COBISS Code 1.01
DOI: 10.14720/aas.2014.103.1.10
Agrovoc descriptors: phosphorus, fertilizer application, losses from soil, climatic factors, precipitation, grasslands, grassland soils, land use, leaching, soil transport processes

Agris category code: p35

The effect of land use on phosphorus dynamics in golf course soil

Maja PODGORNIK[1*] and Marina PINTAR[2]

Received July 04, 2013; accepted October 08, 2013.
Delo je prispelo 04. julija 2013, sprejeto 08. oktobra 2013.

ABSTRACT

Although, it is usually considered that P applied in fertilizers is taken up by crops or immobilized in the soil, and therefore P losses from agro systems is negligible; recent research indicates that significant P leaching out of the root zone, can occur where certain combinations of land use practice, soil properties and climate condition exist. Therefore special attention was given to dynamics of total P (TP) and plant available P in golf course soils. A field study was carried out to assess how different environmental condition and management practices affect dynamics of TP and plant available P in soil. The proportions of plant available P and TP in the golf rough significantly correlated with precipitation. Since no relationship between precipitation and the P dynamics in soil on the greens and fairways was observed.

Key words: management practices, Technosols, greens, fairways, golf course, molybdate-reactive P, total P

IZVLEČEK

VPLIV RABE TAL NA DINAMIKO FOSFORJA V TLEH GOLFIŠČ

Res je, da se dodani P z gnojenjem porabi za prehrano rastlin ali pa se v procesu imobilizacije močno veže na talne delce, vendar so novejše raziskave pokazale, da se pri določeni kombinaciji rabe zemljišč, lastnosti tal in klimatskih pogojev tudi P lahko izpira v globlje plasti tal. Zaradi spoznanja novejših raziskav o izpiranju P v globlje plasti tal smo v naši raziskavi posebno pozornost namenili dinamiki celokupnega P in rastlinam dostopnega P v tleh igrišč za golf. Z terensko raziskavo smo želeli oceniti, kako različni okoljski dejavniki in raba tal vplivajo na dinamiko celokupnega P in rastlinam dostopnega P v tleh. Rezultati raziskave so pokazali, da obstaja značilna povezava med padavinami in vsebnostjo rastlinam dostopnega P ter celokupnega P v tleh ledine na igrišču za golf. Medtem ko, povezava med padavinami in dinamiko P v tleh zelenic in čistin igrišč za golf ni bila ugotovljena.

Ključne besede: tehnike upravljanja, tehnosoli, zelenice, čistine, golf igrišče, rastlinam dostopni P, celokupni P

1 INTRODUCTION

Golf courses often appear to be some of the most natural environments but, as in the case of well-ordered gardens, they are products of human activity, due to the large use of energy and water required in preparing and maintaining them. The mosaic of "greens" (turfed and carefully mown areas), "bunkers" (unvegetated sandy concave areas), thickets, ponds etc. is obtained through marked modification of the original soils or even their complete removal. The fertilizers required annually to keep greens and fairways, in good condition, can cause serious pollution of soil and waters (Suzuki et al., 1998; Certini and Scalenghe, 2006). Although, it is usually considered that P applied in fertilizers is taken up by crops or immobilized in the soil, and therefore P losses

[1] dr. University of Primorska, Science and Research Center of Koper, Garibaldijeva 1, 6000 Koper, Slovenia, University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technologies, Glagoljaška 8, 6000 Koper, Slovenia, maja.podgornik@zrs.upr.si

[2] prof.dr. Biotechnical Faculty, Agronomy Department, Jamnikarjeva 101, SI - 1111 Ljubljana, Slovenia, e-mail: marina.pintar@bf.uni-lj.si

from agro systems is negligible; recent research indicates that significant P leaching out of the root zone, can occur where certain combinations of land use practice (over fertilization or excessive manuring), soil properties (sandy subsoil, high organic matter and the presence of preferential flow paths) and climate condition exist (Sims et al., 1998).

Globally, the creation of golf courses is currently one of the most rapidly expanding types of extensive land development (Tanner and Gange, 2005). In recent years, considerable interest in golf course development has also been expressed in the Balkan region, despite the minor golf tradition and low number of domestic golfers. It is therefore expected that a large number of new golf courses will be built over the next few years in the Balkan region. Currently, thirty-two golf courses cover roughly 12 km^2 in the Balkan region and their areas have been increasing in recent years (Petrova, 2005). Slovenia has the highest number of golf courses per capita in the Balkan region (Meglič, 2001).

Slovenia is an agricultural country with a total area of 20 722.77 km^2. The majority of the country is covered by forest (13 577.03 km^2) and agricultural land (5 387.92 km^2) (Yearbook Republic of Slovenia, 2007). Golf courses cover nearly 0.02 % or 3.50 km^2 of the country's total area (Skumavec and Šabić, 2005). A 9-hole golf course requires approximately 0.34 km^2 of land, which is seven times more than the average family farm (0.05 km^2) and six times less than the average area of a commercial agricultural operation (2.20 km^2) in Slovenia (Meglič, 2001). Golf course development in Slovenia typically replaces agricultural or native lands with intensively managed turf grass, and course construction involves modification of the original soil profile and land surface.

Many golf course studies have documented the transport of phosphorus (P) into the groundwater if excessive loading of fertilizer is applied to sandy soil with limited P sorption capacity (Shuman 2005; Shuman, 2003). In a lysimeter study of a golf course, P levels were higher in the leachate than the threshold value for surface water (0.3 mg l^{-1}) (Wong et al., 1998). In a greenhouse study with simulated golf greens, peak P concentrations in the leachate exceeded 20 mg l^{-1} (Shuman, 2001). Very few publications (Bartlett et al. 2008, Devitt et al., 2007, King et al., 2007 and McCoy and McCoy, 2009) have documented the effects of climatic conditions and land use on the P dynamics in golf course soils. The primary objective of this research was to monitor two golf courses (green, fairway and forest as part of golf rough to which no fertilizer or water for irrigation is applied) in Slovenia to assess how different environmental condition (i.e. precipitation) could affect management practices and dynamics of total P (TP) and plant available P in soil. The second objective of the study was to observe the interaction between precipitation and irrigation regimes and dynamics of TP and plant available P, because environmental condition and management practices (irrigation and fertilizer) could affect the TP and plant available P in soil.

2 MATERIALS AND METHODS

An intensive monitoring study was performed on two golf courses in Slovenia, from December 2005 to December 2006. The first golf course is located in Lipica (N: 45°40'34", E: 13°53'04", Height: 320 m.a.s.l., Holes: 9, Total surface: 40 ha), in typical Karst countryside with a Mediterranean climate. The second golf course is located in Bled (N: 46°22'18", E: 14°08'15", Height above sea level: 510 m, Holes: 27, Total surface: 100 ha), on the periphery of the Julian Alps, with a subalpine climate. The choices of location were based on the different soil conditions (Table 3).

During the study period, precipitation was regularly measured at both plots (Lipica and Bled). The amount of rainfall at both locations (1 024 l m^{-2} - Lipica and 947 l m^{-2} - Bled) was much lower than the 30-year historical average (1 420 l m^{-2} - Lipica and 1 400 l m^{-2} - Bled). The average monthly temperature ranges recorded were from 1.5 ºC (January) to 19.8 ºC (July) in Lipica and -2.2 ºC (January) to 18.1 ºC (July) in Bled.

The golf courses operated from March to November, when the bulk of the granular NPK fertilizers were applied. Different fertilization practices and different irrigation scheduling methods were used for each of the two golf courses (Table 1). In Lipica, more water is used for irrigation due to less precipitation and higher temperatures. The total amount of the water applied to the golf greens was 15 000 m^3 ha^{-1} y^{-1} in Lipica and 7000 m^3 ha^{-1} y^{-1} in Bled, while the average amount of water applied to agricultural land in Slovenia in the same period was 2220 m^3 ha^{-1} y^{-1} (Yearbook Republic of Slovenia, 2006).

Table 1. Phosphorus (kg ha^{-1}) and water (m^3 ha^{-1}) annual application rates for the golf courses – Lipica and Bled

Location	Land use	Area (ha)	Phosphorus application: Period of application	Application frequency	Annual application rate (kg ha^{-1})	Water application: Period of application	Application frequency	Annual application rate (m^3 ha^{-1})	Sum of annual application rate and rainfall (m^3 ha^{-1})
Lipica	Green	2	February - October	twice a month	17.5	April - October	twice a day	15 000	20 123
	Fairway	12	April - October	twice a year	28.3	April - October	once a day	1 250	6 373
Bled	Green	1.5	April - October	three times during growing season	50	June - September	twice a week	7 000	13 098
	Fairway	35	April August October	three times during growing season	70	June - September	twice a week	557	6 655

We monitored the concentration of plant available P (PO_4-P mg kg^{-1}) and TP (mg kg^{-1}) in the soils of three different land uses (golf green, golf fairway and forest as part of the rough). In order to assess the quantity of plant available P and TP in the soil, fresh soil samples were collected every two weeks, with some gaps, as seen in the results. Five soil samples from five randomly chosen sites from the topsoil (10 cm deep) from each type of land use (green, fairway and rough) at both locations (Lipica, Bled) were collected before the monitoring was performed. All samples were analyzed for their concentrations in plant available P and TP. The results obtained were subjected to statistical evaluation. Evaluated standard deviation (CV %) (Table 2) has been used for further statistical analysis. During the monitoring process, subsamples were randomly collected from the topsoil (10 cm deep) from each type of land use (green, fairway and rough) at both locations (Lipica, Bled) and mixed, to form one composite sample per land. Air-dried soil samples were analyzed using aqua regia extraction methods (SIST ISO 11466, 1995) to assess TP, and ammonium–lactate (AL) extracts, which is the most appropriate method due to the pH of the soil (5.7 - 7.2) (Olsen et al., 1954), to assess plant available P. AL extract was used with the photometric molybdenum blue method (Vajnberger, 1996; Hoffmann, 1991).

Table 2: The samples average concentration (mg kg^{-1}) with standard deviation (SDS) and coefficient of variation in brackets (CV %) of soil phosphorus concentrations (total phosphorus - TP and plant available P) (N=5)

	Lipica		**Bled**	
	plant available P	**TP**	**plant available P**	**TP**
Rough	6.1±2.1 (27.66 %)	920±88 (9.60 %)	4.2±1.7 (40.75%)	368±22 (6.23%)
Green	82.6±9.0 (10.88 %)	407±43 (10.63 %)	26.9±3.3 (12.24%)	115±4 (3.49%)
Fairway	10.8±5.8 (54.58 %)	635±120 (18.98 %)	11.4±2.9 (25.38%)	512±56 (11.09%)

Organic carbon (Table 3) was determined by sulfochromic oxidation without external heating and by titration with 0.5 M $FeSO_4$, following Walkley-Black's method (SIST ISO 14235, 1999) (Jackson, 1962). Soil texture was determined following the particle size limit classification of the U.S. Department of Agriculture (USDA) (Soil Survey Manual, 1993). The cation exchange capacity (CEC) was determined using NH_4OAc extraction methods (Peech et al., 1947). Total soil porosity was calculated from particle (Blake and Hartge, 1986a) and bulk density (Blake and Hartge, 1986b), which were measured using the pycnometer method (50 ml flask) and core method (100 cm^3 Kopecky cylinder), respectively. Soil pH was measured in a suspension of soil in 0.01 M $CaCl_2$ (SIST ISO 10390, 2005). Saturated hydraulic conductivity was determined by the standard method (SIST ISO 17313, 2006). Selected chemical and physical properties of the sampling point are shown in Table 3.

Organic matter concentration in these soils varied from 0.6 - 23.1 % with the highest values in the rough (Lipica 32.1 % and Bled 13.4 %) and the lowest in the green (Lipica 3.2 % and Bled 4.4 %). The pH values for all of the soils were lower than 7.1, except for the individual horizons (green - P2 – pH 7.1 and fairway - B1 – pH 7.3) at the Bled location. The CEC (cation exchange capacity) ranged from 7.3 $cmolc^+/kg$ (Bled – green) to 59.5 $cmolc^+/kg$ (Lipica – rough). In the green and fairway profile, soil porosity was lower than in the rough soil. The soil porosity ranged from 70 % to 76 % in rough soils and from 44 % to 59 % in a fairway and green soils. Those chemical and physical properties make possible the classification of the studied soils. According to the World Reference Base for Soil Resources 2006 (IUSS Working Group WRB, 2006), the studied soils were grouped into three different reference groups; Technosol, Leptosol and Phaeozem (Table 3).

Table 3: Soil characteristics on locations of the golf courses – Lipica and Bled

Location	Land use	Horizon	Depth (cm)	Organic carbon (%)	C:N ratio	Soil texture	CEC (cmolc kg^{-1})	Hydraulic conductivity (m day^{-1})	Plant available water (Vol %)	Soil porosity (%)	Soil pH	WRB Reference Group
Lipica	Green	P2	0-9	1.84	11.3	sand loam	12,8	7.62	5.35	44	6.6	Epileptic Technosol
	Fairway	P1	0-9	2.41	11.8	silt clay	40.8	0.67	11.13	57	6.9	Protocambic Leptosol (Humic, Eutric)
		Apg	9-16	3.96	13.0	silt clay	47.3	0.17	7.42	60	7.0	
		C(B)	16-26	3.56	12.8	silt clay	38.3	0.90	8.78	58	6.8	
	Rough	Ah	0-10	13.26	14.9	silt loam	59.5	89.86	4.71	70	6.5	Rendzic Leptosol
Bled	Green	P1	0-5	2.53	19.2	sand	7.3	22.46	1.12	48	5.7	Technosol (Epiarenic)
		P2	5-28	0.34	15.0	sand	4.6	41.04	2.61	56	7.1	
	Fairway	A1	0-7	4.42	10.7	silt loam	27.6	3.54	8.32	44	6.9	Leptosol (Humic, Eutric)
		B1	7-17	2.76	11.7	loam	32.6	8.99	7.64	56	7.3	
	Rough	A1	0-4	7.69	14.4	silt loam	33.9	27.91	5.6	76	6.0	Epileptic Rendzic Phaeozem (Protosiltic[a])
		B1	4-28	3.78	11.5	silt loam	24.7	15.25	10.6	72	6.0	

[a] Indicating an early stage of development of silt loam feature.

STATGRAF software was used for statistical analysis. Two-sided Pearson's correlations were used to test the relationship between the parameters studied. We used the t-test for dependent samples. The significance level was set at $P < 0.05$. Standard deviation (SDS) and coefficient of variation (CV %) were estimated by examining samples taken before the monitoring was performed.

3 RESULTS AND DISCUSSION

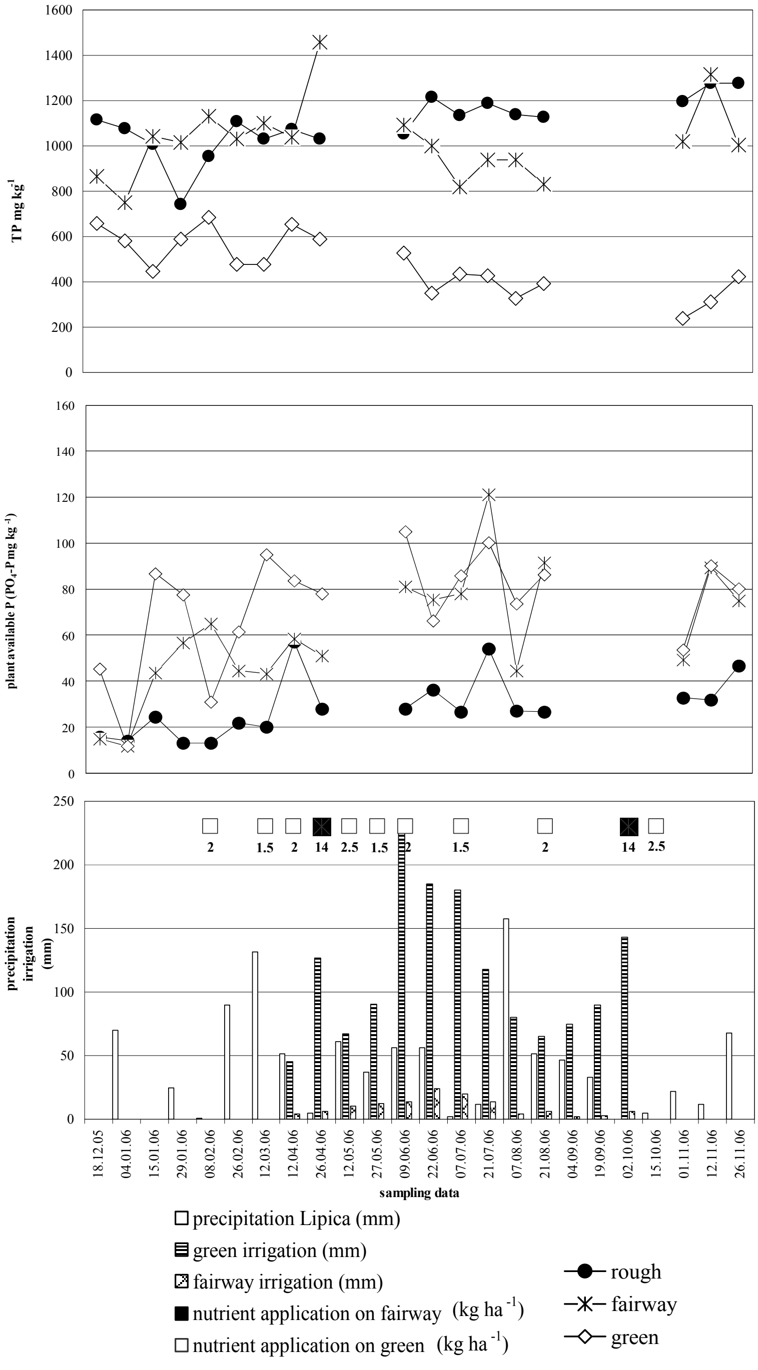
The variation in the quantities of TP and plant available P, which were estimated on five soil samples randomly collected from each of the three studied locations (greens, fairways and rough) at two golf courses (Lipica – 9 holes; 40 ha and Bled – 27 holes; 100 ha), can be attributed to a combination of factors including environmental conditions, vegetation cover and land management practices. Large impact on the quantities of TP and plant available P in different soil can be attributed also to soil sampling procedure. Five soil samples were collected each time but the collected soil samples were then bulked and the chemical analysis of TP and plant available P was conducted on the bulked soil samples. All sampling standard deviations during the P monitoring period were the same as the standard deviations of the five previous samples, collected before the P monitoring work started.

TP and plant available P concentrations

The dynamics of TP concentrations in the soil samples followed different patterns than those for plant available P. Green soils exhibited lower concentrations of TP (average concentration: Lipica - 476±128 mg kg^{-1}; Bled - 187±112 mg kg^{-1}) than rough soils (average concentration: Lipica - 1097±125 mg kg^{-1}; Bled - 740±187 mg kg^{-1}). In contrast, green soils contained a much higher concentration of plant available P (average concentration: Lipica - 73±24 PO_4-P mg kg^{-1}; Bled - 41±17 PO_4-P mg kg^{-1}) than rough soils (average concentration: Lipica - 29±14 PO_4-P mg kg^{-1}; Bled - 26±17 PO_4-P mg kg^{-1}) (Fig. 1 and 2). The results are comparable to a study by Leinweber et al. (1999), in which they found that higher mean concentration of the most labile forms of P tend to occur in arable soils, and more residual (stable) P in soil under fallow or reafforestation. Cultivation and the application of P fertilizers are responsible for the decline in stable P and the higher amount of labile P in the green soil in our study.

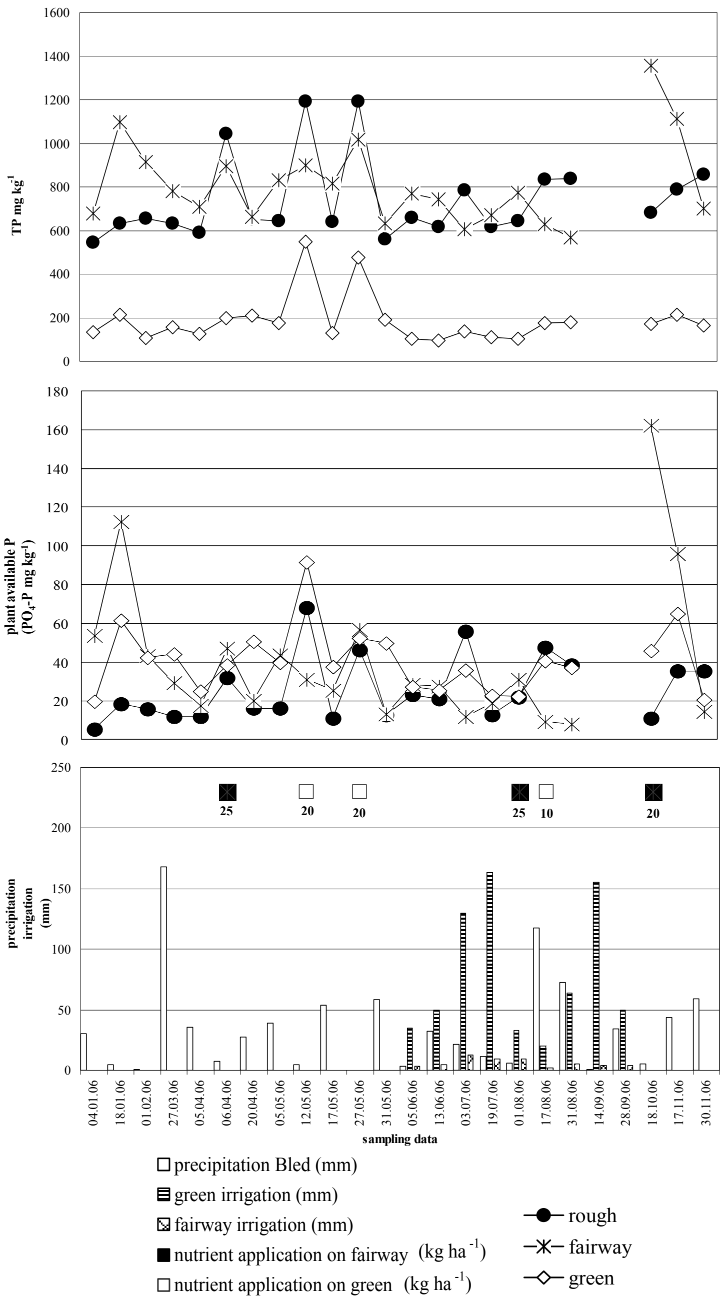
The differences in the concentrations of plant available P and TP between areas of rough and green soil mainly originate from the long-term inputs of plant residue and accumulation of organic matter in uncultivated rough areas and fertilizer application on golf greens. Organic matter is a substantial reservoir for P. The P is bound in phosphate esters, phospholipids and nucleic acids and is released into the soil solution when microbes break down organic matter (Tarafdar et al., 2001). Although the organic carbon concentration of green soils (Lipica: 1.84 %; Bled: 2.53 %) was lower than that of rough soils (Lipica: 13.26 %; Bled: 7.69 %), the plant available P concentrations of green soils (average concentration: Lipica - 73±24 PO_4-P mg kg^{-1}; Bled - 41±17 PO_4-P mg kg^{-1}) were higher than those of rough soils (average concentration: Lipica - 29±14 PO_4-P mg kg^{-1}; Bled - 26±17 PO_4-P mg kg^{-1}). The high concentration of organic carbon and low concentration of plant available P in rough soil might be partially due to the slow decomposition of plant litter and mineralization of organic matter. The mineralization of organic matter is the main source of available P for plants in a natural ecosystem (Srivastava and Singh, 1991). In contrast, the main source of plant available P in green soils are fertilizers, because the maintenance of high-quality turf grass on golf greens requires large P fertilizer inputs. According to the study results, organic matter concentration significantly influenced the level of the TP concentration in the rough soils and the high rates of fertilizer P applied to golf course is a possible cause of plant available P accumulation in the green soils.

Plant available P concentrations in soil samples from the greens in Lipica (average concentration: 73±24 PO_4-P mg kg^{-1}) exceeded the concentration measured in soil samples from the fairways (average concentration: 61±27 PO_4-P mg kg^{-1}), presumably due to the low P adsorption capacity of sandy soils on the greens. In a greenhouse lysimeter study performed by Wong et al. (1998), the leachate from greens contained significantly higher plant available P than that of fairways. We observed a different pattern for TP concentrations. TP in green soil (average concentration: Lipica – 476±128 and Bled – 187±112 mg kg^{-1}) was significantly lower than in fairway soil (average concentration: Lipica – 1 021±170 and Bled – 811±194 mg kg^{-1}) and rough soil (average concentration: Lipica – 1 097±125 and Bled – 740±187 mg kg^{-1}). The higher TP concentrations in fairway soil are in contrast to the low level of TP in fairway soil measured in the aforementioned lysimeter study (Wong et al., 1998). A possible reason for the difference is that fairway soil from the lysimeter study probably reflected the interaction between a high frequency of fertilization and low fertilizer application rates. This indicates that the fertilizer application rate on the studied fairways should be reduced and application frequency should change. Such management could be expected to be less harmful to the environment and to reduce the P loading in fairway soils.



Precipitation shown on the figures is the sum of rainfall between sampling dates.

Fig. 1. Dynamics of total phosphorus - TP (mg kg^{-1}) and plant available P concentrations (PO_4-P mg kg^{-1}) in soil samples from rough, green and fairway – Lipica



Precipitation shown on the figures is the sum of rainfall between sampling dates.

Fig. 2. Dynamics of total phosphorus - TP (mg kg^{-1}) and plant available P concentrations (PO_4-P mg kg^{-1}) in soil samples from rough, green and fairway – Bled

Impact of precipitation on P concentrations

It has been reported that climatic conditions also influence P dynamics in the soil (Ronggui, 2001). We found, a statistically significant correlation was found between precipitation, plant available P (Lipica $r = 0.73$; $P = 0.005$; Bled $r = 0.67$; $P = 0.001$) and TP (Bled $r = 0.67$; $P = 0.001$) in the soil of rough areas, except for the TP in the soil of the rough in Lipica ($r = 0.15$; $P = 0.62$) (Table 4). The concentrations of plant available P and TP in soil of the rough (except TP concentrations in soil of the rough in Lipica) markedly decreased with rainfall events. No correlations were observed among precipitation, plant available P and TP dynamics in soil samples from the greens and fairways (Table 4). In addition to precipitation, the application of water also had an important influence on P dynamics in soil and is the governing factor in soil P consumption. In a greenhouse subsurface irrigation study, Wang and Zhang (2009) showed that the percentage of inorganic P, organic P and plant available P to total P in soil could be affected by irrigation schedules. This was confirmed by the findings of our study. A significant correlation was found for both plant available P and TP concentrations and the application of water on greens at Bled (plant available P: r = 0.89, P = 0.01; TP: r = 0.80, P = 0.05) and Lipica (plant available P: r = 0.73, P = 0.05; TP: r = 0.67, P = 0.01). No statistically significant relationship was observed between precipitation and the P dynamics in soil on the fairways (plant available P: Lipica r = 0.42, P = 0.29; Bled r = 0.71, P = 0.10; TP: Lipica r = 0.27, P = 0.51; Bled r = 0.59, P = 0.21). However, further studies should be done in order to assess how irrigation management practices enhance P availability for plants in green and fairway soil.

Table 4: Correlation between the sum of precipitation between two sampling dates and soil phosphorus concentrations (total phosphorus - TP and molybdate-reactive phosphorus – plant available P) on golf courses Lipica and Bled

	Lipica				Bled			
	plant available P		TP		plant available P		TP	
	Multiple correlation coefficient (*r*)	Significance level (*P*)	Multiple correlation coefficient (*r*)	Significance level (*P*)	Multiple correlation coefficient (*r*)	Significance level (*P*)	Multiple correlation coefficient (*r*)	Significance level (*P*)
Rough	0.73	0.0047 [b]	0.15	0.615	0.67	0.001[b]	0.67	0.001 [b]
Green	0.41	0.11	0.06	0.92	0.27	0.24	0.48	0.03 [b]
Fairway	0.20	0.44	0.14	0.5	0.22	0.34	0.04	0.8

[b] Statistically significance value ($P < 0.05$)

Furthermore, a significant correlation was found between the TP and plant available P concentrations on the golf course in Bled. The TP concentration in soil samples from all the types of land use showed a similar temporal trend as plant available P (Fig. 2). The multiple correlation coefficients between TP and plant available P concentrations are: r = 0.77; P = 0.0001 for greens, r = 0.92; P = 0.0001 for fairways and r = 0.83; P = 0.0001 for roughs.

The dynamics of TP and plant available P in the rough Bled and Lipica reflected the low plant P uptake. Rapid P uptake occurs only with high soil moisture content and that uptake is proportional to the volume of soil brought close to field capacity and the length of time that it remained moist (Simpson and Pinkerton, 1989). On the other hand, the increased moisture content of soils may enhance microbial activity and, consequently, the mineralization of soil organic matter and plant available P. P enrichment in soil solution in topsoil could increase the risk of P leaching into deeper soil layers or even into the groundwater (Sims et al., 1998). This might indicate that the increase of TP and plant available P concentrations after rainfall is due to the leaching of large amounts of plant available P from the topsoil to lower soil layers and reduction in plant P uptake. Unfortunately, no soil sampling was done below the topsoil layer. Since soil water supply (i.e., irrigation) is one of the most important issues on the observed golf courses, it has an important influence on P dynamics in the soil and is the governing factor in plant P uptake.

Impact of fertilization on P concentrations

In addition to soil moisture, the applied fertilizers also had a significant effect on P dynamics in the soil. Motavalli and Miles (2002) reported that the addition of fertilization, either in the form of fertilizers or manure, significantly influences the TP and plant available P in the agricultural soil. A similar P application effect on TP concentration was also observed in the golf course soil in Lipica and Bled (Fig. 1 and 2). A significant correlation was found between the TP concentrations and the application of P fertilizer on greens at Bled ($r = 0.77$; $P = 0.0002$) and fairways at Lipica ($r = 0.74$; $P = 0.001$). Although the TP concentrations increased greatly after the application of P fertilizer, no statistically significant relationship was observed between the quantity of applied P fertilizers and the level of plant available P and TP in soil samples from the greens and fairways. There were much higher concentration of plant available P and TP in the green and fairway soils in Lipica (Fig. 1) than in Bled (Fig. 2), despite that less fertilizer was applied to the golf course in Lipica. The average concentrations of plant available P (and TP) in soil from the greens and the fairways in Lipica were 73±24 and 61±27 PO_4-P mg kg^{-1}, respectively (TP: 476±128 and 1 022±170 mg kg^{-1}) while those in the soils from Bled were 41±17 and 41±38 PO_4-P mg kg^{-1}, respectively (TP: 187±112 and 811±194 mg kg^{-1}). The different level of soil P between the golf courses in Lipica and Bled is possibly due to their different management practices in the removal of plant biomass on the golf course and fertilizer – irrigation histories. Despite the different level of plant available P (Lipica green: 16,72 mgP_2O_5 100g^{-1}; Lipica fairway: 13,94 mgP_2O_5 100g^{-1}; Bled green: 9,32 mg$P_2O_5$100g^{-1}; Bled fairway: 9,38 mg $P_2O_5$100g^{-1}) and fertilizer management practices, AL-method placed the soil from golf course Lipica and Bled in B (6-12 mg$P_2O_5$100g^{-1}) and C (13-25 mg$P_2O_5$100g^{-1})P – supplying levels, which represent an medium-optimal supplied soil with P. The level of plant available P in the green and fairway soils in Lipica and Bled probably reflected the high uptake efficiency of turf grass and impact of biomass removal on soil nutrient. As described in Hladnik (2005), annual removal of phosphorus with the biomass of cut grass is 8-13kg/ha.

The impact of golf course management on P concentration

The soil samples from the green Lipica had a higher plant available P concentration (average value: 73±24 PO_4-P mg kg^{-1}) than those of fairway (average value: 61±27 PO_4-P mg kg^{-1}), while the plant available P concentrations from green and fairway Bled were uniform (green 41±17 and fairway 41±38 PO_4-P mg kg^{-1}). The low concentration of plant available P from the fairways Lipica indicated a high P absorption capacity of the fairway soil compared to the sandy soil of the greens. There is probably a potential for P leaching into groundwater and surface water (Wong et al., 1998). On the other hand, soil samples from the greens had a lower TP concentration than soil samples collected from the fairways (Fig. 1 and 2), which might be due to a low concentration of organic carbon in the soil of greens (Lipica: 1.84%, Bled: 2.53%) in comparison with fairways (Lipica: 3.96%, Bled: 2.76%).

4 CONCLUSION

The results of this study confirm that precipitation significantly alters the amounts and proportions of plant available P and TP in rough. Despite observing no significant relationship between precipitation and the P dynamics in soil on green and fairway, the dynamics of P is probably affected by the quantities of applied water. On the basis of these data, we concluded that apart from precipitation, the application of water also had an important influence on P dynamics in soil and is the governing factor in soil P consumption.

Based on the estimation of contribution of precipitation and irrigation to P dynamics in soil, it was also found that the vegetation systems, fertilization management and organic matter content in soil markedly influence the P dynamics in the soil. Relatively undisturbed forest ecosystems on the rough has less plant available P (average concentration: Lipica - 29±14 PO_4-P mg kg^{-1}; Bled - 26±17 PO_4-P mg kg^{-1}) concentrations than fairways (average concentration: Lipica - 61±27 PO_4-P mg kg^{-1}; Bled - 41±38 PO_4-P mg kg^{-1}) and greens (average concentration: Lipica - 73±24 PO_4-P mg kg^{-1}; Bled - 41±17 PO_4-P mg kg^{-1}). Contrary to this the analyses of the same soil samples, showed that soil from the roughs exhibited significantly greater concentrations of TP (average concentration: Lipica - 1097±125 mg kg^{-1}; Bled - 740±187 mg kg^{-1}) than soils from the greens (average concentration: Lipica - 476±128 mg kg^{-1}; Bled - 187±112 mg kg^{-1}. In forest ecosystems most of the plant available P is supplied by the slow decomposition and recycling of plant residue through microbial processes in the soil, while the higher amounts of plant available P in golf course soils is the consequence of large amounts of fertilizer application.

However, no significant relationship was found between the quantity of applied P fertilizers and the level of total P and plant available P in soil samples of the golf courses, although the total P concentration has increased after fertilizer application. The analyses of soil samples collected from the green and fairway in Lipica showed much higher values of plant available P and TP than the golf course in Bled, despite the fact that a lower quantity of fertilizer was applied to the golf course in Lipica. Despite the different level of plant available and fertilizer management practices the soil form golf course Lipica and Bled belongs to the class of optimal - medium supplied soil with phosphorous.

The result of analyses of soil samples from the golf courses also demonstrated that plant available P concentrations in samples from greens exceeded the concentration measured in samples from fairways, probably due to the low P absorption capacity of sandy soils on the green.

In conclusion, it is obvious that rainfall regime, water supply, organic matter, P absorption capacity and land use appeared to be the most important factors influencing the P dynamic in the soil. Therefore, modified fertilizer management of golf courses which considered all of these factors are needed to ensure better plant uptake, to minimize the risk transportation of P to groundwater and to reduce the risk of eutrophication of water bodies. More investigations need to be done to estimate more accurately the impact of golf courses on groundwater in the Balkan region and to assess the effects of management practices on water quality.

5 ACKNOWLEDGEMENTS

We would like to thank the golf courses of Lipica and Bled for participating in the project and giving permission to take samples from the greens and the fairways. We would also like to thank Peter Korpar, Petra Klanscek, Boštjan Luznar and Pavel Stanič for their technical assistance.

6 REFERENCES

Bartlett M.D., James I.T., Harris J.A., Ritz K. 2008. Size and phenotypic structure of microbial communities within soil profiles in relation to different playing areas on a UK golf course. *European Journal of Soil Science* 59, 835–841, DOI: 10.1111/j.1365-2389.2008.01056.x.

Blake G.R., Hartge K.H. 1986a. Particle density. In 'Methods of Soil Analysis Part – 1 Physical and Mineralogical Methods'. (Ed A. Klute) pp. 377–381. (American Society of Agronomy: Madison)

Blake G.R., Hartge K.H. 1986b. Particle density. In 'Methods of Soil Analysis Part – 1 Physical and Mineralogical Methods'. (Ed A. Klute) pp. 363–375. (American Society of Agronomy: Madison)

Certini G., Scalenghe R. 2006. Soils. Basic Concepts and Future Challenges, Cambridge University Press, Cambridge-New York, p. 310, DOI: 10.1017/CBO9780511535802.

Devitt D.A., Lockett M., Morris R.L., Bird B.M. 2007. Spatial and temporal distribution of salts on fairways and greens irrigated with reuse water. *Agronomy Journal* 99, 692-700, DOI: 10.2134/agronj2006.0183.

Hladnik J., 2005. Bilanca fosforja na travniških tleh Ljubljanskega barja. Diplomsko delo. Ljubljana, Biotehniška fakulteta: 42 str.

Hoffmann G. 1991. Die Untersuchung von Böden. VDLUFA-Metodenbuch. Band I. VDLUFA,Verlag, Darmstadt, Germany.

IUSS Working Group WRB 2006. World Reference Base for Soil Resources. 2006. 2nd edition. World Soil Resources Report 103. FAO, Rome, IT EU p. 142

Jackson M.L. 1962. Soil Chemical Analysis. (Prentice-Hall: New York)

King K.W., Balogh J.C., Harmel R.D. 2007. Nutrient flux in storm water runoff and baseflow from managed turf. *Environmental Pollution* 150, 321–328, DOI: 10.1016/j.envpol.2007.01.038.

Leinweber P., Meissner R., Eckhardt K.U., Seeger J. 1999. Management effects on forms of phosphorus in soil and leaching losses. *European Journal of Soil Science* 50, 413–424, DOI: 10.1046/j.1365-2389.1999.00249.x.

McCoy E.L., McCoy K.R. 2009. Simulation of putting-green soil water dynamics: Implications for turf grass water use. *Agricultural Water Management* 96, 405–414, DOI: 10.1016/j.agwat.2008.09.006.

Meglič V. 2001. Ocena stanja golf igrišč v Sloveniji v odnosu do okolja. In: "Posvet Golf in okolje" Arboretum Volčji potok 27. nov. 2001. Ljubljana, Golf zveza Slovenia, p.8–10.

Motavalli, P.P., Miles, R.J. 2002. Soil phosphorus fractions after 111 years of animal manure and fertilizer applications. *Biology and Fertility of Soils* 36, 35–42, DOI: 10.1007/s00374-002-0500-6.

Olsen S.R., Cole C.V., Watanabe F.S., Dean L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dep. of Agric. Circ. p. 939.

Peech M., Alexander L.T., Dean L.A., Reed J.F. 1947. Methods of soil analysis for soil fertility investigations. U.S. Dept. Agr. Circ. 757, pp. 25.

Petrova L. 2005. Southeast Europe – One jet undiscovered golfing destination. *The Region* 5, 48–52.

Ronggui W. 2001. The effect of land use on soil fertility and phosphorus dynamics in sub-alpine grassland soils of Gansu, China, University of Saskatchewan, Department of Soil Science, Canada

Shuman L.M. 2001. Phosphate and nitrate movement through simulated golf greens. *Water, Air, & Soil Pollution* 129, 305–318, DOI: 10.1023/A:1010303025998.

Shuman L.M. 2003. Fertilizer source effects on phosphorus and nitrate leaching through simulated golf greens. *Environmental Pollution* 125, 413–421, DOI: 10.1016/S0269-7491(03)00081-2.

Shuman L.M. 2005. Normal and flush irrigation effects on phosphorus leaching from simulated golf greens in the greenhouse. *Water, Air, & Soil Pollution* 160, 133–144, DOI: 10.1007/s11270-005-4143-8.

Sims J.T., Simard R.R., Joern, B.C. 1998. Phosphorus loss in agricultural drainage - Historical perspective and current research. *Journal of Environmental Quality* 27, 277–293, DOI: 10.2134/jeq1998.00472425002700020006x.

Simpson J.R., Pinkerton A. 1989. Fluctuations in soil moisture and plant uptake of surface-applied phosphate. *Fertilizer research* 20, 101–108, DOI: 10.1007/BF01055434.

SIST ISO 11466. Soil quality - Extraction of trace elements soluble in aqua regia. 1995: p.6.

SIST ISO 10390. Soil quality - Determination of pH. 2005: p.5.

SIST ISO 14235. Soil quality - Determination of organic carbon by sulfochromic oxidation - Modified Walkley- Black's method. 1999: p.5.

SIST ISO 17313. Soil quality - Determination of hydraulic conductivity of saturated porous materials using a flexible wall permeameter. 2006: p.18.

Skumavec, D., Šabić, D. 2005. Pokrovnost tal v Sloveniji 1993 – 2001. Rezultati raziskovanj št. 815, 1. Ljubljana, Statistični urad Republike Slovenije: p. 66.

Soil survey manual 1993. Soil Survey Division Staff, United States Department of Agriculture, Handbook no.18, pp. 139–143.

Srivastava, S.C., Singh, J.S. 1991. Microbial C, N and P in dry tropical forest soils: Effects of alternate land-uses and nutrient flux. *Soil Biology and Biochemistry* 23, 117–124, DOI: 10.1016/0038-0717(91)90122-Z.

Suzuki T., Kondo H., Yaguchi K., Maki T., Suga T. 1998. Estimation of leachability and persistence of pesticides at golf courses from point-source monitoring and model to predict pesticide leaching to groundwater. *Environmental Science & Technology* 32, 920–929, DOI: 10.1021/es970751+.

Tanner R.A., Gange A.C. 2005. Effects of golf courses on local biodiversity. *Landscape and Urban Planning* 71, 137–146, DOI: 10.1016/j.landurbplan.2004.02.004.

Tarafdar J.C., Yadav R.S., Meena S.C. 2001. Comparative efficiency of acid phosphates originated from plant and fungal sources. *Journal of Plant Nutrition and Soil Science* 164, 279–282, DOI: 10.1002/1522-2624(200106)164:3<279::AID-JPLN279>3.0.CO;2-L.

Vajnberger A. 1996. Određivanje lakopristupičnog fosfora I lakopristupičnog kalijuma u zemljištu. In: Priručnik za ispitivanje zemljišta, Hemijske metode ispitivanja zemljišta. Jugoslovensko društvo za proučevanje zemljišta, Beograd, pp. 184–196.

Wong J.W.C., Chan C.W.Y., Cheung K.C. 1998. Nitrogen and phosphorus leaching fertilizer applied on golf course: lysimeter study. *Water, Air, & Soil Pollution* 107,335–345, DOI: 10.1023/A:1005096122921.

Wang Y., Zhang Y. 2009. Soil – phosphorus distribution and availability as affected by greenhouse subsurface irrigation. *Journal of Plant Nutrition and Soil Science* 000, 1–8.

Yearbook Republic of Slovenia, 2006. 29: p.499

Yearbook Republic of Slovenia, 2007. 33: p. 600