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Influence of poultry manure and its biochar, *Funneliformis mosseae* and salinity stress on corn yield and micronutrients concentration

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ABSTRACT- Direct use of poultry manure (PM) as an organic fertilizer in agriculture may cause environmental concerns; therefore, application of its biochar might be an effective solution. A greenhouse experiment was conducted to investigate the influence of PM and its biochar (PMB) (control, 1% and 2% PM (w/w), 1% and 2% (W/W) PMB) on the growth and micronutrients concentration of corn under salinity stress (0.5, 3.6, 7.9 and 12.4 dS m^{-1}) in the presence or absence of arbuscular mycorrhizal fungus (AMF) (*Funneliformis mosseae*). Results indicated that application of PM and PMB significantly increased corn shoot dry weight (SDW) compared to that of control in non-AMF plants. However, SDW was higher in PMB application compared to that of PM by 15% and 8% for 1% and 2% (w/w) application rates, respectively. In AMF-plants, addition of 2% PMB had no significant effect on SDW compared to that of control. Hence, co-application of PMB (2%), and AMF did not increase SDW due to the fact that AMF was ineffective to enhance corn yield (at high phosphorous (P) concentration in 2% PMB rate). Salinity stress, at low levels (3.6 and 7.9 dS m^{-1}), increased SDW of corn but at a higher level (12.4 dS m^{-1}), decreased it significantly, in both non-AMF and AMF plants. In general, shoot micronutrients concentration (except for Cu) significantly increased along with increasing soil ECe levels in AMF and AMF plants. In non-AMF plants, only addition of 2% PMB increased shoot Mn concentration by 20% compared to that of control. However, in AMF plants, application of PM (2%) and PMB (1% and 2%) decreased Mn concentration by 27%, 16%, and 9% compared to those of control treatment, respectively. Poultry manure biochar increased corn shoot Zn, Cu and Fe concentrations compared to those of control due to the higher concentration of these nutrients in biochar compared to PM. In conclusion, pyrolysis of PM almost eliminated foul odor of PM and increased dry matter yield of corn.

INTRODUCTION

In recent years, declining soil quality continues to rise due to the pressure on agriculture system, because of the population growth (Arif et al., 2016). Application of organic matters such as animal manure in soil is an effective strategy to improve soil fertility and increase crop production (Laghari et al., 2016). For decades, poultry manure (PM) has been added to soil as an organic fertilizer traditionally (Parker et al, 1959; Shortall & Liebhardt, 1975; Bitzer & Sims, 1988; Khaliq et al., 2004; Sahin et al., 2014). The poultry industry creates a huge amount of waste production that might cause environmental concerns over the time (Gunes et al., 2014). Demand for the use of inorganic fertilizer and the negative environmental effects of poultry waste is decreased by application of PM as fertilization of crops. But, direct use of poultry waste has environmental risks such as serious risk to human and animal health, groundwater pollution and odor (Gunes et al., 2015). Although PM is a valuable resource which can be used as a fertilizer for crops, handling, transporting and applying it are very difficult because it is bulky and gives off a foul smell. Pyrolysis of the PM and producing biochar is an effective way to reduce odor. Application of biochar may help to improve environmental quality by reducing soil nutrient leaching, bioavailability of environmental contaminants, and greenhouse gas emissions, and enhancing sequestering C and crop productivity in highly weathered or degraded soils (Ippolito et al., 2012).

Soil salinity is a global problem that existed before human existed and is increasing nowadays (Zhu, 2001). Salinity stress causes loss of productivity of plants with disturbed major processes of plant such as protein synthesis, photosynthesis, metabolism of energy and lipid (Evelin et al, 2009). Generally, chemical and biological methods are used to improve negative effects of soil salinity (Qadir et al., 2000) on crop production. Performance of plant under stress can improve in the presence of some microorganisms such as beneficial bacteria and fungi (Evelin et al, 2009).

One of the important groups of soil microorganisms is arbuscular mycorrhizal fungi (AMF) (Xu et al., 2016). Smith and Read (2008) reported that the largest number of plants (approximately 80% of plant species) interact with AMF. Several studies reported that co-application of poultry manure and AMF is superior to sole amendment with PM (Abdullahi et al., 2015). However, some environmental conditions including phosphorus (P) availability can inhibit the symbiotic interaction of AMF with plants. In other words, when P is available, plant will be deprived of other benefits of AMF such as enhanced resistance to pathogens and stress, water uptake and nitrogen supply at high P levels (Smith and Read, 2008). Considering that P content of PM and its biochar is high and can affect AMF symbiosis with corn roots and uptake of micronutrients from soil solution, the objective of the present study is to investigate the effect of different levels of PM and its biochar on corn growth, root colonization, and micronutrients concentration in the presence or absence of AMF, under salinity stress condition.

MATERIALS AND METHODS

Soil Analysis

The soil used in the present study was taken from the surface layer (0-30 cm) of a soil from Fars Province located in southern Iran (Long53° 13' 48'' E Lat 29° 6' 0'' N), air-dried, and passed through a 2-mm sieve. The texture was determined by the hydrometer method (Bouyoucos, 1962); pH in saturated paste and electrical conductivity (ECe) in saturation extract were measured; calcium carbonate equivalent (Loppert and Suarez, 1996), cation exchange capacity (Summer and Miller, 1996), and organic matter content (Nelson and Sommers, 1996) were also determined. Total nitrogen was determined according to the Kjeldahl method (Bremmer, 1996). Available potassium (K) was extracted by ammonium acetate and determined by flame photometer (Helmke and Sparks, 1996). Sodium bicarbonate-extractable P was determined by spectrophotometer according to Watanabe and Olsen (1965). Available micronutrients were extracted by DTPA (Lindsay and Norvell, 1978) and determined by atomic absorption spectrometry. Some chemical and physical properties of the soil used are given in Table1.

Preparation and Analysis of Poultry Manure and its Biochar

Poultry manure (PM) was air-dried at room temperature and ground to pass a 4-mm sieve. The PM was pyrolysed under oxygen-limited conditions in a muffle furnace (Heraeus, K-1252) at 300 ˚C. The pyrolysis temperature was raised to the selected value at a rate of approximately 15ºC per min and held constant for 4h, cooled down to room temperature and ground to pass a 2-mm sieve (Chun et al., 2004; Yuan et al., 2011). Chemical and physical characteristics of poultry manure and its biochar are presented in Table 2.

Preparation of Arbuscular Mycorrhizal Fungal Inoculum

Arbuscular mycorrhizal fungus used in this study (*Funneliformis mosseae*) was prepared through the trap culture of maize (*Zea mays* L.) which is composed of autoclaved soil/quartz-sand (<1 mm) (1: 4, v/v) and maize as the host plant. Spores of *Funneliformis mosseae* were provided by the Department of Soil Science, College of Agriculture, Shiraz University. For non- mycorrhizal (NM) control treatments, some pots were kept without any spore for preserving the naturally occurring microbial association. At the beginning of the reproductive period (approximately after 316 days from emergenc) , shoots were removed and the contents of pots (mycorrhizal roots plus soil possessing fungal spores and mycelia) were maintained in polyethylene bags at 4°C for analysis. The potential of AM inoculant was measured based on the methods described by Zarei et al. (2008) for spore extraction, counting and evaluation of root colonization. In mycorrhizal plants, each pot of mycorrhizal treatment received 50 g of AM inoculant (containing spore numbers of 11 g^{-1} substrate and root colonization of 85%, respectively) at a depth of 5 cm soil, and was mixed thoroughly with the soil below.

Table 1. Some chemical and physical properties of the soil used in this study

Properties	Quantities / definition	Properties	Quantities / definition
Textural class	Loam	Organic matter (%)	1.6
Sand (%)	29.5	Sodium bicarbonate-extractable P (mg kg^{-1})	8
Silt (%)	44.9	DTPA-extractable Mn (mg kg^{-1})	5.57
Clay (%)	25.6	DTPA-extractable Cu (mg kg^{-1})	0.92
Cation exchange capacity (CEC) ($Cmol_+$ kg^{-1})	8	DTPA-extractable Fe (mg kg^{-1})	3.20
pH saturated paste	7.78	DTPA-extractable Zn (mg kg^{-1})	0.52
ECe (dS m^{-1})	0.5	DTPA-extractable Cd (mg kg^{-1})	ND
Calcium carbonate equivalent (%)	44.8	DTPA-extractable Pb (mg kg^{-1})	ND

ND= Not detectable

Experimental Design

This study was performed as two completely randomized factorial design experiments with three replicates under greenhouse conditions in a soil treated with organic substance at five levels (control, 1% and 2% of poultry manure (PM), 1% and 2% Poultry manure biochar (PMB), and four salinity levels (0, 1000, 2000, 4000 mg NaCl kg^{-1} soil equivalent to ECe of 0.5, 3.6, 7.9 and 12.4 dS m^{-1}, respectively). The second experiment was carried out with similar treatments except for the addition of mycorrhizal inoculation (*Funneliformis mosseae*).

Table 2. Chemical and physical characteristics of poultry manure and its derived biochar

Characteristic	Organic wastes	
	Poultry manure	Poultry manure biochar
pH (1:5 water extractable)	7.30	7.27
EC, dS m^{-1}	5.80	7.5
Total N, %	3.3	3.6
Total P, %	2.0	2.7
Total organic carbon (TOC), %	51	50
Total Fe (mg kg^{-1})	1780	1916
Total Mn (mg kg^{-1})	495	595
Total Zn (mg kg^{-1})	317	430
Total Cu (mg kg^{-1})	35.5	48
Total Ca (%)	13.16	17.65
Total Mg (mg kg^{-1})	1693	3455
Total Pb (mg kg^{-1})	ND*	ND
Total Cd (mg kg^{-1})	ND	ND
Yield, % **	-	70

* ND = Not detectable, **: As the mass of biochar generated from a unit of dry mass of poultry manure

Soil Preparation and Planting

A greenhouse experiment was carried in 2016. Experimental units were pots containing 3 kg of soil. Before planting and based on soil analysis, some nutrient elements were added to pots uniformly. One half of N was added at planting and the other half 4 weeks after emergence. In order to prevent killing corn seedling, NaCl salinity was gradually added to pots. Four corn (*Zea mays* L., KSC703) seeds were planted in pots and kept at about field capacity soil moisture level by adding water to a constant weight and then thinned to two uniform stands one week after emergence.

Plant Analysis

Whole plants were harvested ten weeks after emergence. Root colonization (%) by AMF was determined using the grid-line intersect method after clearing washed roots in 10% KOH and staining with blue ink in lactoglycerol (v/v) according to the Kormanik and McGraw method (1982). Shoots were washed using tap water, rinsed with distilled water, oven-dried at 65°C for 72 h to constant weight, weighed and dry-ashed at 550°C. The ash was dissolved in 2M HCl and the concentrations of Fe, Cu, Mn, and Zn were determined using atomic absorption spectrophotometer (Chapman and Pratt 1961).

Statistical Analysis

Statistical analysis of the collected data was performed using SAS 9.0 software and the mean value of data was compared statistically using Duncan's Multiple Range Test at probability level of 0.05.

RESULTS AND DISCUSSION

Soil Water Content

Plant Growth

Effects of salinity stress and organic substances on shoot dry weight (SDW) at both arbuscular mycorrhizal fungi (AMF) and non-AMF plants are presented in Table 3. The highest SDW at AMF-plant and non-AMF plants were obtained in 7.9 and 3.6 dS m^{-1} ECe, respectively. In other words, salinity stress first increased SDW of corn plants and then decreased it significantly, at both AMF and non-AMF plants. Qados (2011) investigated the effect of sodium chloride concentration (0, 60, 120 and 240 mM) on growth of bean plant (*Vicia faba* L.) and reported that the highest value of fresh and dry weights of shoot was obtained in 60 mM NaCl. Some studies indicated that application of low concentration of NaCl led to an increase in plant dry weight (Nedjimi et al., 2006; Andriolo, 2005).

Application of poultry manure (PM) and its biochar (PMB) significantly increased SDW compared to that of control in non-AMF plants (Table 3). Also, results indicated that addition of PMB was more effective than PM in increasing SDW. In AMF plants, application of PM at both rates and 1% PMB significantly increased SDW, but addition of 2% PMB had no significant effect on SDW compared to that of control, probably due to the high P content of 2% PMB level (Table 2). Rakiya et al. (2015) reported that application of 10 and 12 tones PM ha^{-1} with AMF in a loam soil significantly decreased plant growth. Carreon-Abud et al. (2015) investigated interaction of arbuscular mycorrhizal and chicken manure in avocado rootstock production and stated that high chicken manure fertilization had negative effects on plant growth. Under condition of high soil P concentration, growth enhancement effect of arbuscular mycorrhiza declined and might either be canceled or might lead to a reduction in growth (de Oliveira, 2017; Gosling et al., 2006). Biochar may act as a source of phosphorus (Basiri Jahromi et al., 2018).

Root Colonization

In non-AMF plant, effects of salinity and organic substances on root colonization were not significant; however, in AMF-plant, effects of treatments on root colonization were significant (Table 4). Salinity stress significantly reduced percentage of root colonization in corn plants inoculated with AMF in control treatment (without organic substances) and in all organic substances treatments. Similar results have been reported by several authors (Al-Karaki, 2000; Yang et al., 2014). However, contradictory results are reported (Tarkalson et al., 1998; Abdullahi et al., 2015) which show that application of poultry manure increased the percentage of root colonization in corn plants.

In AMF-plants, application of all organic substances reduced the percentage of root colonization, which could be attributed to the high content of P in organic substances. Maximum reduction in root colonization occurred in plants treated by 2% PM or 2% PMB, probably due to high P content of applied organic substances. Many studies showed that high P concentration significantly decreased root colonization (Gosling et al., 2013; Balzergue et al., 2013).

Shoot Mn Concentration

In non-AMF plants, application of organic substances (PM and PMB) increased Mn concentration in shoot compared to the control ***especially at the highest salinity level***. However, the increase was significant only in corn plants grow in pots amended with 2% PMB (Table 5). Concentration of Mn was significantly enhanced in shoots of both AMF and non-AMF treated plants for all NaCl levels compared to those of control. This result could be attributed to the effect of NaCl to reduce soil pH (Fig. 1) and, consequently, increase the Mn availability to plants. However, the increase in Mn concentration in corn plant at 12.4 dS m^{-1} is related to the reduction of shoot dry weight (Table 3).

Table 3. Effects of salinity, poultry manure and its biochar on shoot dry weight in AMF and non-AMF plants (g pot^{-1})

	Organic substance					
Soil ECe Levels ($dS\ m^{-1}$)	Non-AMF					Mean
	Control	PM 1%	PM 2%	PMB1%	PMB2%	
0.5	21.11bcd	20.72bcd	22.31bcd	23.35bc	24.13bc	22.32B
3.6	20.3bcdl	21.34bcd	24.71bc	26.11b	31.82a	24.87A
7.9	21.89bcd	22.43bcd	23.69bc	24.87bc	23.65bc	23.31AB
12.4	17.24d	21.03bcd	20.48bcd	24.4bc	19.26cd	20.48C
Mean	20.16C	21.38BC	22.80AB	24.68A	24.72A	*22.74A*
	AMF+					
	Control	PM 1%	PM2%	PMB1%	PMB2%	
0.5	19.89ef	22.71cde	23.31cde	22.72cde	21.70def	22.07B
3.6	21.02def	23.28cde	24.80abcd	23.76bcde	21.17def	22.80B
7.9	21.59def	26.06abc	28.09a	27.38ab	22.37cdef	25.10A
12.4	18.46gf	19.81ef	21.91def	21.07def	15.19g	19.28C
Mean	20.24B	22.96B	24.52A	22.73A	20.11B	*22.31A*

Means in each row or column followed by the same lowercase or capital letters are not significantly different (P <0.05) by Duncan's Multiple Range; PM and PMB: poultry manure and poultry manure biochar, respectively; AMF+ and non-AMF: plants with and without arbuscular mycorrhizal fungus, respectively.

Table 4. Effects of salinity, poultry manure and its biochar on the percentage of corn root colonization in AMF and non-AMF plants (%)

	Organic substance					
Soil ECe Levels ($dS\ m^{-1}$)	Non-AMF					Mean
	Control	PM 1%	PM 2%	PMB1%	PMB2%	
0.5	7.67ab	7.66ab	8.33a	7.67ab	7.67ab	7.8A
3.6	7.33ab	7.67ab	7.67ab	7.33ab	7.67ab	7.53A
7.9	8.33a	6.67ab	6.67b	8.00ab	7.00ab	7.33A
12.4	7.67ab	7.67ab	7.33ab	7.67ab	8.00ab	7.67A
Mean	7.75A	7.42A	7.5A	7.67A	7.58A	*7.58B*
	AMF+					
	Control	PM 1%	PM 2%	PMB1%	PMB2%	
0.5	92.00a	89.00ab	68.33e	78.67c	67.67e	78.87A
3.6	89.00ab	85.33b	62.00f	74.00d	59.33fg	73.73B
7.9	80.00c	78.00c	57.00g	68.00e	57.33g	67.53C
12.4	72.5dc	72.00d	51.00h	62.33f	48.33h	60.87D
Mean	83.25A	81.08B	58.00D	70.75C	58.17D	*70.25A*

Means in each row or column followed by the same lowercase or capital letters are not significantly different (P <0.05) by Duncan's Multiple Range; PM and PMB: poultry manure and poultry manure biochar, respectively; AMF+ and non-AMF: plants with and without arbuscular mycorrhizal fungus, respectively.

Table 5. Effects of salinity, poultry manure and the derived biochar on shoot Mn concentration in AMF and non- AMF plants (μg g^{-1} Dry matter)

Soil ECe Levels (dS m^{-1})	Organic substance					
	Non-AMF					
	Control	PM 1%	PM 2%	PMB1%	PMB2%	Mean
0.5	33.64f	36.68ef	44.83def	44.12edf	44.36edf	**40.73C**
3.6	44.64edf	48.68de	46.09def	50.11d	46.91edf	**47.26B**
7.9	50.19d	51.77cd	46.14def	42.29edf	54.3bcd	**48.94B**
12.4	52.63cd	63.37abc	55.55bcd	66.4ab	71.27a	**61.85A**
Mean	**45.28B**	**50.13AB**	**48.15AB**	**50.73AB**	**54.21A**	***49.70A***
	AMF+					
	Control	PM 1%	PM 2%	PMB1%	PMB2%	
0.5	44.57b-g	42.39c-g	26.77h	32.02gh	33.04fgh	**35.76C**
3.6	43.69b-g	61.1a	37.63e-h	40.56d-g	45.37b-f	**45.68B**
7.9	53.67abc	49.24a-e	33.58fgh	45.42b-f	48.78a-e	**46.14B**
12.4	60.13a	55.69ab	49.61a-e	51.38a-e	56.5ab	**54.66A**
Mean	**50.52A**	**52.11A**	**36.90D**	**42.35C**	**45.92BC**	***45.56B***

Means in each row or column followed by the same lowercase or capital letters are not significantly different (P <0.05) by Duncan's Multiple Range Test; PM and PMB: poultry manure and poultry manure biochar, respectively; AMF+ and AMF0: plants with and without arbuscular mycorrhizal fungus, respectively.

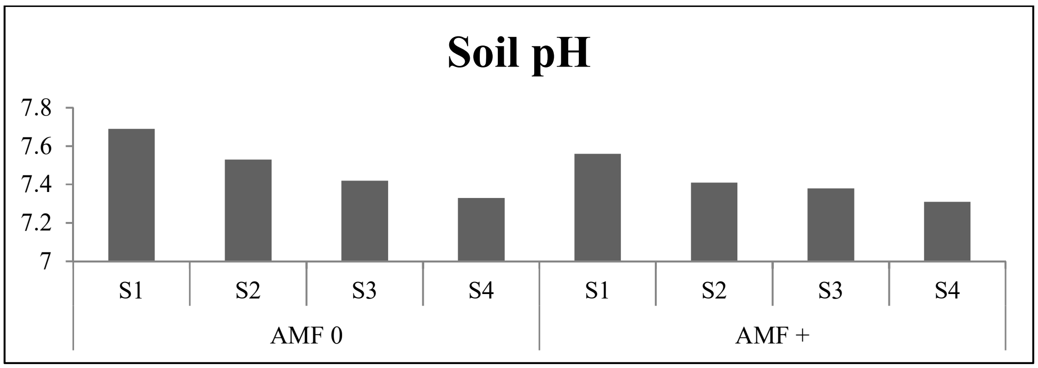

Fig1. Relationship between post-harvested soil pH and NaCl application levels Note: S1, S2, S3 and S4: ECe of 0.5, 3.6, 7.9 and 12.4 dS m^{-1}, respectively

In general, the negative interaction of salinity and organic substances leads to a reduction in shoot Mn concentration in AMF-plants compared to those of non-AMF ones (Table 5). Konieczny and Kowalska (2017) investigated the effect of AMF on the micronutrient concentration in lettuce grown at two P levels and stated that AMF decreased concentration of Cu, Fe, Mn and Mo in lettuce plant. They supposed that this reducing effect of AMF on concentration of micronutrients in AMF-plants could be due to an elevated concentration of micronutrients in the root zone of plant, and Mn concentration significantly decreased by increasing the use of P. Mn concentration significantly decreased as a result of organic substances application in AMF-plants, except for 1% PM treatment, which might be related to the negative interaction of AMF and organic substances (with high P content) on shoot Mn concentration (Table 5).

Shoot Zn Concentration

In non-AMF plants, addition of PM and PMB drastically increased corn shoot Zn concentration. In AMF plants, application of 1% or 2% PM significantly increased shoot Zn concentration, 2.7 and 2.8 times higher than that of control, respectively (Table 6). Also, application of PMB 1% or 2% increased Zn concentration of corn shoot by 61% and 91%, respectively. Results indicated that in both AMF and non -AMF plants, addition of PM was more effective than PMB at all salinity levels in increasing shoot Zn concentration and there was no significant difference between rates of PM or PMB. Several studies indicated that biochar application reduced Zn concentration by sorption of this nutrient (Ippolito et al., 2017; Forjan et al., 2017). Effect of PM and its biochar on the growth of bean and maize plants was investigated by Inal et al. (2015) and they reported that PM and biochar increased concentrations of Fe, Zn, Cu and Mn in bean plants.

Also, PM and biochar applications increased Zn, Cu and Mn, in maize plants. Similar to Mn concentration, Zn concentration also increased in shoots of both AMF and non-AMF treated plants in all NaCl levels compared to the control due to the increase in availability of Zn as a result of reduction in soil pH values (Fig. 1). Also, increase in Zn concentration at highest salinity level (ECe = 12.4 ds m^{-1}) was related to the reduction in shoot dry weight (Table 3), although the increase in Zn concentration was not statistically significant in non- AMF plant.

Table 6. Effects of salinity, poultry manure and the derived biochar on shoot Zn concentration in AMF and non- AMF plants (µg g^{-1} Dry matter)

Soil ECe Levels (dS m^{-1})	Organic substance Non-AMF Control	PM 1%	PM 2%	PMB1%	PMB2%	Mean
0.5	12.93i	35.62b-e	45.65abc	18.67ghi	20.82f-i	**26.74B**
3.6	15.12hi	42.69abc	45.30abc	34.49cdef	32.51cdefg	**34.02A**
7.9	22.23e-h	52.47a	39.87abcd	22.84e-i	27.86d-h	**33.05A**
12.4	19.39ghi	49.93a	48.81ab	31.41c-g	34.54c-f	**36.82A**
Mean	**17.42C**	**45.18A**	**44.91A**	**26.85B**	**28.93B**	***32.66A***
	AMF+					
	Control	PM 1%	PM 2%	PMB1%	PMB2%	
0.5	11.98g	36.90bc	32.65cd	21.49ef	21.14ef	**24.83C**
3.6	14.79fg	41.78ab	47.47a	21.70ef	27.80de	**30.71B**
7.9	15.16fg	36.62bc	40.88ab	25.29de	27.87de	**29.17B**
12.4	17.63fg	46.18a	45.82a	27.69de	36.73bc	**34.81A**
Mean	**14.89D**	**40.37A**	**41.71A**	**24.05C**	**28.39B**	***29.88B***

Means in each row or column followed by the same lowercase or capital letters are not significantly different (P <0.05) by Duncan's Multiple Range Test; PM and PMB: poultry manure and poultry manure biochar, respectively; AMF+ and AMF0: plants with and without arbuscular mycorrhizal fungus, respectively.

Mean comparisons of shoot Zn concentration in AMF and non-AMF plants indicated that AMF significantly decreased Zn concentration in corn shoots (Table 6), probably due to the increased P concentration in AMF treatment by 19.3% compared to non-AMF plants (data not presented). Application of P fertilization significantly decreased Zn concentration in soybeans inoculated with AMF, but concentration of Zn in non-AMF plant was not affected (Lambert et al., 1979).

Shoot Fe Concentration

Results indicated that application of 2% PMB significantly (P<0.05) increased concentration of Fe in shoot of corn plant at both AMF and non-AMF plants. Other organic substances also increased Fe concentration at both AMF and non-AMF plants, although they were not significant at P<0.05 (Table 7). PM had no significant effect on Cu, Mn and Zn leaf concentrations of lettuce (*Lactuca sativa* L. cv.) grown in alkaline soil and decreased leaf Fe concentration (Gunes et al., 2014). Iron shoot concentration of AMF and non-AMF plants was significantly enhanced when plants were grown under the highest NaCl level (12.4 dS m^{-1}) compared to the control due to the reduction in dry matter yield (Table 3). AMF inoculation led to a significant decrease in shoot Fe concentration in corn plant (Table 7).

Shoot Cu Concentration

Shoot Cu concentration significantly increased along with additional 1% and 2% PMB in both AMF (38% and 43%) and non -AMF treated plants (56% and 58%) compared to those of controls, respectively. While, there was no change in shoot Cu concentration with 1% or 2% PM application rates as compared to those of controls (Table 8).

Table 7. Effects of salinity, poultry manure and the derived biochar on shoot Fe concentration in AMF and non- AMF plants (µg g^{-1} Dry matter)

Soil ECe Levels (dS m^{-1})	Organic substance Non-AMF Control	PM 1%	PM 2%	PMB1%	PMB2%	Mean
0.5	36.92e	40.77de	67.03a-e	49.91cde	65.24a-e	**51.97B**
3.6	43.15cde	85.57a	41.05de	52.25a-e	51.08b-e	**54.62AB**
7.9	72.40abcd	48.15cde	55.81a-e	66.93a-e	76.87abc	**64.04AB**
12.4	44.89cde	70.32a-e	62.42a-e	70.96a-e	84.23ab	**66.56A**
Mean	**49.34B**	**61.20AB**	**56.59AB**	**60.01AB**	**69.36A**	***59.30A***
	AMF+					
	Control	PM 1%	PM 2%	PMB1%	PMB2%	
0.5	42.55bc	40.26c	40.75c	48.14abc	42.64bc	**42.87B**
3.6	43.38bc	42.96bc	39.12c	41.15c	44.42bc	**42.21B**
7.9	38.03c	41.69c	48.17abc	48.26abc	48.53abc	**44.93B**
12.4	49.02abc	44.37bc	53.74ab	44.26abc	58.97a	**50.07A**
Mean	**43.24B**	**42.32B**	**45.44AB**	**45.46AB**	**48.64A**	***45.02B***

Means in each row or column followed by the same lowercase or capital letters are not significantly different (P <0.05) by Duncan's Multiple Range Test; PM and PMB: poultry manure and poultry manure biochar, respectively; AMF+ and AMF0: plants with and without arbuscular mycorrhizal fungus, respectively.

Table 8. Effects of salinity, poultry manure and the derived biochar on shoot Cu concentration in AMF and non- AMF plants (µg g^{-1} Dry matter)

Soil ECe Levels ($dS\ m^{-1}$)	Organic substance					
	Non-AMF					
	Control	PM 1%	PM 2%	PMB1%	PMB2%	Mean
0.5	2.86a	2.89a	4.75a	5.44a	5.52a	**4.29A**
3.6	3.04a	4.05a	4.82a	4.91a	4.91a	**4.47A**
7.9	3.48a	4.71a	3.69a	3.53a	3.53a	**4.18A**
12.4	3.04a	4.19a	3.35a	5.56a	5.56a	**3.84A**
Mean	**3.11B**	**3.96AB**	**4.16AB**	**4.86A**	**4.92A**	***4.20B***
	AMF+					
	Control	PM 1%	PM 2%	PMB1%	PMB2%	
0.5	5.05a-f	3.72efg	3.87d-g	5.16a-e	4.79a-g	**4.52A**
3.6	3.51fg	4.48a-g	5.54abc	5.01a-f	5.67abc	**4.84A**
7.9	3.20g	4.36b-g	3.73efg	5.95ab	5.46a-d	**4.54A**
12.4	3.68efg	4.20c-g	5.05a-f	5.15a-e	6.1a	**4.84A**
Mean	**3.86B**	**4.19B**	**4.55B**	**5.32A**	**5.51A**	***4.69A***

Means in each row or column followed by the same lowercase or capital letters are not significantly different ($P < 0.05$) by Duncan's Multiple Range Test; PM and PMB: poultry manure and poultry manure biochar, respectively; AMF+ and AMF0: plants with and without arbuscular mycorrhizal fungus, respectively.

PM increased Zn and Cu leaf concentration but had no significant effect on Fe and Mn concentrations of pepper plants (Sahin et al., 2014). Salinity levels had no significant effect on shoot Cu concentration. In AMF-plant, the highest and lowest shoot Cu concentrations were observed in 2%PMB under the highest salinity level, and without organic substance at EC_e, 7.9 dS m^{-1} salinity level.

Salinity stress increased mean Zn and Cu concentration but decreased Fe concentration in shoot of spinach (*Spinacia oleracea* L.) (Sheikhi and Ronaghi, 2012). Shoot Cu concentration increased by inoculation by AMF (Table 8). AMF increased Cu and Fe concentration by 29% and 7%, respectively, but AMF decreased Mn concentration (Lehman and Rillig, 2015).

CONCLUSIONS

Pyrolysis of poultry manure (PM) almost eliminated foul odor of PM. Also, addition of PMB was more effective than PM in increasing corn shoot dry weight except for 2% PMB in AMF treatment. It seems that simultaneous application of AMF and organic substances, with high content of P, was not beneficial in increasing plant growth or micronutrients concentration, which was confirmed by data obtained from root colonization. Addition of organic substances significantly decreased root colonization by fungi due to the high P content of applied materials. In general, in corn shoot of non-AMF and AMF plants, all micronutrients concentration significantly increased by increasing soil ECe levels except for Cu due to the reduction of soil pH which increased micronutrients bioavailability. However, at EC_e, 12.4, increase in micronutrients concentration in corn plant was due to the reduction of shoot dry weight. In general, separate application of PM or PMB in non-AMF treatments was more effective in increasing growth of corn plant or concentration of micronutrients compared to AMF treated plants.

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تحقیقات کشاورزی ایران (۱۳۹۸) ۳۸(۲) ۳۷-۴۶

اثر کود مرغی و بیوچار آن، *Funneliformis mosseae* و تنش شوری بر عملکرد و غلظت عناصر کم مصرف گیاه ذرت

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پیرولیز

سدیم کلرید

چکیده- استفاده مستقیم از کود مرغی به عنوان کود آلی در کشاورزی ممکن است باعث نگرانی‌های محیط زیستی گردد؛ بنابراین بکاربردن بیوچار آن ممکن است راه حل موثری باشد. یک آزمایش گلخانه‌ای به منظور بررسی اثر کود مرغی و بیوچار آن (عدم مصرف ماده آلی بعنوان کنترل، ٪۱ و ٪۲ (w/w) کود مرغی، و ٪۱ و ٪۲ (w/w) بیوچار کود مرغی) بر رشد و غلظت عناصر کم مصرف گیاه ذرت تحت تنش شوری (۰، ۳/۶، ۷/۹، و ۱۲/۴ دسی‌زیمنس بر متر) در حضور و عدم حضور قارچ میکوریزا آربوسکولار (*Funneliformis mosseae*) انجام شد. نتایج نشان داد که در تیمار بدون قارچ، کاربرد کود مرغی و بیوچار آن به طور معنی‌داری وزن خشک اندام هوایی را نسبت به تیمار شاهد افزایش داده است. با کاربرد بیوچار وزن خشک اندام هوایی در حدود ۱۵ و ۸ درصد به ترتیب در تیمارهای ۱ و ۲ درصد در مقایسه با کود مرغی افزایش بیشتری نشان داد. در تیمار قارچ، اضافه کردن ٪۲ بیوچار کودمرغی اثر معنی‌داری بر وزن خشک اندام هوایی نسبت به تیمار شاهد نداشت. ازاین رو، کاربرد همزمان سطح بالای بیوچار کودمرغی (٪۲) با قارچ در افزایش رشد گیاه، به دلیل بی اثر بودن قارچ بر افزایش عملکرد در سطح بالای فسفر در سطح ٪۲ بیوچار کود مرغی ، مفید نبود. در گیاهان با و بدون قارچ، تنش شوری در سطوح پایین (۳/۶، ۷/۹ دسی‌زیمنس بر متر) ، وزن خشک اندام هوایی را افزایش داد اما در سطح بالا (۱۲/۴ دسی‌زیمنس بر متر) باعث کاهش معنی‌دار آن گردید. به طور کلی، در گیاهان با و بدون قارچ، غلظت عناصر کم مصرف اندام هوایی (به غیر از مس) با افزایش سطوح شوری به طور معنی‌داری افزایش یافت. در تیمار بدون قارچ تنها کاربرد بیوچار٪۲ غلظت منگنز را نسبت به تیمار شاهد به میزان ۲۰ درصد افزایش داد. در تیمارهای با قارچ، اضافه کردن کود مرغی ٪۱، بیوچار ۱و ٪۲ غلظت منگز اندام هوایی را به ترتیب به میزان ۲۷، ۱۶ و ۹ درصد نسبت به تیمار شاهد کاهش داد. کاربرد بیوچار کود مرغی غلظت آهن، روی و مس اندام هوایی را به دلیل غلظت بالای این عناصر غذایی در بیوچار در مقایسه با کود مرغی نسبت به تیمار شاهد افزایش دادند. به طور کلی، پیرولیز کود مرغی به منظور کاهش بوی بد کود مرغی و بهبود خواص آن جهت افزایش رشد گیاه ذرت مفید تشخیص داده شد.