOM resulted in a positive response of 1.86%, which exhibited a higher value compared to the control. The results presented in Table 2 demonstrate the impact of microbial inoculation and organic amendment on the vertical growth of maize plants.

Table 2: Effect of microbial inoculation on bulk density, porosity, SOM under different organic amendments

Treatments	SOM (%)	BD (g cm^{-3})	Porosity (Φ)
CTRL	0.38^{r}±.01	1.47 ^{a}±.06	0.54^{a}±.10
FM$_1$M$_2$	0.31^{q}±.01	1.29 ^{a} ±.01	0.55^{ab}±.08
FM$_1$M$_3$	0.47^{p}±.01	1.37 ^{a} ±.001	0.55^{ab}±.06
FM$_1$M$_{11}$	0.53^{op}±.01	1.37 ^{a} ±.001	0.57^{ab}±.04
FM$_1$M$_{19}$	0.58^{no}±.005	1.38 ^{a} ±.003	0.59^{ab}±.01
FM$_1$M$_{22}$	0.64^{m}±.01	1.38 ^{a} ±.0003	1.05^{ab}±.04
FM$_2$M$_2$	0.70^{l}±.08	1.39 ^{a} ±.0012	1.72^{abc}±.05
FM$_2$M$_3$	0.78^{k}±.01	1.39 ^{a} ±.0008	1.7^{ab}±.02
FM$_2$M$_{11}$	1.86^{a}±.01	1.36 ^{a} ±.003	1.69^{ab}±.03
FM$_2$M$_{19}$	0.93^{h}±.01	1.40 ^{a} ±.001	1.68^{ab}±.05
FM$_2$M$_{22}$	0.98^{g}±.01	1.4 ^{a} 1±.001	1.26^{a}±.16
FA$_1$M$_2$	1.03^{g}±,01	1.4 ^{a} 1±.001	1.68^{a}±.05
FA$_1$M$_3$	0.45^{f}±.01	1.42 ^{a} ±.001	1.65^{ab}±.04
FA$_1$M$_{11}$	0.42^{f}±.01	1.43 ^{a} ±.001	1.62^{ab}±.02
FA$_1$M$_{19}$	0.40^{e}±.02	1.43 ^{a} ±.001	1.65^{ab}±.03
FA$_1$M$_{22}$	0.51^{d}±.01	1.45 ^{a} ±.012	0.58^{ab}±.03
FA$_2$M$_2$	0.45^{cd}±.01	1.46 ^{a} ±.001	0.59^{bc}±.02
FA$_2$M$_3$	0.52^{c}±.01	1.47 ^{a} ±.001	0.60^{cd}±.01
FA$_2$M$_{11}$	0.62^{b}±.02	1.40 ^{a} ±.12	0.55^{d}±.05
FA$_2$M$_{19}$	0.70^{ab}±.008	1.42 ^{a} ±.06	0.51^{ef}±.06
FA$_2$M$_{22}$	0.76^{ij}±.008	1.41 ^{a} ±.006	0.50^{f}±.02

The statistical analysis of the data revealed a significant impact of the treatments on the plant height. The maximum height of the plants was observed in (FM2M11) at 157.6 cm, which was significantly higher than the control group (CTRL) with a height of 83.96 cm. The plant height of the combine application (FA1M11) was found to be the second highest with a value of 155.8 cm, which was greater than that of the control (CTRL). The plant height of the third treatment (FM2M2) was 153.66 cm, which ranked third among all treatments. This height was greater than that of the control group. The findings presented in Table 3 illustrate the impact of microbial inoculation and organic amendments on the fresh weight of maize plants. The statistical analysis of the data reveals a significant impact of the treatments on the fresh weight of the plants. The results indicate that the highest plant weight was observed in... The impact of microbial inoculation and organic amendments on the dry weight of maize plants was documented in Table 3. The statistical analysis of the data reveals a significant impact of the treatments on the dry weight. The highest dry weight of 1.65g was observed in FM2M11, which was greater than the control (CTRL) dry weight of 1.50g. The plant biomass analysis revealed that the combination treatment (FA1M3) exhibited the second highest dry weight of 1.58g, surpassing the control treatment. The third treatment (FA1M2) exhibited the third highest dry plant weight of 1.55 g, surpassing that of the control group. The effects of microbial inoculation and organic amendments on the leaf area index (LAI) of maize were demonstrated in Table 3. Statistical analysis of the data revealed a noteworthy impact of treatments on leaf area index (LAI). The combined treatment (FM2M11) exhibited the highest LAI of 421cm2, which was significantly greater than the control treatment (CTRL) with a LAI of 138.46cm2. The combination of (FA1M2) exhibited a second maximum Leaf Area Index (LAI) value of 417.93cm2, surpassing that of the control. The plant species designated as FM2M2, FM2M2, FM2M2, and FM2M22 exhibited a lower Leaf Area Index (LAI) in comparison to other species. The LAI values for these species were recorded as 398.86, 332.36, 328.13, and 308.33cm2, respectively, which were found to be greater than the control. However, the alternative pairings including (FA1M11), (FM1M22), and (FA1M3) exhibited a favorable impact on the leaf area index (LAI) of maize. The LAI values of these pairings were 294.53, 241.33, and 232.73cm2, respectively, which surpassed that of the control.

Table 3: Effect of microbial inoculation on plant height, plant fresh and dry weight under different organic amendments

Treatments	Plant Height (cm)	PFW(g)	PDW(g)	Leaf AI (cm^2)
CTRL	$96.07^{de}\pm2.26$	$7.01^{f}\pm.14$	$1.50^{e}\pm.03$	$138.46^{d}\pm16.45$
FM_1M_2	$90^{bc}\pm2.76$	$5.66^{bc}\pm.11$	$1.14^{bc}\pm.02$	$172.6^{cd}\pm7.25$
FM_1M_3	$90.63^{bc}\pm4.28$	$6.27^{cd}\pm.34$	$1.25^{bc}\pm.06$	$149.2^{cd}\pm16.08$
FM_1M_{11}	$89.16^{bc}\pm2.20$	$5.48^{cd}\pm.18$	$1.10^{cd}\pm.03$	$167.3^{bc}\pm14.21$
FM_1M_{19}	$85.73^{cd}\pm3.57$	$5.59^{cd}\pm.47$	$1.12^{bc}\pm.09$	$155.8^{bc}\pm8.38$
FM_1M_{22}	$135.46^{ab}\pm1.99$	$5.78^{cd}\pm.18$	$1.16^{bc}\pm.03$	$241.33^{bc}\pm10.71$
FM_2M_2	$153.66^{ab}\pm1.97$	$7.71^{ab}\pm.26$	$1.54^{ab}\pm.05$	$328.13^{ab}\pm19.54$
FM_2M_3	$149.36^{ab}\pm4.45$	$7.60^{ab}\pm.33$	$1.52^{ab}\pm.06$	$332.36^{ab}\pm30.18$
FM_2M_{11}	$157.6^{a}\pm3.27$	$8.74^{a}\pm.25$	$1.65^{a}\pm.07$	$421.63^{a}\pm45.20$
FM_2M_{19}	$148.96^{ab}\pm4.29$	$6.86^{ab}\pm.31$	$1.37^{ab}\pm.06$	$317.46^{ab}\pm28.1$
FM_2M_{22}	$138.73^{ab}\pm2.50$	$5.99^{bc}\pm.31$	$1.20^{ab}\pm.06$	$308.33^{ab}\pm32.63$
FA_1M_2	$154.5^{ab}\pm3.41$	$8.24^{ab}\pm.36$	$1.55^{ab}\pm.05$	$417.93^{ab}\pm41.24$
FA_1M_3	$151.06^{ab}\pm3.06$	$7.90^{ab}\pm.41$	$1.58^{ab}\pm.08$	$232.73^{bc}\pm21.94$
FA_1M_{11}	$155.8^{ab}\pm5.62$	$7.09^{ab}\pm.07$	$1.42^{ab}\pm.01$	$294.53^{ab}\pm29.90$
FA_1M_{19}	$152.9^{ab}\pm2.83$	$7.72^{ab}\pm.25$	$1.54^{bc}\pm.05$	$398.86^{bc}\pm7.42$
FA_1M_{22}	$60.26^{ab}\pm2.63$	$4.98^{ab}\pm.28$	$0.99^{bc}\pm.05$	$173.96^{bc}\pm22.78$
FA_2M_2	$61.26^{f}\pm.93$	$5.82^{cd}\pm.64$	$1.16^{ab}\pm.12$	$177.76^{bc}\pm9.04$
FA_2M_3	$58.06^{f}\pm.1.97$	$5.35^{de}\pm.42$	$1.07^{de}\pm.08$	$160.23^{cd}\pm14.30$
FA_2M_{11}	$56.06^{f}\pm2.88$	$5.63^{bc}\pm.57$	$1.13^{bc}\pm.11$	$150.13^{cd}\pm19.43$
FA_2M_{19}	$62.66^{f}\pm2.60$	$5.32^{de}\pm.17$	$1.06^{de}\pm.03$	$186.16^{bc}\pm15.22$
FA_2M_{22}	$77.9^{ef}\pm9.45$	$5.21^{ef}\pm.12$	$1.09^{cd}\pm.06$	$172.56^{bc}\pm2.79$

Following root washing, the root fresh weight was measured and the resulting data, as presented in Table 4, depicts the impact of microbial inoculation and organic amendments on the root fresh weight of maize. Additional statistical analysis revealed that the treatments exhibited significance. The highest fresh weight of roots was observed in plants subjected to combined application (FM2M11), with a weight of 15.80g, surpassing the control treatment (CTRL) with a root fresh weight of 4.54 g. The combination under FM2M2 ranked second with a root weight of 15.62 g, which was also higher than the control. The roots were subjected to an oven drying process at 65°C, following which their dry weight was measured. Table 4 illustrates the impact of microbial inoculation and organic amendments on the dry weight of maize roots. Additional statistical analysis revealed that the treatments had a significant impact on the dry weight of the roots. The plants that received the combined application of (FM2M11) exhibited the highest root dry weight of 1.72 g, whereas the (CTRL) plants had a lower root dry weight of 0.47 g. The combination of FM2M3 exhibited a second-ranked performance with a root weight of 1.7 g, which was higher than that of the control. The length of roots was measured using a hp-Scanjet-8200 scanner. Table 4 displays the impact of microbial inoculation and organic amendments on the root length of maize. Additional statistical examination revealed that the treatments had a significant impact on the length of the roots. The plants that received the combined application of (FM2M11) exhibited a maximum root length of 44.69 cm, which was significantly greater than the root length of 9.26 cm observed in the (CTRL) group. In the second position, there existed an alternative pairing of (FM2M3) and (FA1M2) that exhibited a root length of 43.55 and 43.06 cm, respectively. This measurement was 75.58% greater than the control group. The combined application of FA1M3 and FM2M2 resulted in a third-ranked growth performance with a root length of 41.61 and 41.55 cm, respectively. This exhibited a 41.78% increase compared to the control group. The root length density (RLD) of maize was assessed by utilizing a scanner (hp-Scanjet-8200) to scan the roots and dividing the root length by the root density. The findings presented in Table 4 demonstrate the impact of microbial inoculation and organic amendments on the RLD of maize. Additional statistical examination revealed that the interventions applied to the root lesion nematode (RLD) had a significant impact. The plants that received the (FM2M11) treatment exhibited the highest root length density (RLD) with a value of 2.27 mm mm^{-3}. This RLD value was 48% greater than that of the (FA1M3) treatment and the control group (CTRL), which had an RLD of 1.78 mm mm^{-3}. The combination (FM1M22) exhibited a root length of 2.21 mm mm^{-3}, surpassing that of the control and securing second place. A different combination, namely FM2M22, exhibited a root length of 2.13 mm mm-3, surpassing that of the control and ranking third in the experiment.

Table 4: Effect of microbial inoculation on plant height, fresh and dry weight under different organic amendments

Treatments	RFW(g)	RDW(g)	Root length cm	Root LD mm mm-3
CTRL	$4.54^{de}\pm.40$	$0.47^{e}\pm.10$	$9.26^{cd}\pm1.42$	$1.78^{cd}\pm.09$
FM$_1$M$_2$	$4.96^{cd}\pm.26$	$0.55^{de}\pm.08$	$9.64^{cd}\pm1,23$	$0.65^{d}\pm.10$
FM$_1$M$_3$	$4.76^{cd}\pm.19$	$0.55^{de}\pm.06$	$11.73^{cd}\pm.96$	$0.82^{cd}\pm.08$
FM$_1$M$_{11}$	$4.96^{cd}\pm.07$	$0.57^{cd}\pm.04$	$9.95^{cd}\pm.55$	$0.70^{cd}\pm.07$
FM$_1$M$_{19}$	$4.60^{cd}\pm.30$	$0.59^{de}\pm.01$	$11.29^{cd}\pm.86$	$0.82^{cd}\pm.04$
FM$_1$M$_{22}$	$10.48^{cd}\pm.23$	$1.05^{bc}\pm.04$	$34.73^{ab}\pm1.11$	$2.21^{a}\pm.05$
FM$_2$M$_2$	$15.62^{a}\pm.28$	$1.65^{ab}\pm.03$	$41.55^{a}\pm.45$	$1.99^{ab}\pm.06$
FM$_2$M$_3$	$15.38^{a}\pm.34$	$1.7^{ab}\pm.02$	$43.32^{a}\pm.70$	$1.85^{ab}\pm.04$
FM$_2$M$_{11}$	$15.80^{a}\pm.28$	$1.72^{a}\pm.05$	$44.69^{a}\pm.62$	$2.27^{a}\pm.12$
FM$_2$M$_{19}$	$14.88^{a}\pm.40$	$1.68^{ab}\pm.05$	$40.1^{ab}\pm1.05$	$1.95^{ab}\pm.03$
FM$_2$M$_{22}$	$9.34^{ab}\pm.22$	$1.26^{ab}\pm.16$	$30.86^{ab}\pm1.05$	$2.13^{a}\pm.07$
FA$_1$M$_2$	$14.00^{a}\pm.38$	$1.68^{ab}\pm.05$	$43.06^{a}\pm.78$	$2.11^{a}\pm.07$
FA$_1$M$_3$	$13.16^{ab}\pm.31$	$1.65^{ab}\pm.04$	$41.61^{a}\pm1.18$	$2.00^{a}\pm.08$
FA$_1$M$_{11}$	$14.12^{a}\pm.17$	$1.62^{ab}\pm.02$	$40.39^{ab}\pm.67$	$2.09^{a}\pm.03$
FA$_1$M$_{19}$	$13.46^{cd}\pm.31$	$1.65^{bc}\pm.03$	$40.03^{bc}\pm1.02$	$1.93^{bc}\pm.05$
FA$_1$M$_{22}$	$3.18^{ab}\pm.36$	$0.58^{bc}\pm.03$	$7.81^{ab}\pm.55$	$0.78^{bc}\pm.04$
FA$_2$M$_2$	$3.38^{de}\pm.26$	$0.59^{cd}\pm.02$	$6.92^{d}\pm.29$	$0.64^{d}\pm.05$
FA$_2$M$_3$	$3.52^{de}\pm.14$	$0.60^{cd}\pm.01$	$7.33^{d}\pm.27$	$0.72^{d}\pm.02$
FA$_2$M$_{11}$	$3.36^{de}\pm.21$	$0.55^{de}\pm.05$	$7.84^{cd}\pm.31$	$0.78^{cd}\pm.06$
FA$_2$M$_{19}$	$2.70^{e}\pm.24$	$0.51^{e}\pm.06$	$7.22^{d}\pm.38$	$0.64^{d}\pm.03$
FA$_2$M$_{22}$	$3.68^{ef}\pm.31$	$.503^{e}\pm.02$	$9.24^{cd}\pm1.38$	$0.66^{d}\pm.06$

CONCLUSION

The study results indicated that the application of exopolymer producing microbial inoculants along with the application of organic amendments not only improves the growth parameters of plants but also have a strongly positive impact on physical parameters of soil especially soil aggregate stability. Therefore, it is strongly recommended to use microbial inoculants with organic manures to stabilize soil structure and physical characteristics.

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