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The role of some lichen species on phosphorus fertilizer use efficiency and growth parameters of corn (*Zea mays* L.) plants

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Abstract

The aims of this study were to evaluate some lichen species increasing fertilizer use efficiency and improve soil fertility without affecting the quality of soils and plants. A greenhouse experiment was conducted in 2009 to investigate the effects of lichen species on P, K, Ca, Mg, Na, S, Fe, Cu, Mn, Zn and B nutrient contents of soil, plant yield and phosphorus content of maize (*Zea mays* L.) plants grown on Aridisol eastern Anatolia, Erzurum province, Turkey. Pot experiments were conducted using a randomized complete block design with four P fertilizer doses (0, 100, 200 and 300 kg P_2O_5 ha^{-1}), four lichen species (*Rhizoplaca melonophthalum*, *Rhizoploca crysoleuca*, *Peltigera rupescens*, and *Peltigera proetexfota*), three lichen doses (0, 5, and 10 g kg^{-1}) and three replicates. The studies were done with an aridisol sampled to a depth of 0-15 cm from agricultural fields in Erzurum province (39° 55' N, 41º 61' E) in Turkey. Plant was harvested 45 d after planting. Phosphorus fertilizer and lichen species affected significantly plant growth and soil chemical properties especially in rhizosphere soil and plant P nutrient contents after one growing season. Dry-matter yield of plant were significantly and quadratically increased with P fertilization and different lichens doses. Concentrations of nutrient content were significantly increased in a quadratic fashion with the increasing nutrient content rates. P, K, S, Ca, and Mg contents were increased with increasing P fertilizer doses, but microelement content was decreased after 200 kg ha^{-1} P doses at all of the lichen species. The highest P was obtained from *R.melonophthalum* , Na and K were *R. crysoleuca*, B, Ca, Mg and Zn were *P. rupescens*, Fe, Cu, Mn and S were *P. proetexfota* lichen species. Phosphorus use efficiencies and physiological efficiencies were decreased with increasing P rates. However, lichen application increase P use and physiological efficiencies efficiency, and the highest efficiency parameter were obtained from parameter varied from *P. Proetexfota*.

Key words: Ardisol, fertilizer use efficiency, lichen, macro and micro nutrient, physiological efficiencies

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N. Ataoğlu, A. Güneş, A. Esringü, O. Uzun, S. Ata, M. Şahin, F. Akkuş, A. Gürsoy, M. Turan*, A. Aslan, 2010. The role of some lichen species on phosphorus fertilizer use efficiency and growth parameters of corn (*Zea mays* L.) plants. *In:* Proceedings of the International Soil Science Congress on Management of Natural Resources to Sustain Soil Health and Quality. R.Kizilkaya, C.Gulser, O.Dengiz (*eds.*), May 26-28, 2010. Ondokuz Mayis University, Samsun, Turkey. pp. 1242-1251.

INTRODUCTION

Increasing world population has created a continued demand on agricultural production. Intensive farming practices adopted involve the use of costly inputs such as chemical fertilizers, pesticides, and other chemicals. Phosphorus is one of the major essential macronutrients for biological growth and development for agricultural production. Most soils contain substantial reserves of total phosphorus, most of it remains relatively inert, and only less than 10% of soil phosphorus enters the plant-animal cycle. The conventional approach to improve phosphorus nutrition for optimum crop yield is to apply a phosphatic fertilizer which contains phosphorus in soluble form. However, the applied P is also subjected to the same fixation processes, resulting in a large fraction of it unavailable to plants. It has been estimated that the proportion of phosphorus fertilizer used by plants is in the order of only 5–25% (Wild, 1988; Vance, et al. 2003). The most important factors controlling the availability of P to plant roots are its concentration in the soil solution and the P-buffer capacity of the soil. The latter controls the rate at which P in the soil solution is replenished, i.e. the rate of desorption of P from the solid phase of the soil, which is faster in soils with a high buffer capacity (Syers, et al. 2008).

Lichens are known for their ability to cope with extreme environments. They can adapt to extreme temperatures, drought, inundation, salinity, high concentrations of heavy metals (Nash, 2008), or even survive in outer space (Sancho, et al. 2007). Another outstanding character of lichens is tolerance to nutrient-poor environments. Lichen substances are a chemically diverse group of more than 800 mostly phenolic compounds largely specific to lichen-forming fungi. They recently were shown to specifically inhibit the intracellular uptake of toxic amounts of transition metals, whereas other metals absent at toxic concentrations from the environment of the lichen could pass (Hauck, 2008). It is well known that a considerable number of lichen species, mostly those associated with the plant rhizosphere, are able to exert a beneficial effect upon plant growth (Hauck, 2008). Some of them render these insoluble phosphates into soluble form through the process of acidification (usnic acid), chelation and exchange reactions. This process not only compensates for higher cost of manufacturing fertilizers in industry but also mobilizes the fertilizers added to soil. Solubilization of rock phosphate (RP), especially low grade and its use in agriculture is receiving greater attention. Therefore, their use as bio fertilizers or control agents in agriculture has been a focus of research for a number of years. A large number of heterotrophic and autotrophic micro organisms, such as bacteria (Louw and Webly, 1959), fungi (Agnihotri, 1970), and cynobacteria (Roychoudhury and Kaushik, 1989) are reported to solubilize insoluble phosphate, e.g. hydroxyapatite, tricalcium phosphate, and rock phosphate. Such activities are often demonstrated in agricultural soils where crop production has been augmented considerably (Banik and Dey, 1981; Bhattacharya, et al. 1986). But there is not enough information about lichens.

The purpose of this study of this investigation is to examine the effects of lichen species on phosphorus use efficiency and phosphorus nutrient content of soil, yield of maize (*Zea mays* L.) plants grown on Aridisol eastern Anatolia, Erzurum province, Turkey.

MATERIAL AND METHODS

Initial Soil Sampling and Characterization

The experiment was conducted to determine effects of lichen species to increase phosphorus fertilizer use efficiency, yield and phosphorus nutrient contents of maize (*Zea mays* L.) plants grown on Aridisol to the USA taxonomy (Soil Survey Staff, 1992). The soil had loamy texture (33.2 % sand, 38.4 % silt, and 28.4% clay); 2.40% $CaCO_3$, 212.2 m mol kg^{-1} P_2O_5, 335.1 m mol kg^{-1} K_2O, 7.25 pH (H_2O) and 1.63 dS m^{-1} electrical conductivity. Four lichen species were collected from Erzurum province in July 2009 and they were identifed in the laboratory of lichenology at the Department of Biology by Dr. Aslan (Aslan, et al. 2002). Sample specimens have been stored in the herbarium of Kazım Karabekir Faculty of Education, Ataturk University, Erzurum (Turkey).

Experimental Design: Pot experiments were conducted using a randomized complete block design with four P fertilizer doses (0, 100, 200 and 300 kg P_2O_5 ha^{-1}), four lichen species (*Rhizoplaca melonophthalum*, *Rhizoploca crysoleuca*, *Peltigera rupescens*, and *Peltigera proetexfota*), three lichen doses (0, 5, and 10 g kg^{-1}) three replicates. The studies were done with an aridisol sampled to a depth of 0-15 cm from agricultural fields in Erzurum province (39° 55' N, 41º 61' E) in Turkey and 1000 g soil was transferred to 108 polyethylene pots (20 cm diameter and 15 cm depth). Four lichen species with three lichen doses (0, 5, and 10 g kg^{-1}) were added to soil. Soils were saturated with dionized water prior to air-drying to room temperature and further mixing. The wetting-drying mixing process was repeated to ensure equilibrium following 1 mo after incubation. The wetting-drying mixing process was repeated to ensure equilibrium following 1 mo after incubation. To support optimum maize growth 150 kg ha^{-1} N (NH_4NO_3 33 % N), 100 kg ha^{-1} K_2O (K_2SO_4 50% K_2O) were applied before planting. One month after the addition of lichen, maize seed was placed at the same depth (approximately 2.5 cm below the soil surface) in all pots according to 1 plant pot^{-1} in a heated greenhouse under natural light (14 h day length), a minimum temperature of 10-11ºC and maximum of 25-30ºC, and a relative humidity of 30-40%.

Treatments all of the study were regularly irrigated with pure water. Soil water content was carefully controlled. When 70% of useful water in the soil had consumed, pure water was applied to the soil and leakage from the pots was not allowed. At the end of the experimental period (45 days), the plants were harvested in the each pot with corn plant planted, measured, and analyzed.

Plant and Soil Analysis

Plant samples were oven-dried at 68°C for 48 h and ground to pass 1mm sieve. P content of plant was determined after wet digestion of dried and ground sub-samples using a HNO_3-H_2O_2 acid mixture (2:3 v/v) with three step (first step; 145ºC, 75%RF, 5 min; second step; 180ºC, 90%RF, 10 min and third step; 100ºC, 40%RF, 10 min) in microwave (Bergof Speedwave Microwave Digestion Equipment MWS-2) (Mertens, 2005a). Tissue P, K, Ca, Mg, Na, S, Fe, Cu, Mn, Zn and B were determined using an Inductively Couple Plasma spectrophotometer (Perkin-Elmer, Optima 2100 DV, ICP/OES, Shelton, CT 06484-4794, USA) (Mertens, 2005b).

Soil samples were air-dried, crushed, and passed through a 2-mm sieve prior to analysis. Cation exchange capacity (CEC) was determined using sodium acetate (buffered at pH 8.2) and ammonium acetate (buffered at pH 7.0) according to Sumner and Miller (1996). The Kjeldahl method (Bremner, 1996) was used to determine organic N while plant-available P was determined by using the sodium bicarbonate method of Olsen et al. (1954). Electrical conductivity (EC) was measured in saturation extracts according to Rhoades (1996). Soil pH was determined in 1:2 extracts, and calcium carbonate concentrations were determined according to McLean (1982). Soil organic matter was determined using the Smith-Weldon method according to Nelson and Sommers (1982). Ammonium acetate buffered at pH 7 (Thomas, 1982) was used to determine exchangeable cations.

Statistical analysis

All results contained the mean values of duplicate analyses from at least tree individual plants. All data were subjected to one way analysis of variance (ANOVA) and separated by Duncan's multiple range tests using the (SAS) statistical software (SAS 1982).

RESULTS AND DISCUSSION

Plant total yield

Phosphorus fertilizer and lichen applications to different levels positively affected on plant dry weight of plants (Figure 1) and statistically significant differences were obtained among P doses and different lichen species. The highest shoot dry matter was determined at 200 kg ha^{-1} P with 5 g kg^{-1} *R. melonophthalum* lichen application doses when compared to the other treatments.

Soil P content

Phosphorus fertilizer and lichen applications to different levels positively affected on soil available P content (Figure 2). The highest P concentrations were determined at 200 kg ha^{-1} P with 10 g kg^{-1} *R. melonophthalum* lichen application doses when compared to the other treatments.

Phosphorus use efficiency: Phosphorus fertilizer and lichen applications ratio significantly influenced P use efficiency. P use efficiency were decreased with increasing P application doses, but lichen application increased the P use efficiency all of the lichen species. The highest positive effect was obtained form *R. melonophthalum* lichen application at 100 kg P ha^{-1}.

Phosphorus physiological efficiency: Phosphorus fertilizer and lichen applications ratio significantly influenced physiological efficiency. Physiological efficiency were increased with increasing P application doses and the highest positive effect was obtained form *.P proetexfota* lichen application at highest P doses (300 kg P ha^{-1}).

Nutrient content

Concentrations of nutrient content were significantly increased in a quadratic fashion with the increasing nutrient content rates. P, K, S, Ca, and Mg contents were increased with increasing P fertilizer doses, but microelement content was decreased after 200 kg ha^{-1} P doses at all of the lichen species. The highest P was obtained from *R. melonophthalum* , Na and K were *R. crysoleuca*, B, Ca, Mg and Zn were *P. rupescens*, Fe, Cu, Mn and S were *P. proetexfota* lichen species. Phosphorus use efficiencies and physiological efficiencies were decreased with increasing P rates. However, lichen application increase P use and physiological efficiencies efficiency, and the highest efficiency parameter were obtained from parameter varied from *P. proetexfota.*

Phosphorus fertilizer and lichen applications to different levels positively affected on soil P concentration, P fertilizer use efficiency, physiological efficiency and plant dry weight of corn. The highest P fertilizer use efficiency, soil P concentrations and yield were determined at 200 kg ha^{-1} P with 10 g kg^{-1} *R. melonophthalum* lichen application doses but, the highest physiological efficiency was determined at 200 kg ha^{-1} P with 10 g kg^{-1} *P proetexfota* when compared to the other treatments. On the other hand plant nutrient content were affected P application doses depend on lichen species. The most effective lichen species were *R. melonophthalum, R. crysoleuca, P. rupescens, P. proetexfota* lichen species for P, Na and K, B, Ca, Mg and Zn, and S, respectively. Our results were in good agreement with those reported by Makkonen, et al. 2007; Sancho, et al. 2007; Nash, 2008; Hauck, 2008; Bowker, et al., 2008; Hauck, et al. 2009).

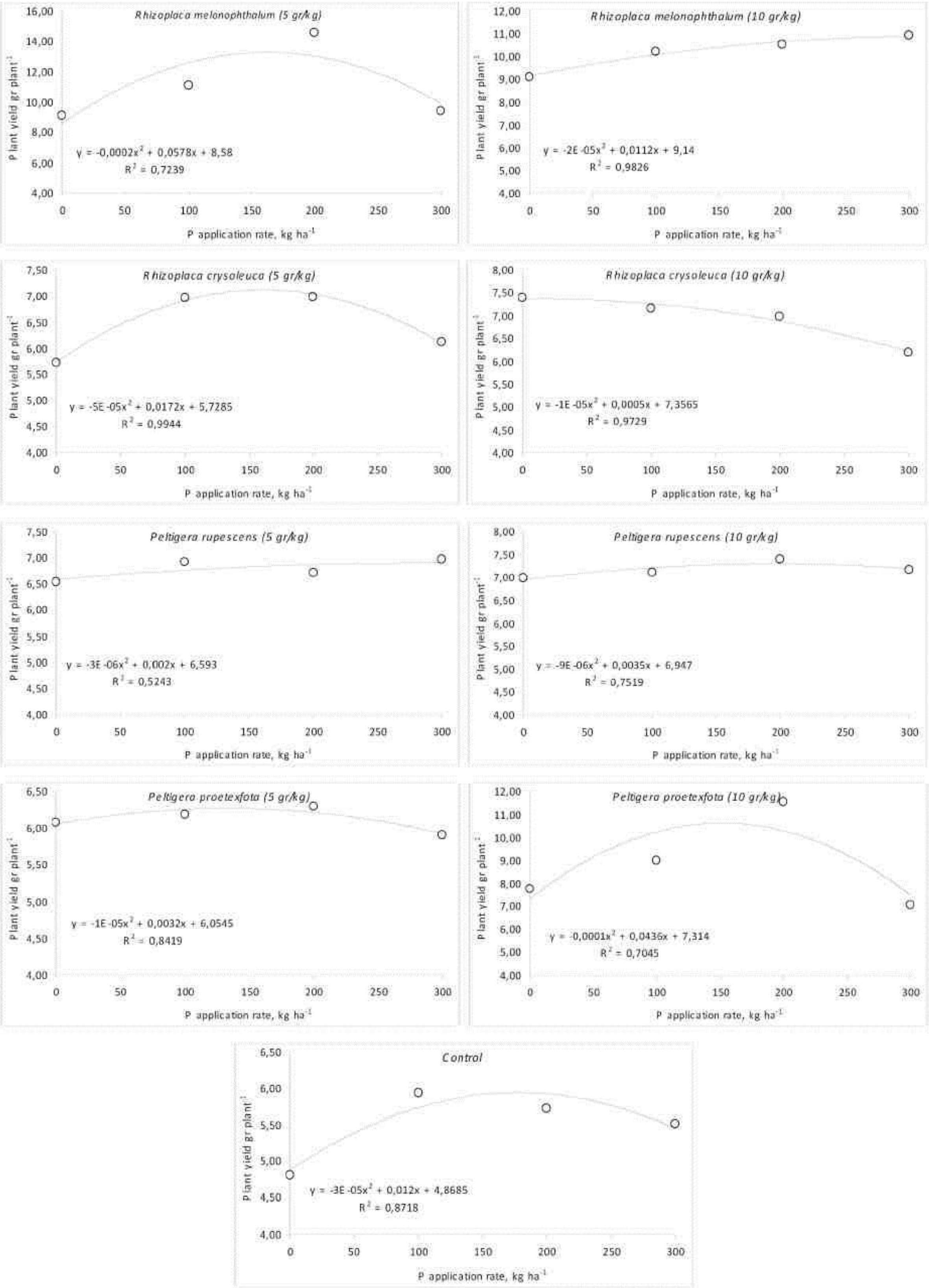

Figure 1. Effects of lichen and phosphorus application on maize yield

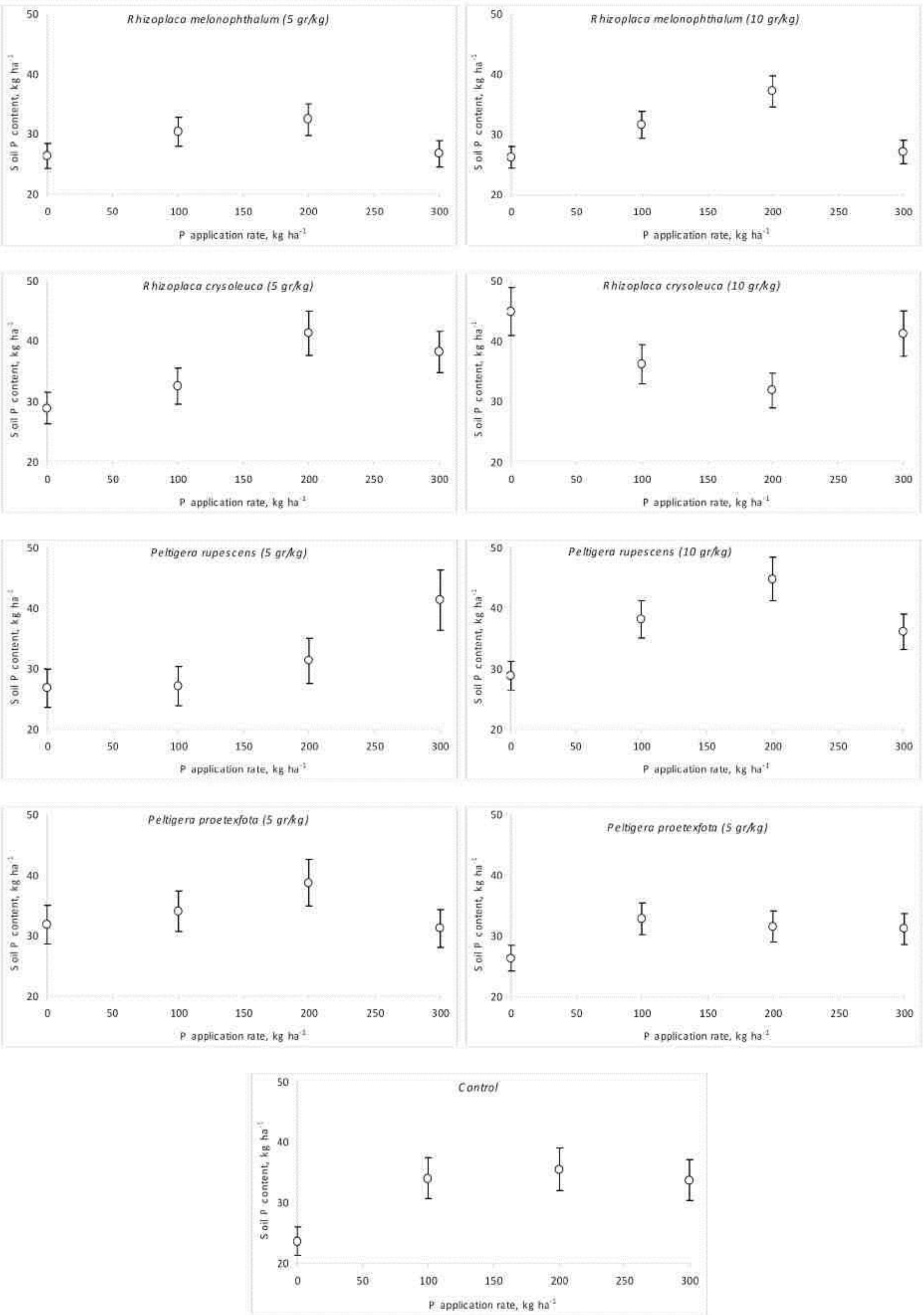

Figure 2. Effects of lichen and phosphorus application on soil P content

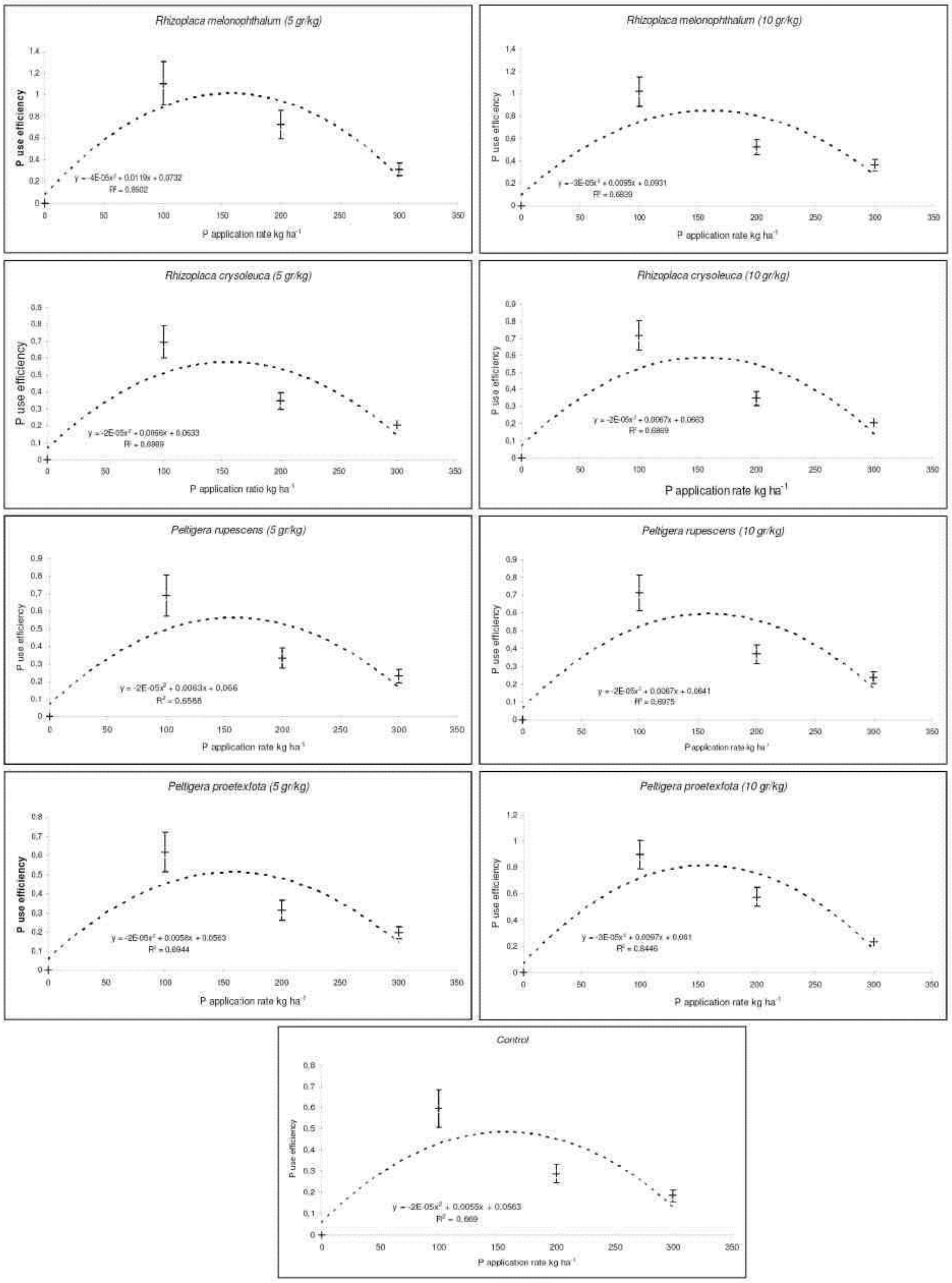

Figure 3. Effects of lichen and phosphorus application on P use efficiency

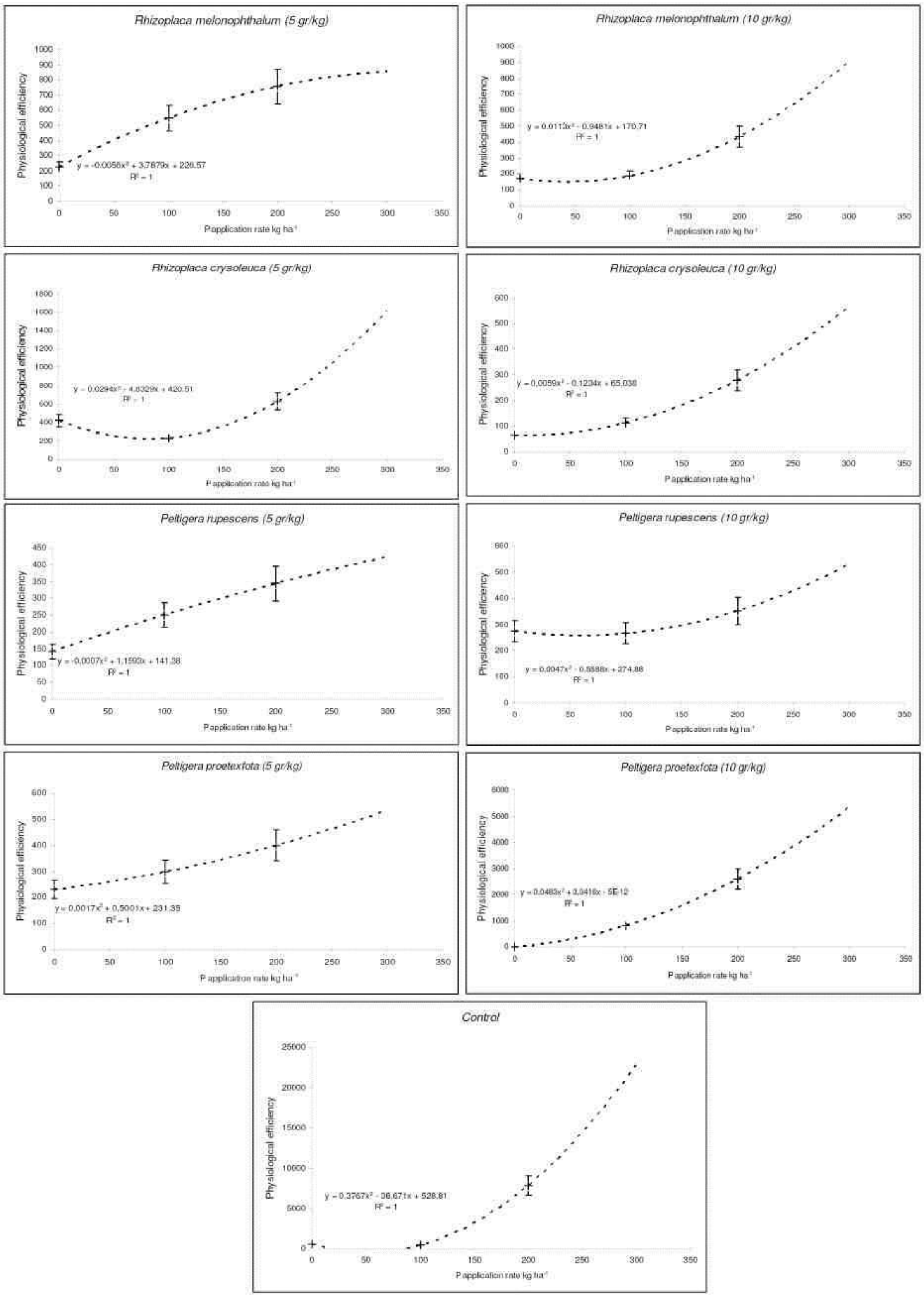

Figure 4. Effects of lichen and phosphorus application on P physiological efficiency

CONCLUSION

The result indicated that application of some lichen species had positive effect on P fertilizer us efficiency and plant growth. Among the lichen species tested in this study, *R.*

melonophthalum was found to have better capacity increasing the P availability and plant uptake. Therefore, *R. melonophthalum* may have potential use in the development of bio-fertilisers in organic agriculture, but further studies are required in order to determine the efficiency of this lichen in solubilizing rock phosphate under natural field conditions, and relationships between biomass of each lichens and their P solubilization.

Table 1. Effects of lichen species and phosphorus fertilizer on nutrient content of corn plant

	B	Ca	Cu	Fe	K	Mg	Mn	Na	P	S	Zn
Kontrol	3,10	1978	8,02	31,08	11120	599	5,52	411	925	148	3,60
10 kg P/da	3,85	1810	14,24	78,16	14490	707	7,27	558	1110	138	7,47
20 kg P/da	3,65	1810	10,44	84,69	12290	722	7,30	524	1152	255	7,21
30 kg P/da	2,37	1703	10,20	62,69	12380	502	4,84	348	822	158	6,05
R. Melanophtalma-5 + KF-0	2,34	2087	6,69	36,16	8865	629	6,16	668	782	140	7,48
R. Melanophtalma-5 + KF-10	2,70	4544	9,92	46,84	14220	795	7,04	703	1426	532	7,19
R. Melanophtalma-5 + KF-20	3,37	2703	6,21	106,80	6479	757	7,98	944	1172	247	7,20
R. Melanophtalma-5 + KF-30	2,48	1781	5,00	50,54	11710	677	5,84	466	1178	559	3,58
R. Melanophtalma-10 + KF-0	3,09	1963	4,94	83,87	14630	796	6,82	480	832	425	8,88
R. Melanophtalma-10 + KF-10	2,47	3391	4,48	19,15	9896	661	6,92	527	1374	212	2,62
R. Melanophtalma-10 + KF-20	3,14	2142	5,15	31,62	15100	844	7,34	521	1441	718	9,77
R. Melanophtalma-10 + KF-30	6,00	2818	5,11	51,25	14050	961	12,34	872	1078	435	6,67
R. crysoleuca -5 + KF-0	4,80	2962	4,84	67,86	15190	938	9,27	767	796	500	6,12
R. crysoleuca -5 + KF-10	4,44	2456	12,07	56,37	11840	810	9,29	806	1082	369	6,67
R. crysoleuca -5 + KF-20	3,42	2282	12,41	114,00	14930	876	8,05	523	1438	714	7,52
R. crysoleuca -5 + KF-30	3,38	2697	9,58	138,70	10240	799	8,71	497	848	528	5,16
R. crysoleuca -10 + KF-0	2,71	2073	4,86	42,13	14850	794	6,68	454	750	716	7,59
R. crysoleuca -10 + KF-10	2,84	2856	3,70	115,00	11300	926	9,77	775	1268	580	3,94
R. crysoleuca -10 + KF-20	3,16	3178	4,57	123,60	13990	909	9,47	764	1318	428	6,61
R. crysoleuca -10 + KF-30	2,61	2088	3,70	33,51	10220	792	8,74	539	820	458	3,63
P. Rupescens -5 + KF-0	2,76	2010	4,54	48,09	13940	780	7,50	490	736	627	5,61
P. Rupescens -5 + KF-10	9,49	3264	5,52	78,92	12720	1820	22,02	146	1084	441	7,20
P. Rupescens -5 + KF-20	14,00	3150	5,83	64,71	11260	1851	26,42	96	1120	717	8,25
P. Rupescens -5 + KF-30	7,80	4001	5,07	61,30	10250	2019	28,91	91	690	522	6,00
P. rupescens-10 + KF-0	13,41	2826	4,36	46,00	8071	1660	22,48	89	706	642	6,60
P. rupescens-10 + KF-10	10,90	3460	5,03	49,00	10570	2239	31,49	82	760	653	9,94
P. rupescens-10 + KF-20	13,34	3847	6,45	52,57	7517	2144	30,00	77	876	464	9,35
P. rupescens-10 + KF-30	17,35	2892	8,87	40,78	10040	1633	25,31	84	664	841	9,51
P. pratextata-5 + KF-0	5,99	3072	5,91	38,81	7749	1663	25,96	86	738	528	5,06
P. pratextata-5 + KF-10	4,99	2201	7,66	51,52	11570	1253	14,61	96	796	516	9,74
P. pratextata-5 + KF-20	9,42	4792	7,54	64,38	8265	2017	33,92	90	825	508	8,97
P. pratextata-5 + KF-30	11,73	3403	4,58	66,81	10690	1695	31,13	112	762	576	5,24
P. pratextata-5 + KF-0	5,19	2963	13,14	68,75	9853	1376	24,61	116	818	543	7,97
P. pratextata-5 + KF-10	3,27	2378	9,01	120,00	10700	1481	25,02	126	844	740	6,79
P. pratextata-5 + KF-20	15,54	2053	5,40	55,51	9549	1730	25,04	98	952	873	4,24
P. pratextata-5 + KF-30	8,88	2276	12,02	131,80	10930	2204	24,41	119	884	993	5,68

REFERENCES

Agnihotri, V.P., 1970. Solubulization og insoluble phosphates by some fungi from nursery seed beds. Can. J. Microbiol. 16:877-880.

Aslan A., Aproot A., Yazıcı, K., 2002. New lichens for Turkey. Mycotaxon 84: 277-280.

Banik, S., Dey, B.K., 1981. Phosphate solubilizing microorganisms isolated from Bihar soils. I. Solubilisation of inorganic phosphate and production of organic acids by microorganisms isolated in sucrose calcium phosphate agar plates. Zbl. Bakt. II Abt. 136:478-486.

Bhattacharya, P., Dey, B.K., Banik, S., Nath, S., 1986. Organic manures in relation to rhizosphere effect. V. Effect of organic manures on phosphate solubilizing power of rice and successing wheat rhizosphere soils. Zbl. Mikrobial. 141:357-365.

Bowker, M.A., George, W.K., Jayne, B., Nancy, C.J., 2008. Nutrient availability affects pigment production but not growth in lichens of biological soil crusts. Soil Biology & Biochemistry 40 (2008) 2819–2826

Bremner, J.M., 1996. Nitrogen-total. pp,1085–1121 *In:* Methods of soil analysis. Part III. Chemical Methods (Bartels, J.M., and J.M. Bigham eds.) 2nd Ed. ASA SSSA Publisher *Agron.* No: 5 Madison WI, USA.

Hauck, M., 2008. Metal homeostasis in Hypogymnia physodes is controlled by lichen substances. Environ. Pollut. 153:304–308.

Hauck, M., Jürgens, S.R., Wıllenbruch, K., Huneck, S., Leuschner, C., 2009. Dissociation and metal-binding characteristics of yellow lichen substances suggest relationship to site preferences of lichens. Ann. Bot. 103:13–22.

Louw, H.A., Webly, D.M., 1959. A study of soil bacteria dissolving bacteria, certain mineral phosphate fertilisers and related compounds. J. Appl. Bacteriol. 22:227-233.

Makkonen, S., Rııkka, S., Hurri, K., Marko, H., 2007. Differential Responses of Lichen Symbionts to Enhanced Nitrogen and Phosphorus Availability: An Experiment with Cladina stellaris Annals of Botany 99: 877–884, 2007.

Mclean, E.O., 1982. Soil pH and Lime Requirement. Methods of Soil Analysis Part2. Chemical and Microbiological Properties Second Edition. Agronamy. No: 9 Part 2 . Edition P: 199-224.

Mertens, D., 2005a. AOAC Official Method 922.02. Plants Preparation of Laboratuary Sample. Official Methods of Analysis, 18th edn. Horwitz, W., and G.W. Latimer, (Eds). Chapter 3, pp1-2, AOAC-International Suite 500, 481. North Frederick Avenue, Gaitherburg, Maryland 20877-2417, USA.

Mertens, D., 2005b. AOAC Official Method 975.03. Metal in Plants and Pet Foods. Official Methods of Analysis, 18th edn. Horwitz, W., and G.W. Latimer, (Eds). Chapter 3, pp 3-4, AOAC-International Suite 500, 481. North Frederick Avenue, Gaitherburg, Maryland 20877-2417, USA.

Nash, T.H., 2008. Lichen sensitivity to air pollution. In: Nash, III, T.H. (Ed.), Lichen Biology, second ed. Cambridge University Press, Cambridge, MA in press.

Nelson, D.W., Sommers, L.E., 1982. Organic Matter. Methods of Soil Analysis Part2. Chemical and Microbiological Properties Second Edition. Agronamy. No: 9 Part 2 . Edition P: 574-579.

Olsen, S.R., Cole C. V., Watanabe, F. S., Dean. L. A., 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United States Department of Agriculture Circ. 939.

Roychoudhury, P., Kaushik, B.D., 1989. Solubilization of Mussorie rock phosphate by cyanobacteria. Curr. Sci. 58:569-570.

Sancho, L.G., De La Torre, R., Horneck, G., Ascaso, C., Los Rıos, A., Pıntado, A., Werzchos, J., Schuster, M., 2007. Lichens survive in space: results from the 2005 Lıchens experiment. Astrobiol. 7:443–454.

SAS Institute, 1982. SAS Users guide. SAS Institute, Cary, N.C.

Sumner, M. E., Miller, W.P., 1996. Cation exchange capacity and exchange coefficients. p. 1201–1229. *In* D. L. Sparks (ed.) Methods of Soil Analysis. Part 3. Chemical Methods. Soil Sci. Soc. Am. Books, Madison. WI.

Syers, J.K., Johnston, A.E., Curtin, D., 2008. Efficiency of soil and fertilizer phosphorus use: Reconciling changing concepts of soil phosphorus behaviour with agronomic information. FAO, Rome

Thomas, G.W., 1982. Exchangeable cations. p. 159–165. *In* A.L. Page C.A. Black et al. (ed.) Methods of soil analysis. Part 2. Agron. et al. (ed.) Methods of soil analysis. Part 2. Agron. Monogr. 9. 2nd Monogr. 9. ASA, Madison, WI. ed. ASA and SSSA, Madison, WI

Vance, C. P., 1997. Enhanced agricultural sustainability through biological nitrogen fixation. In: Bio Fix Nitrogen for Eco and Sustain Agric. Proc NATO Adv Res Work., Ponzan, Poland, 10-14 Sept.1996. Springer-Verlag, Berlin, Germany, p.179-1

Wild, A., 1988. Plant nutrients in soil: Phosphate. p. 695–743. *In* A. velocity characteristics of eroded sediment. Aust. J. Soil Res. Wild (ed.) Russell's soil conditions and plant growth. Longman 29:685–695. Scientific and Technical, Harlow, UK.