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EFFECT OF LIQUID ORGANIC FERTILIZERS AND SOIL
MOISTURE STATUS ON SOME BIOLOGICAL AND PHYSICAL
PROPERTIES OF SOIL

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Abstract. This study was conducted to evaluate the effects of liquid organic fertilizers (LOFs) and soil moisture status on some biological and physical properties of postharvest soil of maize cultivation. For this purpose, a factorial greenhouse experiment was performed based on the completely randomized design with three replications. Treatments consisted of five levels of LOFs (control, vermicompost tea, vermiwash, plant growth-promoting rhizobacteria [PGPR] enriched vermicompost tea and PGPR enriched vermiwash) and three levels of soil moisture status (field capacity [FC], 0.8 FC and 0.6 FC). The results showed LOFs caused an increase of soil biological properties (soil microbial respiration, soil microbial biomass, dehydrogenase activity and the number of aerobic heterotrophic bacteria) and the improvement of soil physical condition. LOFs increased aggregate stability, hydrophobicity and total porosity, while decreased bulk density and soil penetration resistance. Increasing water stress levels reduced soil biological activity and made soil physical properties more unfavorable. In general, LOFs improved soil conditions by enhancing soil physical and biological properties and decreased the negative effects of water stress. In addition, results showed that LOFs enriched with PGPR could be more effective than non-enriched ones.

Keywords: maize, plant growth-promoting bacteria, postharvest soil, vermicompost tea, vermiwash

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INTRODUCTION

Water deficit is the most common environmental stress causing great damages in plant growth and productivity and has the potential to worsen soil properties (Zhang *et al.* 2018). Drought significantly changed soil properties in the topsoil layer and caused a significant decline in soil aggregate stability, total soil organic carbon, and nitrogen concentration (Zhang *et al.* 2019). It exerts a major influence on microbial physiology and function (Kempf and Bremer 1998). Size and microbial biomass and soil basal respiration can be affected negatively under drought stress (Hueso *et al.* 2012). The results of laboratory and field research show that soil moisture is an important factor in population and microbial activity soil and affects the population and their activity by reducing the access of soil microorganisms to nutrients or their death (Klute 1982). Due to the great effect of physical properties on other soil microbial activities, any factor that changes the physical properties of soil affects the biochemical and biological properties of soil (Kohls *et al.* 1999).

The use of organic fertilizers and their derivatives along with irrigation may be the ways of coping with water stress. Organic fertilizers are one of the most important soil fertility factors which lead to improving soil properties (Werner 1997). They provide nutrients for the plant (Moridi *et al.* 2019), increase soil biotic activities, diminish bulk density, form stable aggregates, increase water holding capacity and soil exchange capacity, increase porosity and avoid soil compaction and destruction caused by erosion, and improve infiltration rates (Garcia *et al.* 1991). It has a considerable effect on reducing the negative effects of drought stress (Solinas *et al.* 1996). Organic fertilizers typically increase soil microbial biomass through the supply of C-rich organic compounds to the generally C-limited microbial communities in arable soils (Knapp *et al.* 2010). Incorporation of organic fertilizers can also increase microbial activity in soils between 16% and 20% as compared to inorganic fertilizers (González *et al.* 2010). Increases in the enzyme activities involved in the release of the main plant macronutrients with organic fertilizers have also been reported in several studies (Marinari *et al.* 2000). Vermicompost and its derivatives are known as bio-organic fertilizers which are environmentally friendly and important for soil health (Ansari and Ismail 2012). Vermiwash and vermicompost tea as liquid organic fertilizers may consist of different enzymes, plant regulatory hormones, organic acids, nutrients, and beneficial soil microorganisms. These fertilizers can be used either in soil or foliar spray (Zambare *et al.* 2008). In our previous research, the results indicated that vermicompost tea produced from all three vermicompost types was richer in terms of macro and micro-nutrients, organic carbon, and C/N toward the vermiwash produced from the same vermicompost (Zarei *et al.* 2017). Pant *et al.* (2011) reported that vermicompost tea significantly increased microbial respiration and dehydrogenase enzyme activity in the soil. The increased water holding capacity, porosity, and

moisture content were noticed in a mixture of vermicompost and vermiwash treated pots. Esakkiammal *et al.* (2015) reported that the combination of vermicompost and vermiwash caused the maximum positive effects on the growth and yield of lablab beans. The aqua organic fertilizers proved to be an effective fertilizer that contributed to growth and yield of plants, and reduced insect-pest population (Verma *et al.* 2018). Moridi *et al.* (2019) indicated that the application of liquid organic fertilizers led to an increase in shoot dry weight and shoot N, P, Zn, Cu, and Fe uptake of maize under water deficit conditions. Treatments of liquid organic fertilizers enriched with plant growth-promoting rhizobacteria had a more positive effect on plant growth and nutrition than non-enriched ones. The effects of organic fertilizers on soil fertility and plant nutrition are well known but their application on the other soil properties such as soil physical conditions and biological properties, especially in drought situations, need to be investigated further. Therefore, the objective of this study was to investigate the effect of application of liquid organic fertilizers at different soil moisture levels on some biological and physical properties of soil after the harvest of maize cultivation in a calcareous soil.

MATERIALS AND METHODS

The experiment was conducted with a factorial arrangement in a completely randomized design with three replications. Treatments consisted of five levels of liquid organic fertilizers (control, vermicompost tea, vermiwash, vermicompost tea enriched with PGPR and vermiwash enriched with PGPR) and three levels of soil moisture status (field capacity [FC], 0.8 FC and 0.6 FC). The soil passed through a 4-mm sieve and 3 kg of soil were filled into the plastic pots. The information about soil characteristics is reported by Moridi *et al.* (2019). Essential nutrient elements based on soil testing were added to all pots uniformly at the rate of 75 mg N kg⁻¹ soil (as urea, 46% N), P at the rate of 10 mg P kg⁻¹ soil (as Ca (HPO₂)₂), Fe, Zn and Mn at the rate of 5 mg kg⁻¹ soil (as FeSO₄ · 7H₂O, ZnSO₄ · 7H₂O, MnSO₄ · 4H₂O, respectively) and Cu at the rate of 2.5 mg kg⁻¹ soil (as CuSO₄ · H₂O). Five seeds of maize (*Zea mays* cv. 380) were planted in each pot. Plants were thinned to two uniform stands after germination and irrigated to each intended soil moisture status with distilled water. To apply soil moisture status, the weighted method (using a digital scale with an accuracy of 0.001 g) was used. The field capacity (FC) point at the 1/3 bar was measured by the pressure plate that was equal to 18 g g⁻¹. At each irrigation interval, the volume of the used liquid organic fertilizers was equivalent to 60% of the volume of water required for 60% FC.

The ratio of 1:1 by weight of leaf meal and cow manure was prepared and added into the barrel. Approximately 17 g live weight of *Eisenia foetida* earthworms were inoculated to bed material. Collection of vermiwash and preparation of vermicompost tea were performed based on the method of Zarei *et*

al. (2017) and Moridi *et al.* (2019). The properties of liquid organic fertilizers, the used strain of PGPR, *Micrococcus yunnanensis*, and the method of bacterial culture, and enrichment of liquid organic fertilizers were the same as those in the previous research of Moridi *et al.* (2019). After a growth period of 11 weeks, aerial parts of plants were cut off from the soil surface. In order to obtain a uniform soil sample, each pot was mixed thoroughly. Afterward, some of the soil was transferred to the soil physics laboratory and the other to the soil biology laboratory of Shiraz University. The samples transferred to the biology laboratory were kept in plastic bags (until the end of microbiological tests) at 4°C.

The number of aerobic heterotrophic bacteria was estimated through the plate count method (Zabaloy and Gómez 2008). Soil microbial respiration (mg CO₂-C. kg soil⁻¹.h⁻¹) and soil microbial biomass were determined by measuring CO₂ concentration via titration of the remaining alkali in the solution (Anderson *et al.* 1982) and using the chloroform fumigation-incubation method (Jenkinson and Powelson 1976), respectively. The method used to measure dehydrogenase activity was the triphenyl tetrazolium chloride (TTC) method (Thalman 1968) that is based on the estimation of the TTC reduction rate to triphenylformazan (TPF) in soils after incubation at 30°C for 24 h.

The penetration resistance of the undisturbed postharvest soils was determined by the use of the portable penetrometer device. Bulk density (P_b) was determined by the core method (Blake and Hartge 1986). Particle density was measured by the pycnometer method (Klute and Dinauer 1986) And total porosity (φ) was calculated using the following equation (Gavili *et al.* 2018):

$$\varphi = 1 - (P_b/P_s) \quad (1)$$

Soil hydrophobicity was determined by the water droplet penetration time method (Olorunfemi *et al.* 2014). Soil aggregate stability was determined by the dry sieving method (Gavili *et al.* 2018). The data were used to calculate mean weight diameter (MWD) and geometric mean diameter (GMD) of soil aggregates was calculated using the following equations (eqs. 2 and 3):

$$MWD = \sum_{i=1}^n W_i X_i \quad (2)$$

$$GMD = \exp \frac{\sum_{i=1}^n (W_i \cdot \log X_i)}{\sum_{i=1}^n W_i} \quad (3)$$

where X_i is the average diameter of the remained aggregates on each sieve and W_i is the ratio of reminded aggregate on each sieve to the total sample weight and n represents the number of sieves used for separation.

Statistical analysis

All data were processed by Microsoft Excel 2013, and statistical analyses were conducted using the SAS 9.1 software packages. The means were compared statistically using Duncan's multiple range test at the probability level of 5%. The Pearson correlation coefficient between the studied soil attributes was also determined.

RESULTS AND DISCUSSION

Soil biological characteristics (SBC)

Soil microbial respiration (MR)

Soil respiration is a biological biomarker of the soil and it shows the amount of soil metabolism and the ability of the soil to convert and supply the food needed by microorganisms (Singh and Gupta 1997). The results showed that the effects of organic fertilizer, water stress, and their interactions on soil microbial respiration (MR) at 1% level were significant (Table 1). The use of organic fertilizers increased the rate of MR, which was more noticeable in the application of fertilizers enriched with bacteria (plant growth-promoting rhizobacteria (PGPR) enriched vermicompost tea and PGPR enriched vermiwash). The highest microbial respiration in the treatment of vermicompost tea and bacteria (VTP) at the soil moisture status of 80% FC was 7.5 ($\text{mg CO}_2 \text{ kg}^{-1} \text{ 24h}^{-1}$) and the lowest 1.5 ($\text{mg CO}_2 \text{ kg}^{-1} \text{ 24h}^{-1}$) and was observed in the control treatment. These results show that the application of fertilizers enriched with bacteria is more efficient and the stress conditions in the soil are better adjusted (Fig. 1). Applying water stress reduced MR (Fig. 1), Wong and Griffin (1976) have shown the movement of bacteria in the soil is largely dependent on water films in the soil. In fact, bacteria are able to function as long as food can spread in the soil. Therefore, by decreasing the soil water potential and reducing the nutrient distribution in the soil, the activity of the bacteria and the resulting biomass and microbial respiration decreases. Respiration decreasing may be a sign of increasing compound consumption by microorganisms (Nziguheba *et al.* 2005). Appropriate humidity conditions affect the behavior of the microbial population. According to this study, the highest microbial respiration was observed at soil moisture status of 80% FC, which is consistent with the results obtained by Conant *et al.* (2000). The highest rate of MR was obtained at the soil moisture status of 80% FC in all treatments, which was significantly different from the control treatment and the level of soil moisture status of 60% FC. Conant *et al.* (2000) reported that appropriate moisture conditions affected microbial respiration and soil respira-

tion that was generally highest in the wettest soils. At each level of water stress, the rate of MR in vermicompost tea treatments was higher than vermiwash. Significant differences between different treatments indicate that the quality of organic matter added to the soil plays a very important role in the rate of microbial decomposition and MR (Schomberg and Steiner 1997).

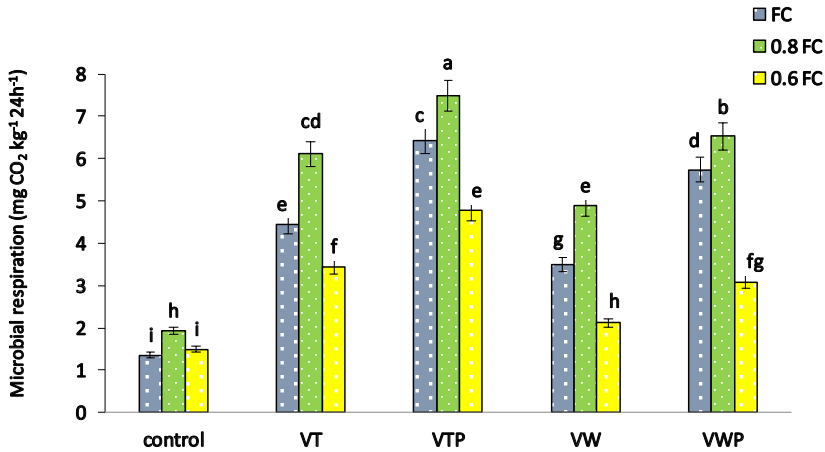


Fig. 1. The effect of liquid organic fertilizers and soil moisture status on soil microbial respiration rate (Mean±SD); vermicompost tea (VT); vermiwash (VW); vermicompost tea enriched with PGPR (VTP); vermiwash enriched with PGPR (VWP)

Soil microbial biomass (MB)

The results showed that the effects of organic fertilizers, water stress, and their interactions on soil microbial biomass (MB) at 1% level were significant (Table 1). In general, the application of liquid organic fertilizers had positive effects on MB (Fig. 2). The lowest MB amount of 11.69 (mg C kg⁻¹) was observed in the control treatment by soil moisture status of 60% FC (Fig. 2). There is a significant interaction between the soil water potential and temperature and nutrients that affect the activity of soil bacteria (Griffin 1981). It seems that the main reason for MB reduction is moisture loss. It is due to its essential role in the life of living cells. The results are consistent with the results of Orchard and Cook (1983). They are responsible for reducing microbial respiration and biomass after soil drying and, as a consequence, microbial death. Among the water stress levels, the highest amount of MB observed was 56.26 (mg C kg⁻¹) in the soil moisture status of 80% FC. This increase was higher in the presence of vermicompost tea than in the presence of vermiwash. Also, for both types of fertilizers, the application of fertilizers enriched with bacteria was more effective than the application of fertilizer without it (Fig. 2). Vermicompost tea provides better biological conditions for soil microorganisms than ver-

miwash, so vermicompost tea treatments were better than vermiwash ones even in soil moisture status of 60% FC (Fig. 2). An increase in microbial biomass may be due to organic fertilizer application in soil that provided an appropriate medium for microorganisms to stimulate their activities (Fierer *et al.* 2003). Also, a positive and significant correlation was observed between MB and other biological characteristics (Table 5).

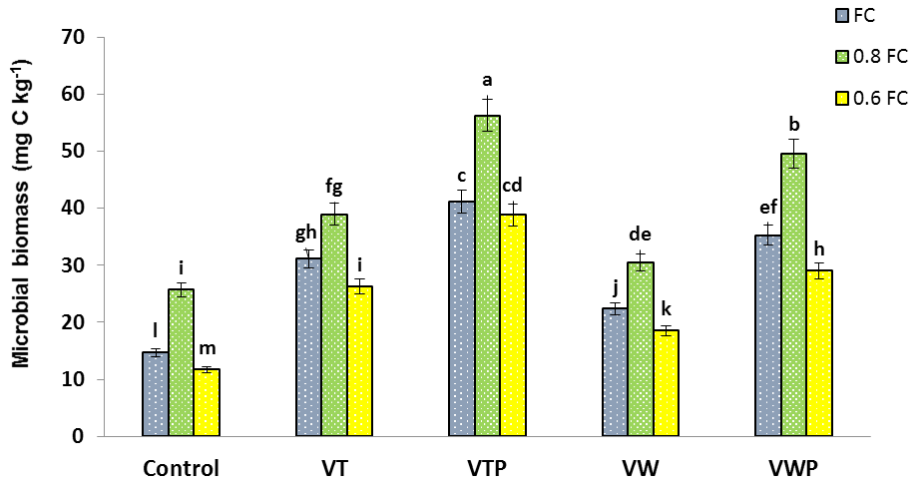


Fig. 2. The effect of liquid organic fertilizers and soil moisture status on soil microbial biomass (Mean±SD); vermicompost tea (VT); vermiwash (VW); vermicompost tea enriched with PGPR (VTP); vermiwash enriched with PGPR (VWP)

The number of aerobic heterotrophic bacteria (AHB)

Examination of the changing trend with reference to the number of AHB shows that with decreasing moisture in the soil, it decreased significantly, while it increased with the application of liquid organic fertilizers to the soil (Fig. 3). The highest rate of AHB (4.336701×10^6 CFU g⁻¹) was observed in the treatment of VTP and soil moisture status of 80% FC. The lowest rate of AHB (1.280022×10^6 CFU g⁻¹) was observed in the control treatment and soil moisture status of 60% FC (Fig. 3). Agaba *et al.* (2010) stated that drought stress has an unfavorable effect on soil conditions by reducing the soil microbial community. Researchers indicated that microbial community increased with the application of compost and vermicompost to the soil (Tejada *et al.* 2009). Chun-xi *et al.* (2018) reported that the application of organic matter to the soil increased the microbial population, soil respiration, and soil enzyme activity. They also stated that the application of fertilizers increased the growth and reproduction of microorganisms and, finally, improved the microbial population structure of the soil and increased the microbial biomass of the soil. In general, at each level

of water stress, liquid-enriched organic fertilizers with bacteria have the highest AHB compared to treatments of non-enriched organic fertilizers. At each level of water stress, AHB was not significantly different between vermiwash and vermicompost tea fertilizer treatments. While, with the addition of bacteria at soil moisture status of 80% FC and 60% FC, AHB showed a significant increase in vermicompost tea treatments compared to vermiwash ones (Fig. 3). The application of organic fertilizers increased the amount of organic matter and then the quantity and activity of microorganisms, which both affect the amount of organic carbon in the soil, CO₂ emission, and respiratory rate (Zang *et al.* 2015). Also, a positive and significant correlation was observed between AHB and other biological characteristics (Table 5).

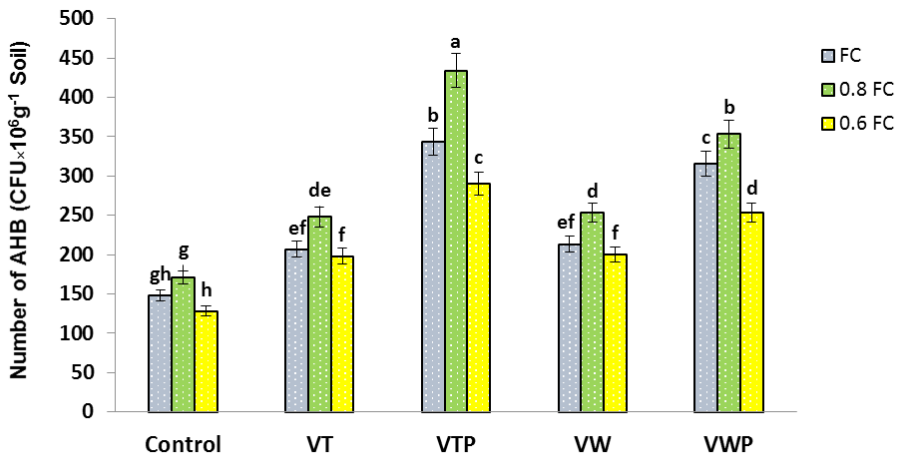


Fig. 3. The effect of liquid organic fertilizers and soil moisture status on the number of aerobic heterotrophic bacteria (AHB) (Mean±SD); vermicompost tea (VT); vermiwash (VW); vermicompost tea enriched with PGPR (VTP); vermiwash enriched with PGPR (VWP)

Dehydrogenase activity (DHA)

The results showed that the application of organic fertilizers, water stress, and their interactions on DHA at 1% level were significant (Table 1). The application of liquid organic fertilizers caused an increase in DHA (Fig. 4). The increase of organic matter in the soil increased the activity and population of microorganisms and subsequently increased the enzymatic activities of the soil (Fig. 4). The results are consistent with Chun-xi *et al.* (2018). The use of organic fertilizers in two ways increases the activity of soil enzymes: First, the use of organic matter increases the reproduction and metabolism of microorganisms by providing the nutrients needed, which ultimately increases the activ-

ity of enzymes in the soil (Ma *et al.* 2012). Second, organic matter improves the growth conditions of microorganisms by improving the physicochemical properties of the soil. In such conditions, the decomposition of organic matter is faster, resulting in increased soil enzyme activity (Kautz *et al.* 2006). The results of Xiangzhen and Sarah (2003) by investigation of arylsulfatase activity of soil microbial biomass along a Mediterranean-arid transect showed that with increasing aridity, soil organic carbon, soil microbial biomass carbon, soil microbial biomass nitrogen, respiration rate, and soil enzyme activity decreased. The highest amount of DHA ($452.14 \mu\text{g TPF g}^{-1}$) was observed in the combined treatments of fertilizers and bacteria and soil moisture status of 80% FC (Fig. 4). The increasing water stress levels in all treatments caused a decrease in DHA (Fig. 4). The lowest rate of DHA ($121.84 \mu\text{g TPF g}^{-1}$) was observed in the control treatment and soil moisture status of 60% FC. DHA was increased by 2.9 and 1.8 times more in vermicompost tea enriched with PGPR and vermiwash, respectively than the control treatment (Fig. 4). Also, DHA was higher in vermicompost tea enriched with PGPR and vermiwash enriched with PGPR than not enriched ones (Fig. 4).

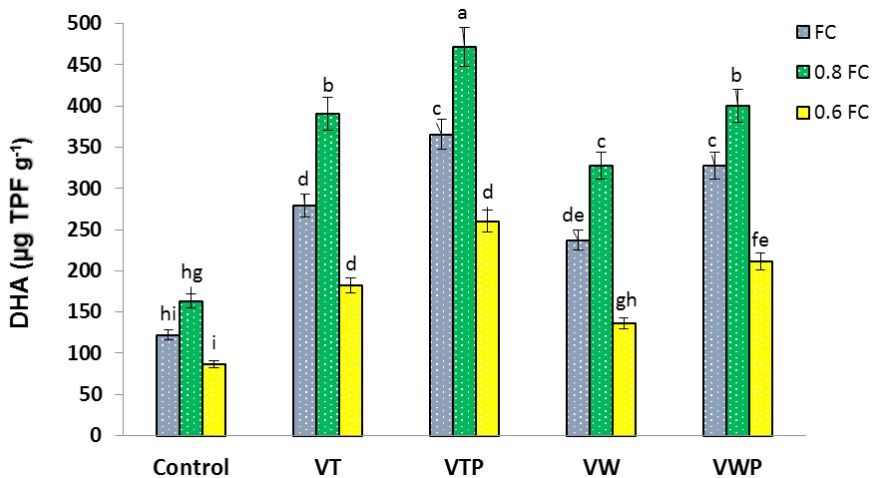


Fig. 4. The effect of liquid organic fertilizers and soil moisture status on dehydrogenase enzyme activity (DHA) (Mean±SD); vermicompost tea (VT); vermiwash (VW); vermicompost tea enriched with PGPR (VTP); vermiwash enriched with PGPR (VWP)

Table 1. Analysis of variance (ANOVA) for the effect of liquid organic fertilizers (LOFs) and soil moisture status (SMS) on soil biological properties

Sources	DF	MR	MB	AHB	DHA
SMS	2	39.92**	971.49**	11.66**	128672**
LOFs	4	38.49**	1048.50**	9.20**	78391.80**
SMS × LOFs	8	4.27**	32.59**	7.02**	3142.44**
Error	30	0.09	2.54	1.67	595.73
CV		5.78	5.08	10.45	9.13

SMS – soil moisture status; LOFs – liquid organic fertilizers; CV – coefficient of variation; DF – degree of freedom; MR – microbial respiration; MB – microbial biomass; AHB – aerobic heterotrophic bacteria; DHA – dehydrogenase enzyme activity; ns: non-significant, ** – significant at the probability levels 0.01.

Physical characteristics of postharvest soil

Bulk density (P_b), porosity and penetration resistance

Results indicated that soil moisture status, liquid organic fertilizers, and their interactions had a significant effect on bulk density (P_b), porosity, and penetration resistance (Table 2). Comparisons of means indicated that liquid organic fertilizers and soil moisture status led to an increase in soil porosity and a decrease in P_b and penetration resistance (Table 3). Cercioğlu (2017) reported that the impact of composted tobacco waste, bio-humus, chicken manure on soil physical properties was positive and that organic fertilizer application increased soil porosity, and decreased P_b and particle density of soil. Decreasing in the total porosity of soil and an associated increase in its P_b due to organic fertilizer application can result in a greater number of fine pores and contact points between soil particles in a single aggregate (Król *et al.* 2013). The positive diminishing effects of organic fertilizer applications on P_b may be also due to organic fertilizer incorporation in the soil and improvement of the physical quality of the soil with low organic carbon content (Mosaddeghi *et al.* 2009). The lowest value of P_b (1.35 g cm⁻³) and the highest value of porosity (49%) were observed in PGPR enriched vermicompost tea treatment under soil moisture status of 0.6 FC. The lowest value of penetration resistance (0.44a MPa) was observed in vermicompost tea treatment under FC conditions (Table 3). Soil penetration resistance mainly depends on soil type, P_b , and soil water content (Henderson *et al.* 1988). Soil compaction affects the root distribution and consequently its uptake and growth (Adeleye *et al.* 2010). Agbede *et al.* (2017) reported that by applying organic fertilizer to the soil, the total soil compaction reduced, and root growth of carrot increased. They also reported that improved soil particle accumulation and total soil porosity were a result of organic fertilizer application. Compaction leads to the changes in soil porosity (Alaoui and Helbling 2006), and pore-size distribution (Hayashi *et al.* 2009). Wetting and drying cycles

naturally influence the soil moisture content that affects cohesion, angle of internal friction, compressibility, and adhesion. In the saturated soil conditions, cohesion is at its minimum value because of the presence of free water in soil pores. When soil moisture reduces, negative water potentials develop and water held by soil particles takes action as a bonding agent, therefore, cohesion increases. Penetration resistance increased as the soil dried, and decreased as the soil became wetter (Bar-Yosef and Lambert 1981). Vaz *et al.* (2001) reported that penetration resistance data indicated a decrease after irrigation as a result of the increasing water content. In the present study, the highest value of P_b and penetration resistance and the lowest value of porosity were related to the control treatment (Table 3). Vermicompost tea treatments decreased the soil P_b , penetration resistance, and increased the soil porosity more than vermiwash probability due to its high organic matter content and its role in the constitution and stability of soil structure. Marinari *et al.* (2000) stated that the greater porosity in the soil treated with vermicompost was due to an increase in the number of pores. Compost addition caused a significant increase in moisture content due to an increase in soil porosity.

Soil hydrophobicity, aggregate stability, mean weight diameter (MWD), and geometric mean diameter (GMD)

The soil moisture status, liquid organic fertilizers, and their interactions had a significant effect on the soil hydrophobicity, MWD, and GMD, at the statistical level of 1% (Table 2). The application of liquid organic fertilizers and soil moisture status increased hydrophobicity (Table 3). The highest value of hydrophobicity (6.5 s) was observed in the vermicompost tea enriched with PGPR treatment under soil moisture status of 0.6 FC. Since most mineral compounds of soils are hydrophilic (Tschapek 1984), it is generally accepted that soil water repellency (hydrophobicity) is mainly caused by organic compounds in the form of more or less continuous coatings on mineral surfaces (Bisdorn *et al.* 1993) or as interstitial particulate organic matter. Repellency is generally considered to increase with increasing dryness of soil (Doerr and Thomas 2000). The application of liquid organic fertilizers increased MWD and GMD (Table 3). The highest values of MWD and GMD were observed in the vermicompost tea enriched with PGPR treatment. One reason for this may correspond to the high potential of vermicompost tea enriched with PGPR in increasing the number of bacteria relative to other treatments that could improve the formation and stability of soil aggregates. Chen *et al.* (2009) observed positive significant correlations between soil organic carbon, labile organic C fractions, MWD, and GMD. The soil moisture status of 0.8 FC increased MWD and GMD but 0.6 FC decreased them, significantly. Organic matter acts as a cementing agent that puts soil particles together to form aggregates, as well as bonding small aggregates together to form larger and more stable aggregates. This role of organic matter has been confirmed by

other researchers (Lado *et al.* 2004). Rasiah and Kay (1995) reported a difference in the soil structural stability under various moisture conditions. A decrease and increase in structural stability under different soil moisture conditions can be due to reducing in the microbial community under 0.6 FC and increasing at 0.8 FC conditions, respectively. At each level of soil moisture status, vermicompost tea enriched with PGPR treatment was more effective than vermiwash in producing more stable soil aggregates. This may be related to its higher content of organic matter and microorganisms.

Correlation between soil physical and biological properties

There is a positive correlation between soil porosity with all measured soil biological characteristics, penetration resistance with MR and DHA, MWD with DHA, and GMD with MR and DHA (Table 4). These results indicated that increased microbial activity has been associated with improved physical properties. The role of soil microorganisms in enhancing agglomeration, and consequently increasing MWD, should not be ignored. The role of biological activities in the formation and stabilization of aggregates has been reported by Bidisha *et al.* (2010). Increasing the organic matter in the soil reduces the P_b and increases the soil porosity, hydrophobicity and improves the soil structure. On the other hand, the substrates needed by soil microorganisms are provided by the use of organic fertilizers in the soil. There is a negative and significant correlation between P_b with all measured soil biological characteristics (Table 4). Increased organic matter in the soil reduced P_b and subsequently increased soil porosity. It seems that good nutritional and aeration conditions have increased the number of aerobic heterotrophic bacteria in fertilizer treatments. Soil biological characteristics improves as the soil porosity and aeration condition increase, and *vice versa* (Bidisha *et al.* 2010). Also, a positive and significant correlation was observed between the studied biological parameters (Table 5).

Table 2. Analysis of variance (ANOVA) for the effect of liquid organic fertilizers (LOFs) and soil moisture status (SMS) on the soil physical properties

SOV	DF	P_b	Porosity	Penetration resistance	Hydrophobicity	MWD	GMD
SMS	2	0.011**	0.002**	0.219**	32.237**	0.277**	0.035**
LOFs	4	0.237**	0.034**	0.032**	9.189**	0.132**	0.020**
SMS × LOFs	8	0.002*	0.001*	0.001*	0.288**	0.043**	0.002**
Error	30	0.0008	0.0002	0.0007	0.6155	0.0015	0.0008
CV		3.41	5.62	3.76	11.93	4.35	5.47

* and ** are significant at the probability levels of 0.05 and 0.01, respectively. SOV – sources of variation, SMS – soil moisture status; LOFs – liquid organic fertilizers; CV – coefficient of variation; DF – degree of freedom; P_b – bulk density; MWD – mean weight diameter; GMD – geometric mean diameter.

Table 3. Effect of liquid organic fertilizers (LOFs) and soil moisture status (SMS) on the soil physical properties

Fertilizer treatments	SMS		
	FC	0.8FC	0.6FC
Bulk density (g cm ⁻³)			
Control	1.58 ^{ax}	1.53 ^a	1.45 ^b
VT	1.47 ^b	1.47 ^b	1.37 ^c
VTP	1.45 ^b	1.38 ^c	1.35 ^c
VW	1.53 ^a	1.48 ^b	1.42 ^{bc}
VWP	1.48 ^b	1.40 ^{bc}	1.38 ^c
Porosity (%)			
Control	40.00 ^b	42.00 ^g	45.00 ^e
VT	45.00 ^e	45.00 ^e	48.00 ^b
VTP	45.00 ^e	48.00 ^b	49.00 ^a
VW	42.00 ^g	44.00 ^f	46.00 ^d
VWP	44.00 ^f	47.00 ^e	48.00 ^b
Penetration resistance (MPa)			
Control	0.60 ^{cd}	0.70 ^b	0.86 ^a
VT	0.44 ^f	0.56 ^d	0.71 ^b
VTP	0.46 ^{ef}	0.57 ^{cd}	0.69 ^b
VW	0.50 ^e	0.61 ^c	0.73 ^b
VWP	0.50 ^b	0.61 ^c	0.71 ^b
Hydrophobicity (s)			
Control	1.26 ^h	1.90 ^{sh}	3.43 ^{def}
VT	1.96 ^{gh}	3.16 ^{d-g}	5.43 ^{ab}
VTP	3.26 ^{d-g}	5.03 ^{sd}	6.50 ^a
VW	1.70 ^h	3.30 ^{d-g}	4.60 ^{bcd}
VWP	2.70 ^{e-h}	3.83 ^{cde}	5.55 ^{ab}
Mean weight diameter, MWD (mm)			
Control	0.78 ^{efg}	0.80 ^{def}	0.72 ^g
VT	0.85 ^d	1.11 ^b	0.77 ^{fg}
VTP	0.98 ^c	1.44 ^a	0.82 ^{def}
VW	0.82 ^{def}	0.85 ^{de}	0.75 ^{fg}
VWP	0.87 ^d	0.96 ^c	0.76 ^{fg}
Geometric mean diameter, GMD (mm)			
Control	0.72 ^{gh}	0.75 ^{ef}	0.68 ⁱ
VT	0.78 ^{cd}	0.87 ^b	0.74 ^g
VTP	0.85 ^b	0.92 ^a	0.75 ^{ef}
VW	0.75 ^{ef}	0.77 ^{de}	0.71 ^h
VWP	0.78 ^{cd}	0.80 ^c	0.74 ^f

× for each parameter, means in each row or column followed by the same lower letters are not statistically significant at $p < 0.05$ based on the Duncan's Multiple Range Test. Vermicompost tea (VT); vermiwash (VW); vermicompost tea enriched with PGPR (VTP); vermiwash enriched with PGPR (VWP).

Table 4. Correlation coefficient between studied soil biological and physical properties

	AHB	MR	MB	DHA
P _b	-0.69**	-0.75**	-0.75**	-0.65**
Porosity	0.69**	0.75**	0.75**	0.65**
Penetration resistance	-0.23 ^{ns}	0.54*	-0.42 ^{ns}	0.59*
Hydrophobicity	-0.52 ^{ns}	-0.31 ^{ns}	-0.38 ^{ns}	0.2 ^{ns}
MWD	0.23 ^{ns}	0.54*	0.47 ^{ns}	0.52*
GMD	0.36 ^{ns}	0.71**	0.63**	0.69**

ns – non-significant; * and ** are significant at the probability levels of 0.05 and 0.01, respectively. MR – microbial respiration; MB – microbial biomass; AHB – aerobic heterotrophic bacteria; DHA – dehydrogenase enzyme activity; P_b – bulk density; MWD – mean weight diameter; GMD – geometric mean diameter.

Table 5. Correlation between soil biological properties

	DHA	MR	MB	AHB
DHA	1			
MR	0.96**	1		
MB	0.91**	0.95**	1	
AHB	0.74**	0.81**	0.80**	1

ns – non-significant, * and ** are significant at the probability levels of 0.05 and 0.01, respectively. MR – microbial respiration; MB – microbial biomass; AHB – aerobic heterotrophic bacteria; DHA – dehydrogenase enzyme.

CONCLUSIONS

Results showed that the application of vermicompost tea and vermiwash led to an increase in MR, MB, AHB and DHA, while drought stress reduced them. This increase was more in the vermicompost tea enriched with PGPR and vermiwash enriched with PGPR than not enriched ones. Liquid organic fertilizers and drought stress led to an increase in soil porosity and a decrease in soil P_b and penetration resistance. Vermicompost tea decreased soil P_b, penetration resistance, and increased soil porosity more than vermiwash, which can be due to its high organic matter content and its role in the constitution and stability of soil structure. The lowest value of P_b and the highest value of porosity were observed in vermicompost tea enriched with PGPR treatment under soil moisture status of 0.6 FC. The lowest value of penetration resistance was observed in the vermicompost tea treatment under FC conditions. The most value of hydrophobicity was observed in the vermicompost tea enriched with PGPR treatment under soil moisture status of 0.6 FC. The highest values of mean weight diameter and geometric mean diameter were observed in the vermicompost tea treatment. Overall, the negative effects of soil moisture status on growth and nutrients uptake of maize (Moridi *et al.* 2019), and some soil biological and physical properties of soil were enhanced by the application of liquid organic fertilizers, especially those enriched with PGPR.

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