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Assessment of soluble phosphate enhancement in tea garden soils using cost-effective organic, mineral, and biological sources

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ABSTRACT

Given the rising costs of imported phosphorus-based fertilizers, there has been increasing interest in utilizing phosphate-rich soils as an alternative source of this plant nutrient. The present study was conducted as a complete randomized block design at the Islamic Azad University, Lahijan Branch, in Bandban village, to investigate the possibility of replacing rock phosphate with phosphorus fertilizers in some rainfed tea orchards. The treatments were: 1- control (no fertilizer), 2- triple superphosphate (TSP) (based on soil test), 3- rock phosphate (phosphorus equivalent to that of superphosphate enters the soil), 4- compost 10 t ha^{-1}, 5- rock Phosphate + phosphate solubilizing bacteria (PSB), 6- rock phosphate + phosphate solubilizing fungi(PSF), 7- rock Phosphate soil + compost 10 t ha^{-1}, 8- rock phosphate + compost + phosphate solubilizing bacteria and 9- rock phosphate + phosphate solubilizing fungi . The yield of green tea (buds and lower two leaves), phosphorus, manganese, zinc, iron, and copper concentrations in leaf and soil and also soil acidity and salinity were measured. The results showed that it is possible to use rock phosphate in acidic soils of the tea gardens, and organic matter can play an important role in the better dissolution of phosphate by microorganisms. Phosphate solubilizing bacterial fungi, and also compost application along with the rock phosphate significantly increased soil-available phosphorus. These treatments could also enhance the green tea yield. There were no significant differences in the tea plant leavs concentration for phosphorus in any of the treatment comparing with the no fertilizer control. Applying compost-containing treatments should be with cuation because of the higher trace elements concentration in these ammendments comparing to the others**.**

Keywords: Mycorrhiza, Phosphate solubilizing bacteria, Rock Phosphate, Tea plant, Phosphate fertilizers

1. Introduction

The tea plant, or *Camellia sinensis*, is an evergreen shrub from the Theaceae family. This species has two varieties – *sinensis* (from China) and *assamica* (from Assam). Together they are the sources of all white, green, yellow, pu'er, oolong, and black teas. Hot and humid weather; sandy and clay soils with pH 4.5-5.5 (Hosseinikhah-Choshali et al., 2013), are considered the most suitable growing conditions for tea plants. Optimum cultivation of tea according to its water requirement is carried out in regions with rainfall of 1800 mm/year (average rainfall of 150 mm/month), but the minimum required rainfall is 1175 mm /year (Hajiboland, 2017). In Iran, tea is cultivated in areas with an average rainfall of 1211 mm/year and between 1000 and 1400 mm /year. Top 10 Tea Producing Countries In The World 2023 were in order:

1-China: 2.2 million tons. The birthplace of tea, China leads the world in tea production. 2-India: 1.2 million tons. 3- Kenya: 432,000 tons. 4-Sri Lanka: 340,000 tons. 5-Vietnam: 214,000 tons. 6- Turkey: 212,000 tons. 7- Iran: 160,000 tons. 8-Indonesia: 148,000 tons.

Tea is a non-native plant that has been cultivated in Iran for more than 100 years. However, the development of its cultivation in Iran has been limited to Gilan and Mazandaran provinces (about 12000 hectares) due to climatic and soil limitations and has not spread to other regions of the country. Of course, this limited area provides approximately 34% of the country's tea needs and is particularly important in this regard. Soil acidification is a process in which the pH decreases with the entry of hydrogen ions into the soil during carbon, nitrogen, and sulfur cycles and fertilizer reactions, which causes the washing of alkaline cations and increases the solubility of elements such as aluminum (Inisi et al., 2023). Also, the reduction of soil CEC due to the decomposition of 2:1 clay minerals or the reduction of their negative charge due to the addition of hydroxy aluminum polymers has been reported (Wang et al., 2010). This process in tea gardens is intensified over time due to the high consumption of nitrogen fertilizers and the return of pruning residues of tea bushes, and it is obvious that old gardens are more acidic than young gardens (Feng et al., 2014). It has been reported that in the tea gardens in eastern China, compared to the adjacent barren soils, after 13, 33 and 54 years of tea cultivation, the pH of the soil decreased by 1.37, 1.62 and 1.85 units, respectively (Wang et al., 2010). In the north of Iran, the change of use and conversion of forests to tea gardens is one of the important factors of soil acidification. Acidification of the soil, increases the solubility of aluminum and stabilization of elements such as phosphorus (Frankovski, 2013). Phosphorus deficiency is one of the most important problems of tea in acidic and heavily aerated soils. Mineral phosphorus in acidic soils is one of the limiting factors for plant growth due to its fixation by iron and aluminum oxides (Yadav et al, 2017). The available phosphorus in more than 70% of the lands in Iran is less than the critical limit (15 mg/kg) (Shahbazi and Besharati, 2013) and more than 700000 tons of phosphorus fertilizers must be consumed in the lands every year to supply the phosphorus needed by the plants. Most of the phosphorous fertilizer applied in the country is triple superphosphate (TSP) fertilizer, which is imported, and a huge amount of money is spent on providing this fertilizer every year. Rock phosphate (Apatite) is the source and raw material for the production of phosphate fertilizers in the world. The industrial production of phosphate fertilizers from rock phosphate requires having the relevant technology and spending money. Due to the limited sources of soluble phosphorus fertilizers and the increase in the global trade price of this product, the direct use of rock phosphate has been proposed as one of the alternative methods. The direct application of rock phosphate as a phosphorus fertilizer is one of the simplest and cheapest methods of supplying phosphorus to plants, especially in acidic soils (Salimpour 2010). The application of rock phosphate mixed with sulfur and organic materials and the use of phosphate soil with various microorganisms, including phosphate solubilizers, sulfur oxidizers, and mycorrhizal fungi, are among the direct methods of rock phosphate application. One of the ways to increase the efficiency of phosphate rock and also the availability of soil phosphorus is the use of phosphate solubilizing bacteria (PSB). The main mechanism of phosphate-dissolving bacteria is to increase the availability of phosphorus, decrease pH through the production of protons, organic acids, mineral acids and phosphatase enzyme. Many studies have reported the use of microorganisms that dissolve phosphate compounds as a solution for phosphate fertilizers fixation; (Sudisha et al., 2018. Abdelrahman et al., 2017). Yadav and Singh (1991) reported that *Bacillus megaterium* and *cereus* species, *Aspergillus niger* and *Penicillium digitatum* significantly reduce soil acidity. In acidic soils, phosphate-dissolving fungi are better than bacteria (Yadav and Singh, 1991). It has been proven that mycorrhizal fungi increase the absorption of water and nutrients by plants due to the effective increase of the root absorption surface by creating hyphae (Smith 2008). Several studies have been done in connection with the role of mycorrhiza in providing phosphorus and other nutrients (Mochoj 2009). Dong Shao et al (2021) demonstrated that arbuscular mychoriza (AM) seedlings displayed a higher growth performance (shoot biomass, root biomass, and plant height), root morphology (total length, taproot length, 2nd- and 3rd-lateral root number, and volume), and root-hair length, but lower root-hair density than non-AM seedlings. Chelation of elements that stabilize phosphorus can be considered as one of the mechanisms of the effect of organic materials on increasing the solubility of phosphorus in the soil rhizosphere (Tian and Kolavel, 2004). Factors affecting the release of phosphorus from rock phosphate include farm management such as time and method of rock phosphate application, chemical and physical characteristics of soil, especially acidity and phosphorus stabilization ability, type of crop and its nutritional status, particle size and relative surface area, mineralogy and chemical properties of rock phosphate, reactivity and solubility of rock phosphate (Grover et al, 2003). An experiment was conducted to determine the effect of rock phosphate in acidic soils (with a pH of about 4.5) in 8-month-old tea plants cultivated in Sri Lanka, showed that 5 months after adding phosphorus sources, due to higher solubility, triple superphosphate fertilizer increased P concentration. Phosphorus was superior to rock phosphate, while 10 months after adding phosphorus sources, absorbable phosphorus concentration was higher in treatments containing rock phosphate due to long-term solubility. After 5 and 10 months, 52 and 75% of phosphorus from the rock phosphate source were dissolved in the plots where tea plants were cultivated, while in the plots without tea plants, these values were equal to 40 and 55% in 5 and 10 months, respectively (Zoisa et al., 1999). Unlike the soils of other parts of the country, which are calcareous and have a high pH, the soils under the cultivation of tea gardens are acidic, and in some cases, a pH of less than 3 has been reported. In this situation, it will not be cost-effective to use expensive and imported fertilizers such as triple superphosphate fertilizer to supply the phosphorus required by the plant. In such conditions, the use of rock phosphate as a source of plant phosphorus can be dissolved in the acidic conditions of these soils and provide a part of the phosphorus required by the plant. The results of soil analysis of tea gardens in Gilan province show that due to the acidity of these soils, rock phosphate can have greater solubility in these soils. Undoubtedly, organic matter and the presence of microorganisms that dissolve phosphate and organic matter will be very effective in this reaction. In Iran, there has been no study on the effect of rock phosphate application on phaspate availability in the acidic soils of the north. Therefore, the current research was done on domestic and cheap alternative sources and the integration of rock phosphate and organic and biological fertilizers in tea gardens.

2. Method and Material

2.1. Ecological condition of the study area

The experiment was conducted in a tea garden in Bandban Lahijan village, where the climate of the region is moderate and humid with an average rainfall of 1100 mm/year.

2.2. Statistical features of the plan:

This experiment was conducted in a completely randomized block design. with the following applied treatments in the tea garden:
1 -Control (no use of any additives)
2-Triple superphosphate fertilizer (TSP) (according to the soil test),
3 -Rock phosphate (phosphorus equivalent to that of superphosphate enters the soil)
4 -Compost 10 tons/ hectare
5 - -Rock phosphate + phosphate bacterial dissolvers (PSB) (mixture of *Bacillus* and *Pseudomonas*)
6 - Rock phosphate + phosphate dissolving fungi. (Mycorrhiza symbiotic species)
7 - Rock phosphate + compost 10 tons/hectare
8 -Rock phosphate + compost + phosphate bacterial dissolvers
9- Rock phosphate + phosphate dissolving fungi
The project was implemented in the fall of 2016 and the harvest carried out fom May to September of 2017. Each treatment was applied in 3 replicates in a 3 x 3 meter plot. The statistical model of the plan is as follows:

$$Y_{ij}= \mu + R_j + Ti + + e_{ij} \quad [1]$$

Yij: value observed in each experimental unit
μ: Average of observations
Rj: Repetition effect
Ti: Effect of experimental treatments
eij: Effect of experiment error

2.3. Experiment stages

Biological fertilizers (phosphate-dissolving bacteria and fungi) were obtained from the soil biology research department of the Soil and Water Research Institute. Apatite was obtained from Asfordi mine in Yazd province and compost was obtained from Kodali factory in Rasht. Treatments were applied on October 25, 2016 in the tea garden. To mix the fertilizer treatments with the soil, a channel was created next to the rows of bushes, and after mixing the fertilizers with the soil, the materials were mixed with the surface soil. During the experimental stages, all crop care and technical issues, including irrigation, fertilization, thinning, weeding, and operations against pests and diseases were done by the needs of the farm. All agricultural operations were done on time. Based on the information obtained from the meteorological station of the farm and related estimates, due to the good rainfall of the region (annual average of 1100 mm), the project was carried out as rain-fed. At the end of the experiment, 2 spuair meters were randomly taken from each plot to measure the yield and yield components and the concentration of elements in the plant and in the soil of the plots.

2.4. Soil analysis

To determine soil properties prior to applying the treatments and also to find total nitrogen, the available potassium and phosphorus at the end of the experiment, three soil samples from each plot were taken, randomly from different parts of the plot at depth of 0-30 cm. The samples were taken at the time of field capacity soil moisture, by a shovel. The samples were air-dried and passed through a 2 mm sieve for the relevant tests. Soil pH and electrical conductivity (EC) were determined at a water-to-soil ratio (2:1) (Thomas et al., 1996). Cation exchange capacity (CEC) was measured by (Chapman, 1965), and soil organic matter (OM) was measured by (Nelson et al., 1982). Total nitrogen (TN) was measured by (Bremner and Mulvaney, 1982). Available potassium was measured by (Pitch et al., 1982). The soil avilable phosphorus was extracted using the method of Bray & Kurtz (1945) and then measured with a spectrophotometer.

2.5. Measurement of elements in tea leaves

a) Preparation of leaf samples

After harvesting the leaves of the upper bud in the tea plants, the leaves were put in a plastic bag and the relevant treatment and replication labels were inserted on them and immediately transferred to the laboratory. The samples were washed well in the laboratory first with tap water and then with a dilute solution of hydrochloric acid (0.1 M) then rinsed several times with distilled water. The washed samples were left in the oven at 70 °C for 48 hours to dry completely. Dry samples were powdered with an electric mill and passed through a fine sieve (0.5 mm). Macro and micro elements measured through wet digestion method for N while for other elements dry ashing were used. In the wet digestion method, sulfuric acid, salicylic acid, and hydrogen peroxide were used, while in the dry digestion method, the plant sample is burned in a furnace at a temperature of 550°C, and then 2 M , HCl added to the ash.

b) Measurement of macro elements (nitrogen, phosphorus and potassium)

Total nitrogen was measured by titration method after distillation and using an automatic system (Kajal Tec). The samples were digested in special tubes with sulfuric acid, salicylic acid and hydrogen peroxide, and the tube containing the extract was installed in the distillation place of the device, and the device automatically injected boric acid and then the soda solution. The emitted

Table 1. Some Physical and Chemical characteristics of the soil prior to applying the treatment

pH	EC	CEC	Clay	Sand	Silt	OM	N	K	P
	dS m^{-1}	Cmolc Kg^{-1}		%					$mgkg^{-1}$
6.1	0.1	35	50	29	21	2.2	0.9	205	12

Table 2. Some chemical characteristics of the compost

pH	EC	N	P	K	Fe	Cu	Mn	Zn
	dS m^{-1}		%			$mgkg^{-1}$		
7.8	12.4	1.8	0.7	1.2	11340	680	483	850

Table 3. Variance analysis of the effect of experimental treatments on soil characteristics

SOV	df	P	Fe	Zn	Mn	EC	pH
				MS			
Replicant	2	5.26	1160	0.013	107	0.016	0.639
Treatment	8	27.3*	513*	0.16*	167.6*	0.012*	0.249*
Error	16	81.9	359	0.135	258.6	0.004	0.39
COV(%)		11.2	8.1	14.6	10.8	9.6	4.2

- Significant at 5% <P

ammonia entered the boric acid, and with the color change of the solution, a volume of hydrochloric acid entered the titration container, and this process continued until the end of the distillation, finally, the amount of acid used is determined and calculations are made based on it.

Phosphorus was measured by calorimetric method (molybdate-vanadate yellow color). Ammonium molybdate and ammonium vanadate solutions added to the extract obtained from plant digestion. Orthophosphate ions in an acidic environment with molybdate-vanadate solution create a yellow complex, the intensity of which is proportional to the concentration of phosphorus. The intensity of the yellow color is read with a spectrophotometer with a wavelength of 470 nm and compared to the standards, the phosphorus concentration is calculated.

Potassium was measured by flame emission method (flame photometry). The extract obtained from digesting the leaf is vaporized using the flame of the flame photometer and the excited potassium atoms produce light radiation that is measured at a wavelength of 766 nanometers. The reading obtained from the plant sample is compared with the reading of standard solutions containing different amounts of potassium and the concentration of potassium in the plant is determined.

c) Measurement of microelements (iron, zinc, copper and manganese):

The measurement of micro elements in Tea leaves was done by dry digestion method and then reading with an atomic absorption device. The results of the reading of the samples were compared with the reading of the standard and control solutions and finally the concentration of these elements in the leaf was determined.

2.6. Data analysis

The data were analyzed using the SPSS 21.0 statistical software package and Excel 2016 for Windows. And the LSD test was used at the 5% level to compare the variables.

3. Results and Discussion

The physical and chemical characteristics of the soil of the test plots before the project are presented in Table 1 and 2. The tested soil had an acidic pH, 2.2% organic matter content, non-saline with heavy texture (clay). The amount of available phosphorus was low (less than 15 mg/kg).

The results of analysis of variance of the effect of experimental treatments on soil and plant characteristics are presented in Tables 3 and 4. The effect of treatments on all the parameters measured in soil and plants was significant at the 5% level.

Table 4. Variance analysis of the effect of experimental treatments on plant (Tea leaves)

SOV	df	Zn	Fe	Mn	Total P	Leave yield
		MS				
Replicant	2	15.8	30.3	817	31.1	139881
Treatment	8	24.8*	64.1*	2724*	38.07*	512777*
Error	16	45.1	82.3	2749	3.46	113501
COV(%)		19.1	8.12	16.6	9.3	21.2

- Significant at 5% <P

MS Mean squares

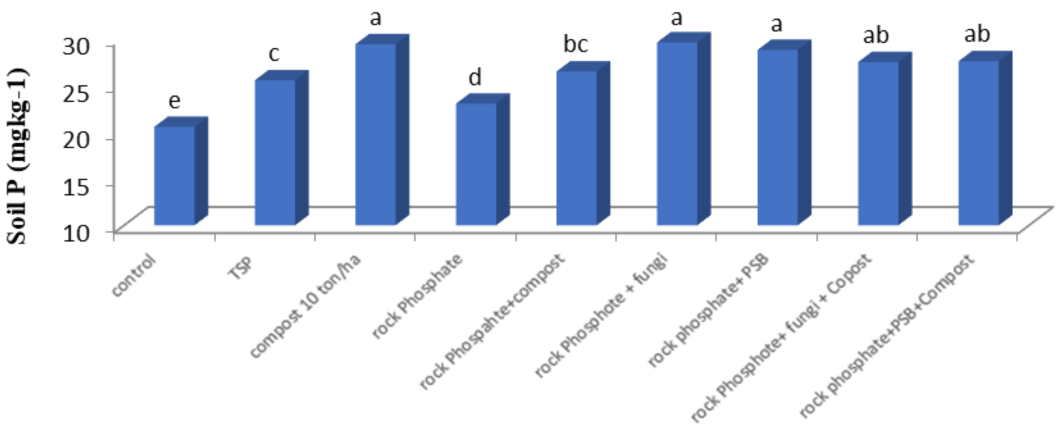

Fig 1. Effect of fertilizer treatments on soil available P.

3.1. The effect of experimental treatments on soil phosphorus

All the treatments significantly increased the avilable phosphorus of the soil compared to the control. The rock phosphate application with phosphate-dissolving fungi or bacteria and the compost application treatment had the highest amount of available phosphorus (Figure 1).

Apatite treatment with phosphate-dissolving fungi had the highest effect on soil phosphorus. 10 t ha^{-1} compost treatments and apatite + phosphate dissolving bacterial did not have a significant difference with the highest level and were placed in the group of the best statistical level. The lowest soil phosphorus concentration belonged to the control, followed by the apatite, which shows that the application of apatite alone adds a little to the soil available phosphorus, and its application with fungi or phosphate-dissolving bacteria is very effective in its efficiency. Adding 10 tons of compost per hectare was even more effective than TSP in increasing soil-soluble phosphorus. It seems that, the phosphate released from the TSP fertilizer, due to the low pH and the abundance of iron and aluminum ions of the soil, is quickly fixed in the soil. The effect of compost on soil phosphate solubility and increasing its efficiency was significantly lower than that of phosphate-dissolving fungi and bacteria. The experimental treatments increased soluble phosphorus from 20 mg/kg in the control to 29 mg/kg in apatite + phosphate-dissolving fungi, as well as the treatment of 10 tons of compost per hectare (Figure 1).

3.2. The effect of treatments on leaf phosphorus concentration

In terms of phosphorus concentration in tea leaves, all treatments, except apatite, caused an increase in phosphorus concentration in tea leaves compared to the control (Figure 2).

3.3. The effect of treatments on the yield of green tea leaves

Harvestable green leaf yield was also affected by different treatments (Figure 3). All treatments significantly increased the yield of green tea leaves compared to the control. The highest yield was obtained from treatments containing compost. Treatments 8, 9, and 7 significantly produced the highest yield of green tea leaves. After these treatments, the 10- t ha^{-1} compost produced the highest yield of green tea leaves, which shows the effectiveness of compost as an organic fertilizer in the yield of green tea leaves. The control with 2008 kg/ha showed the lowest yield among the experimental treatments, and then apatite and TSP

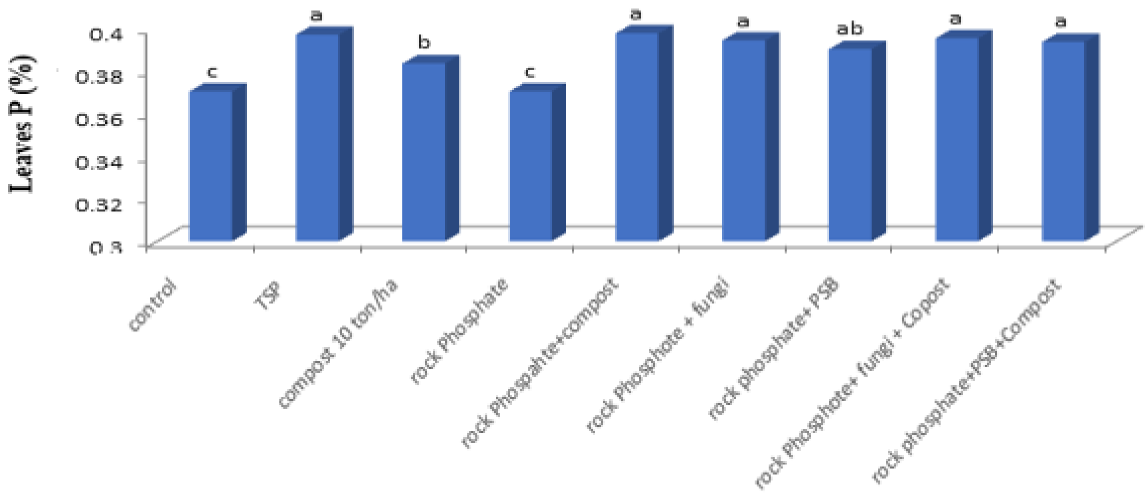

Fig 2. Effect of treatments on leaves P concentration

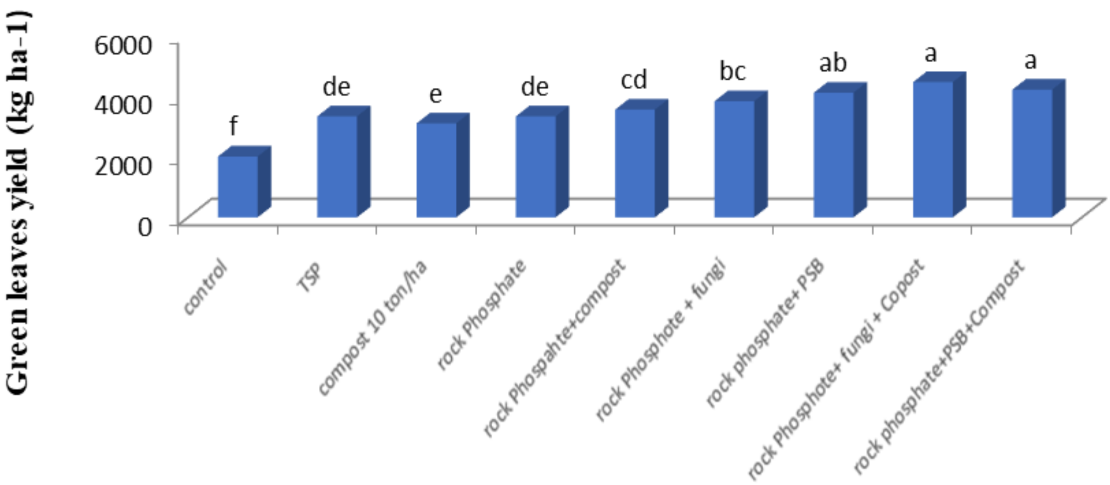

Fig 3. Effect of treatments on the yield of green tea leaves

fertilizer showed a higher yields than the control. One reason for the lower effectiveness of TSP fertilizer compared to other treatments is that both compost and phosphate-dissolving bacteria and fungi have other effects in addition to phosphorus absorption. As a result, due to other properties, the yield of organic fertilizers was higher than TSP chemical fertilizer. This may be of special importance as the main decision criterion for choosing the best treatment, and based on this, the use of compost is recommended, especially in soils with low organic matter.

3.4. Effect of fertilizer treatments on soil salinity

One of the problems of using chemical fertilizers is increasing soil salinity. Of course, in the Hyrcanian climate, rainfall of more than 1000 mm leaches salts and reduces the negative effects of soil salinity. The 10 t ha^{-1} compost was the only treatment that significantly increased soil salinity in comparison with the control (Figure 4). In the TSP treatment, because the salinity was measured at the end of the experiment, there was no effect on the salinity due to the high solubility of the fertilizer or its rapid precipitation in the form of iron and aluminum phosphate. Of course, it should be noted that the salinity obtained even at the highest levels is less than the threshold of damage to the tea plant.

3.5. The effect of treatments on soil pH

The effect of fertilizers on soil pH was also significant at the level of 1% (Figure 5). Apatite and apatite + compost + phosphate-dissolving fungi had significantly higher pH than the control and other treatments. The lowest pH was

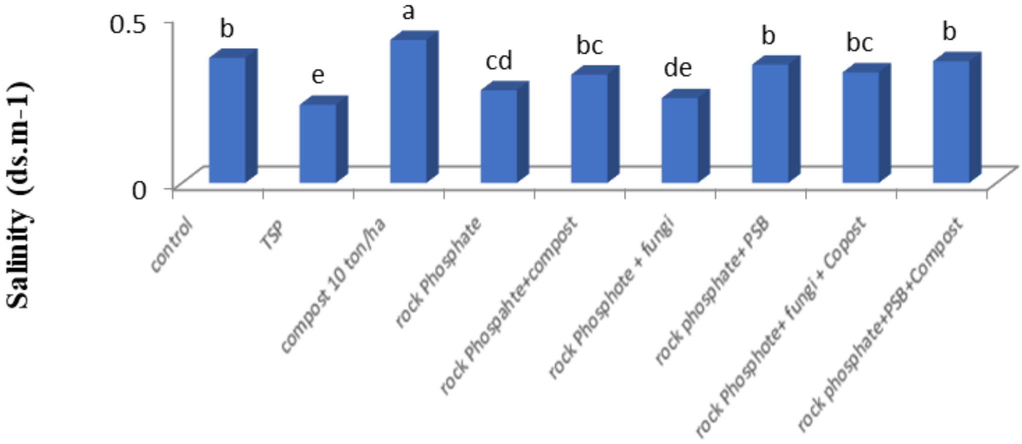

Fig 4. Effect of treatments on soil salinity

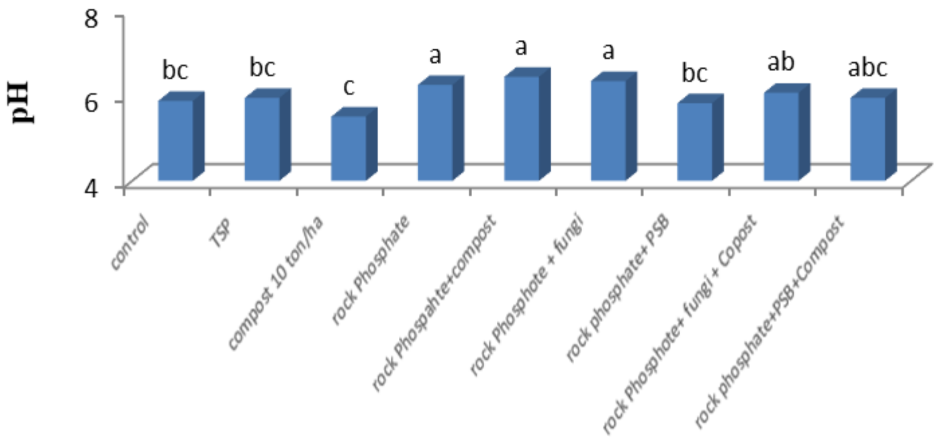

Fig 5. Effect of treatments on soil pH

observed in 10 t ha^{-1} of compost. Considering that phosphate dissolving bacteria and fungi are mainly active in the rhizosphere, their effects on soil acidity in the whole soil mass may not be significant; But they may have caused a change in acidity around the roots, which should be measured with special rhizosphere acidity tests.

3.6. Effect of treatments on manganese concentration in tea leaves

The highest concentration of leaf manganese was observed in TSP treatment. Other treatments were statistically at the same level and there was no significant difference between them (Figure 6). One of the reasons for not increasing the concentration of manganese in leaves in the treatments containing apatite and bacteria and fungi as well as compost may be the dilution effect.

3.7. The effect of treatments on available manganese concentration in the soil

The highest concentration of manganese was observed in compost treatment. Except for the mentioned treatment, other treatments were at the same statistical level as the control (Figure 7).

3.8. The effect of treatments on iron concentration in soil

None of the treatments could increase the available Fe in the soil, but a decrease in a number of treatments was observed compared to the control. This decrease was significant in some treatments, including compost, TSP treatments (Figure 8). The soil available Fe was relatively high in all treatments, which is due to the acidity of soil and the high solubility of iron compounds so that in all treatments, the concentration of soil absorbable Fe was more than 200 mg/kg of soil.

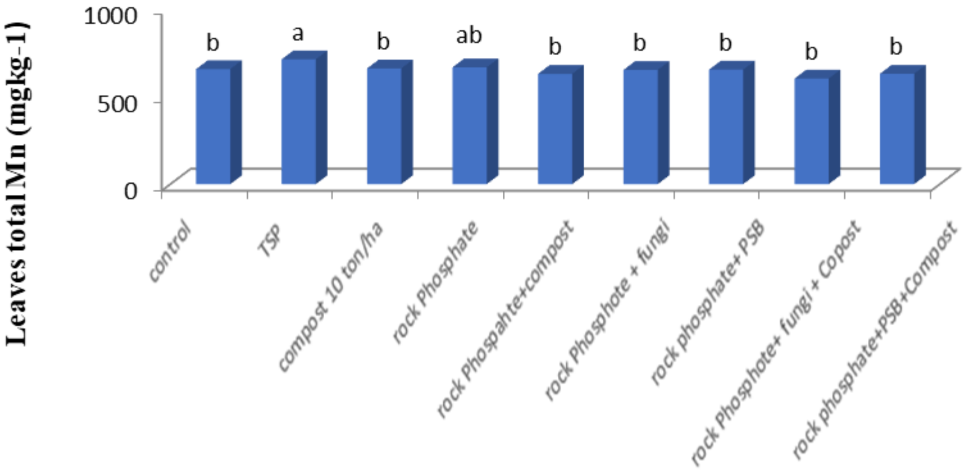

Fig 6. Effect of treatments on leaves Mn concentrations

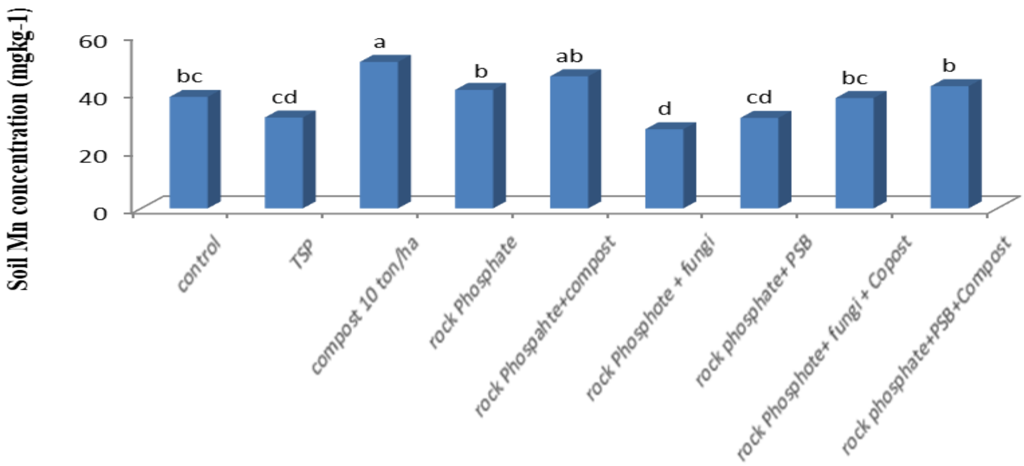

Fig 7. Effect of treatments on soil Mn

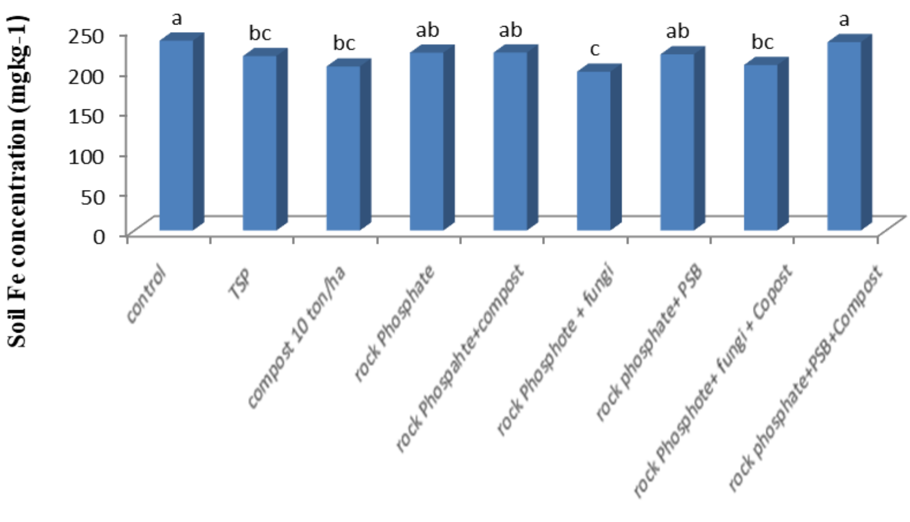

Fig 8. Effect of treatments on soil Fe

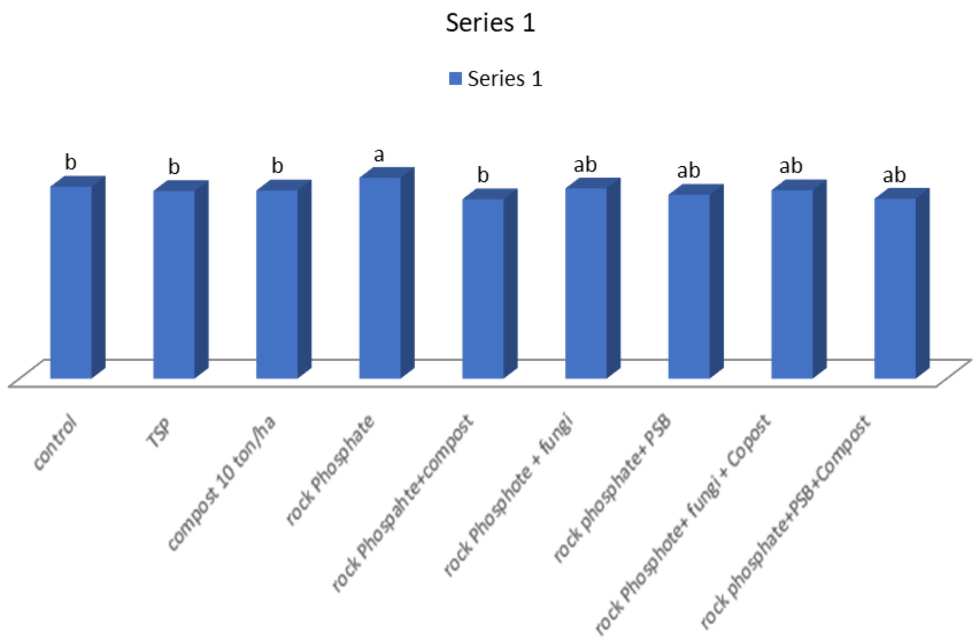

Fig 9. Effect of treatment on leaves Fe

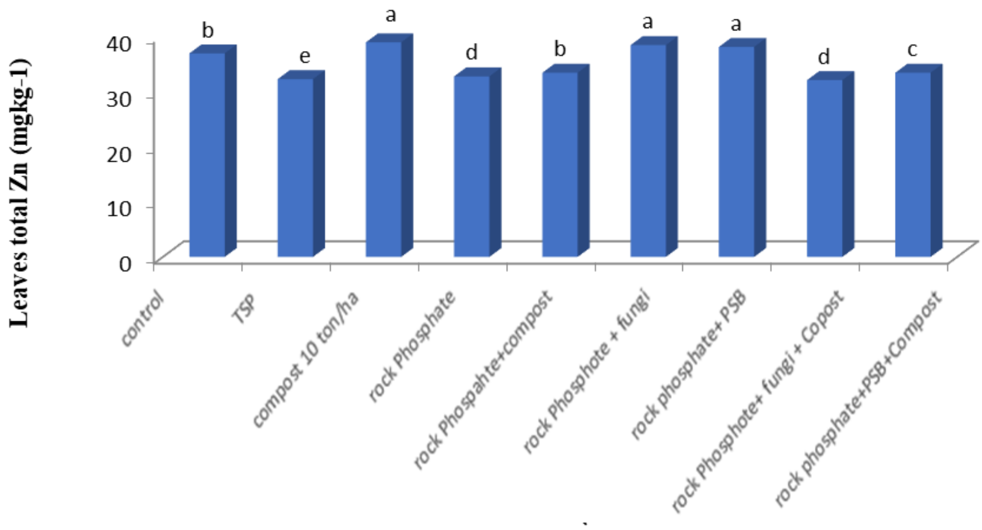

Fig 10. Effect of treatments on leaves Zn concentration

3.9. Effect of treatments on iron concentration in tea leaves

Apatite treatment was the only treatment in which the iron concentration of tea leaves was significantly higher than other treatments. One of the reasons for increasing the concentration of iron in leaves in the treatment containing apatite is the dilution effect. In all treatments, except for the mentioned treatment, due to the better growth of plants, the concentration of elements, including iron, is diluted in the shoot parts, and therefore, no significant difference was observed with the control (Figure 9).

3.10. Effect of treatments on zinc concentration in tea leaves

The concentration of zinc in tea leaves in different treatments varied from 32 mg/kg to about 39 mg/kg. The treatment using 10 tons per hectare of compost, with the highest level of avilable zinc, showed the highest concentration of zinc in tea leaves. Triple superphosphate and rock phosphate treatments(Apatite) showed the lowest leaf Zn (Figure 10).

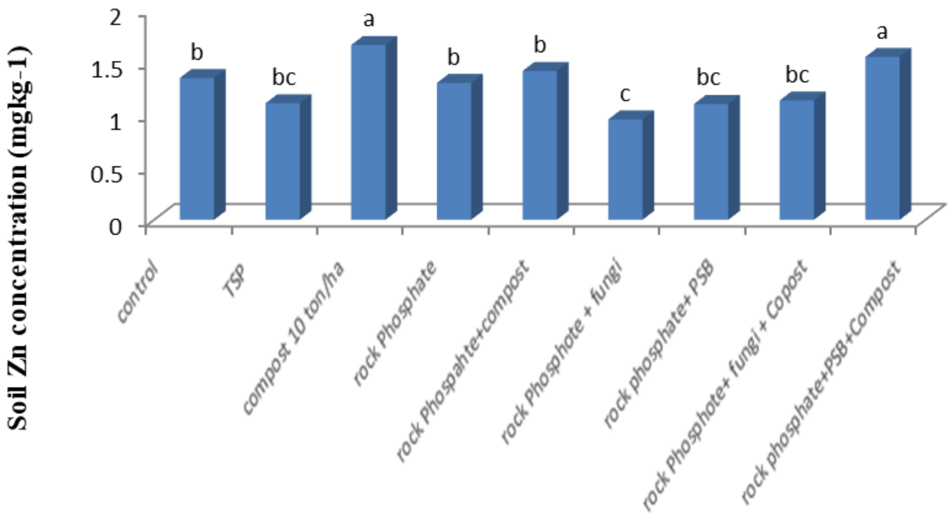

Fig 11. Effect of treatments on soil available Zn concentration

3.11. Effect of treatment on soil available zinc concentration

The 10 tons of compost per hectare and the compost + apatite and phosphate-dissolving bacteria showed higher concentrations of zinc compared to the control and other treatments, and the other treatments did not have a significant difference with the control (Figure 11).

4. Discussion

Different plants have different ability to use rock phosphate as a source of phosphorus. Among the plants, the ones that have the characteristics and extent of the root system are better able to absorb phosphorus from the rock phosphate. Organic acids secreted from the roots of plants have a significant effect on the ability to absorb phosphorus from the soil. Camellia family plants (such as tea) have a great ability to utilize relatively insoluble soil phosphorus (Zoisa et al., 1997). The reason for the increase of phosphorus in the soil and tea plant in some treatments is probably related to the fact that the tea plant has been able to use rock phosphate due to its root system. One of the nutritional problems of tea gardens is lack of phosphorus in acidic and highly weathered soils. In an experiment, rock phosphate was used in acidic soils under tea cultivation, and the results showed that after 5 months use of TSP fertilizer, it was superior to rock phosphate in increasing phosphorus concentration, while after 10 months, absorbable phosphorus concentration in the treatments containing rock phosphate was higher (Zoisa et al., 2001). The present experiment was carried out in one year in the tea garden, that may not be enough for disolution of all the applied rock phosphate, and the remaining rock phosphate usually will be effective in the following years. Probably, if the experiment was extended for a longer period of time, the results of using rock phosphate would be more promising than the measured values. Therefore, it is recommended to carry out similar work for at least a few years in tea gardens so that the results can be generalized and recommended with more confidence. The use of compost increased soil pH. This is one of the benefits of compost for acidic soils. Zhang et al. (2006) reported that the amount of phosphorus in compost is sufficient for dominant plant growth. One of its reasons is the reduction of phosphorus fixation in the soil as a result of compost consumption. Some sources have also mentioned that the amount of soluble phosphorus in compost is equal to the phosphorus released from chemical fertilizers (Igleshiyaz et al., 1993). The activity of the phosphatase enzyme also increases with the increase in the amount of compost (Crecchio et al., 2004). In the current research, also in treatments containing compost due to the improvement of chemical, physical, and soil bioactivity (increase in enzyme activity and dissolution and release of elements) indicators measured in soil and plant were significant compared to the control. Also the effect of using organic fertilizer (compost) on some of the parameters measured in soil and plants was significant, and its combined use with rock phosphate and microorganisms was considered the best treatment. Among the fungi, mycorrhizal fungi, especially arbuscular mycorrhiza (AM), and among the bacteria, *Bacillus* and *Pseudomonas* strains are the most important phosphate-solubilizing organisms. The results of Taha et al. (1969) showed that the inoculation of phosphate solubilizers with sterile soils, dry weight, increases the absorption of phosphorus and the concentration of phosphorus in the soil solution. This research also aimed to find a combination of rock phosphate with effective microorganisms as a bio-fertilizer instead of chemical phosphorus fertilizer in tea gardens and a mixture of rock phosphate and compost.

Bacillus bacteria and mycorrhizal fungus in increasing soil absorbable phosphorus, plant yield and phosphorus content, showed very good results. Banik and Day (1982) reported that soil inoculation with *Bacillus* bacteria was more effective in sterile soils than in non-sterile soils; Because most of the phosphorus dissolved by phosphate solvents is absorbed by other microorganisms. There are several reasons for the plant not responding to the inoculation with bacteria, which can be the reduction of the number of bacteria after inoculation into the soil due to insufficient nutrient root secretions, the bacteria not settling in the rhizosphere, the reduction of the efficiency of bacteria to dissolve insoluble phosphate and the competition between bacteria and The plant indicated for the absorption of nutrients. Another effective factor in the number of phosphate-dissolving bacteria is pH suitable for activity. The microorganisms used in this research were isolated from non-acidic soils, so if in some cases their efficiency is lower than expected, this issue could possibly be due to the environmental conditions of acidic soil, so one of the proposals of this research for next researches is the isolation and use of native microorganisms of acidic soils.

5. Conclusions

The soils under tea cultivation in northern parts of Iran, phosphorus deficiency is usually observed because of the fixation processes. The fixation is due to the abundant iron and aluminum, resulting in less phosphorus plant availability.. The solubility of rock phosphate and the release of phosphorus in acidic soils are much higher than in calcareous soils. Therefore, the effectiveness of the direct application of rock phosphate in acidic soils is significant, , so direct application of rock phosphate in acidic soils can be considered. In this regard, combining of rock phosphate with substances like organic materials and phosphate-dissolving microorganisms (bacteria and fungi) is suggested as a suitable alternative to imported phosphorus fertilizers, which was confirmed in the present study.

It is suggested that considering the tea plant as a multi-year plant and some treatments such as compost and rock phosphate have residual effects therefore, several years of testing should be done on tea so that the results are recommendable in tea gardens. Of course, in this experiment, considering this issue, treatments were applied in September and sampling of soil and plants was done in May of the following year for having sufficient time interval to observe the effects of treatments. It is also suggested to determine the most appropriate amount and time of rock phosphate consumption in acidic soils under tea cultivation, as well as to determine the minimum number of phosphate-dissolving microorganisms so that the solubility of phosphorus is at a significant level. Experiments should be carried out in tea gardens. Finally, it is recommended to use native bacteria of tea gardens in similar experiments and measure the qualitative properties of tea, aroma, taste, coloring, aluminum concentration, , which the measuring were not possible in this study.

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