Fertility of Soils over Loess in the Danubian Plain

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Abstract

The loess in the Danubian plain is rich of nutrients and there is situated the south border of so called "corn belt of Europe", where are the most fertile soils of Balkan Peninsula. There are five main typical soil types spread over loess - Chernozems, Phaeozems, Kastanozems, Regosols and Calcisols. There is also a big diversity in the content of basic nutrient elements – it varies between low and high content of organic carbon and mobile forms of nitrogen, phosphorous and potassium. As a whole there is shortage of phosphorus in all soil types. Soils over loess are characterized by a surface layer that is rich in organic matter, minerals and nutrients with abundant natural grass vegetation and high fertility soil types such as Chernozems, Phaeozems and Kastanozems. Eroded and shallow soils such as Regosols and Calcisols have low quantities of major nutrient elements as mobile nitrogen, phosphorus, and total organic matter, consequently their fertility is low.

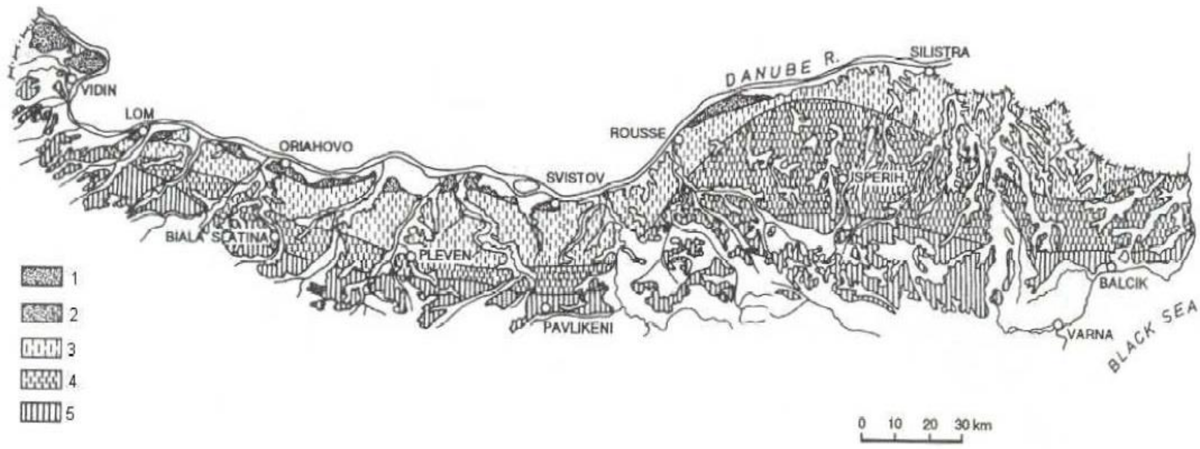
Key words: Agrochemical properties, soil fertility, Chernozems, Phaeozems, Kastanozems, Regosols, Calcisols

Introduction

Soils over loess are among the most fertile in the world. Loess is full of minerals and drains water very well, it is easily tilled, or broken up for planting seeds. Under appropriate climatic conditions, this is some of the most agriculturally productive land in the world. The fine grains weather rapidly due to their large surface area, making soils derived from loess rich of nutrients. Loess deposits are widely distributed on a global basis, covering approximately 10% of the total land cover (Rhotonet at., 2017).

Since Roman Empire in Danubian plain many villages and towns were created and settlers had been produced good yields for over two thousand years. According to Catt (2001) soil fertility depends on a range of physical and chemical properties that are determined by present climatic and biological factors, past climatic and geomorphological history and recent human activities as well as by the nature of the soil parent material. One theory states that the fertility of loess soils is due to cation exchange capacity (the ability of plants to absorb nutrients from the soil) and porosity (the air-filled space in the soil).

The research of the agrochemical properties and characteristics of the soils over loess on soft rocks such as Chernozems, Phaeozems, Kastanozems, Regosols and Calcisols were made to clarify their agrochemical conditions (Koinov et al., 1998; Krasteva et al., 2011; Lubenova et al., 2011, Hristov, 2013; Teoharov et al., 2015, Ilinkin et al., 2017, Bogadanov, et al. 2017). Some key features of these soils have been studied. There is a big diversity in the content of basic nutrient elements – it varies between low and nearly medium content of total carbon and mobile forms of phosphorous, nitrogen and potassium. The pH varies from slight acid to slight alkaline and it is favorable for many crops.



Legend

1, loess-like sand; *2,* sandy loess; *3,* typical (silty) loess; *4,* clayey loess; *5,* loess-like clay

Figure 1. *The Loess lithofacial varieties in Danubian plain (Minkov and Stoilov, 1965; digitized by Evlogiev and Evstatiev, 2007)*

The loess in Danubian plain constitutes the northern part of Bulgaria, situated north of the Balkan Mountains and south of the Danube River (figure 1). Its western border is the Timok River and to the east it borders the Black Sea. The relief of the Danubian plain is hilly, featuring numerous plateaus and river valleys and the most fertile soils in Bulgaria. The climate is markedly temperate continental with a weak Black Sea influence in the east. Precipitation is on average 450–650 mm a year (Galabov, 1982). Loess is well sorted, usually calcareous, non-stratified, yellowish-grey, aeolianclastic sediment. Loess is mostly created by wind, but can also be formed by glaciers. When glaciers grind rocks to a fine powder, loess can form. Streams carry the powder to the end of the glacier. This sediment becomes loess. It consists predominantly of silt-sized particles, and contains normally less than 20 percent clay and less than 15 percent sand.

The aim of the study is to clarify their agrochemical properties and characteristics which provides information about their fertility Along with the well-developed deep soils such as Chernozems (CH), Kastanozems (KS) and Phaeozems (PH) and other zonal soils in Northern Bulgaria (figure 2), there are soils with weak developed profile, classified as Regosols (RG) and Calcisols (CL). Understanding the impact of the natural development of plant cover on the processes of humus formation and mineralization of soil organic matter will help to improve the fertility of such soil types.

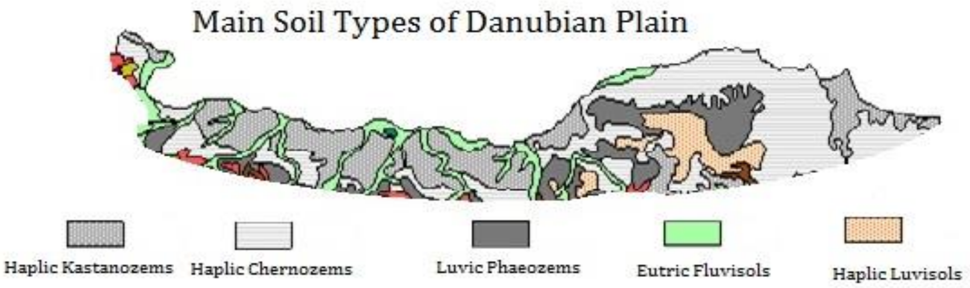


Figure 2. *Main soil types of Danubian plain (Soil map of Bulgaria M 1:1,000,000, Kolchakov, 1994),*

Materials and Methods

According to soil geographic zoning, the studied sites and soils fall into the Danubian plain, Danubian subzone province of Chernozems and hills of Grey forest soils (Koinov et al., 1972, 1998; Gyurov et al., 2001). The whole area includes the studied sites, which are the lands of the settlements - Yakimovo, Kovachitsa and Stanevo, Montana district; Muselievo and Milkovitsa, Pleven region; Trustenik and Mechka, Rousse Region. The region covers the northern parts of the Danube Plain from Archar River (to the west) to the Roussenski Lom River (to the east). The data of the soil profiles 29, 30, 31 are taken form “Atlas of the soils in Bulgaria” (Koinov et al., 1998). Studied soils are uncultivated.

Photo 1. *The loess in the Danubian plain, Bulgaria*

For the determination of organic matter of the soils was used method of Tyurin (Belchikova,1965); ammonia and nitrate nitrogen by Bremner and Keeney (1966); the mobile forms of phosphorus and potassium in the acetate-lactate method of Ivanov (1984) and pH in water with combined “pH and EC meter”, Microsoft Excel (2010) is used for graph and statistics.

Results and Discussion

The soil reaction is essential for internal soil processes and the level of soil fertility. Soil acidity depends on the type of soil, parent rock, vegetation and it can vary widely. Loess in the Danubian valley is usually with alkaline reaction.

Table 1. *Agrochemical properties of the soils over loess in the Danubian plain*

Number (Soil Sample)	Soil Profile number	Depth cm	Soil Type* WRB2006	Horizon	pH (H_2O)	$\sum NH_4^+ + NO_3^-$ mg\kg	P_2O_5 mg/100 g	K_2O mg/100 g	Organic Mater (humus)%
1	1	0 - 13	KS	A_{k1}	7.5	25.4	5.7	48.0	4.13
2	1	13 - 26	KS	AC_{k1}	7.5	12.0	3.2	20.0	1.54
3	1	26 - 41	KS	C_{k1}	7.4	7.9	3.2	18.9	1.02
4	6	0 – 22	CH	A_1	7.4	10.8	4.5	44.5	1.62
5	6	22 – 47	CH	A_{k2}	7.5	16.5	1.2	18.0	1.39
6	6	47 – 74	CH	A_{k3}	7.6	15.1	2.0	18.8	1.14
7	6	74 - 104	CH	AC_{k1}	7.6	11.1	1.4	18.8	1.14
8	6	104 - 145	CH	C_{k1}	7.7	12.1	4.1	16.5	0.76
9	7	0 - 20	CH	A_{k1}	7.5	20.5	6.3	37.5	4.48
10	7	20 – 42	CH	A_{k2}	7.4	22.2	4.1	21.5	3.03
11	7	42 – 65	CH	A_{k3}	7.6	10.4	2.8	17.5	1.79
12	7	65 – 90	CH	AC_{k1}	7.7	14.6	2.5	16.5	1.26
13	7	90 – 110	CH	Ck_1	7.1	13.5	2.0	16.7	0.83
14	7	110 - 130	CH	Ck_2	7.7	10.8	2.5	15.5	0.66
15	8	0 – 21	KS	A_{k1}	7.2	15.1	4.0	14.5	2.59
16	8	21 – 36	KS	AC_{k1}	7.2	10.4	2.9	12.0	1.83
17	8	36–45	KS	C_{k1}	7.3	8.7	2.9	13.0	1.05
18	9	0 - 20	KS	A_{k1}	7.3	15.5	4.2	14.0	2.60
19	9	20 – 40	KS	C_{k1}	7.5	13.1	4.0	13.5	1.15
20	9	40 - 60	KS	Ck_2	7.5	12.4	3.4	13.5	0.91
21	10	0 – 22	RG	A_{k1}	7.2	17.4	3.5	18.0	2.30
22	10	22 – 33	RG	AC_{k1}	7.3	13.5	3.6	13.0	0.91
23	10	33 - 50	RG	C_{k1}	7.4	11.4	3.2	9.0	0.30
24	11	0 – 18	CL	A_{k1}	7.4	15.2	3.5	12.5	2.23
25	11	18 - 35	CL	C_{k1}	7.7	10.8	2.9	13.5	0.41
26	12	0 - 10	CL	A_{k1}	7.5	16.8	4.2	16.5	2.62
27	12	10 - 32	CL	C_{k1}	7.6	7.1	3.5	9.0	0.74
28	14	0 – 16	RG	A_{k1}	7.9	16.0	2.0	17.2	1.83
29	14	16 – 32	RG	AC_{k1}	7.5	13.4	2.3	24.5	1.35
30	14	32 – 50	RG	C_{k1}	7.7	5.9	2.4	17.8	0.61
31	15	0 – 16	RG	A_{k1}	7.2	16.0	2.3	24.5	2.21
32	15	16 – 35	RG	C_{k1}	7.5	11.2	2.5	15.5	0.71
33	16	0 – 15	RG	A_{k1}	7.7	14.6	2.4	17.8	1.81
34	16	15 – 30	RG	C_{k1}	7.8	9.3	2.4	10.0	0.32
35	17	0 – 21	RG	A_{k1}	7.7	14.9	3.4	18.8	2.68
36	17	21 – 40	RG	C_{k1}	7.8	9.7	2.6	12.5	1.14
37	17	40 - 55	RG	Ck_2	8.0	10.1	2.9	12.5	0.64
38	18	0 – 14	RG	A_{k1}	7.7	9.3	4.0	33.5	1.78
39	18	14 – 30	RG	C_{k1}	8.0	9.7	2.9	18.0	0.29
40	19	0 – 15	CL	A_{k1}	7.7	12.3	2.6	44.5	2.16
41	19	15 – 30	CL	C_{k1}	8.0	8.6	3.4	14.5	0.76

**Soil Types - CH = Chernozems; KS = Kastanozems; RG= Regosols; CL=Calcisols*

Table 1. *Agrochemical properties of the soils over loess in the Danubian plain (continue)*

Number (Soil Sample)	Soil Profile number	Depth cm	Soil Type* WRB2006	Horizon	pH (H_2O)	$\sum NH_4^+ + NO_3^-$ mg\kg	P_2O_5 mg/100 g	K_2O mg/100 g	Organic Mater (humus)%
42	20	0 – 11	CH	A_{k1}	7.3	12.0	4.4	18.9	2.89
43	20	11 – 25	CH	A_{k2}	7.2	10.8	2.9	17.8	1.96
44	20	25 – 57	CH	A_{k3}	7.4	7.8	2.6	21.8	1.03
45	20	57 - 84	CH	A_{k4}	7.8	8.6	4.5	21.8	0.78
46	20	84 - 120	CH	AC_{k1}	7.9	6.0	4.1	18.8	0.93
47	20	120-150	CH	C_{k1}	7.8	9.0	6.5	17.8	0.93
48	20	150 - 200	CH	C_{k2}	7.8	9.7	5.4	17.5	0.74
49	21	0 – 21	KS	A_{k1}	8.0	10.9	3.4	18.0	3.04
50	21	21 – 40	KS	AC_{k1}	7.8	7.1	2.7	12.5	1.37
51	21	40 - 60	KS	C_{k1}	8.0	6.0	3.1	10.0	0.83
52	23	0 – 25	KS	A_{k1}	7.7	12.7	3.3	23.5	3.77
53	23	25 – 45	KS	C_{k1}	8.0	9.3	1.9	10.2	1.18
54	24	0 – 19	CL	A_{k1}	7.4	12.7	3.1	16.5	2.6
55	24	19 - 38	CL	C_{k1}	7.7	10.8	2.9	10.2	0.82
56	25	0 – 20	KS	A_{k1}	7.7	15.7	9.4	29.0	3.14
57	25	20 – 40	KS	AC_{k1}	7.5	16.1	8.8	21.8	1.57
58	25	40 - 60	KS	C_{k1}	7.7	12.4	8.2	18.8	0.83
59	26	0 – 18	KS	A_{k1}	7.5	12.3	5.8	46.5	3.82
60	26	18 – 42	KS	AC_{k1}	7.8	9.7	4.9	40.0	1.47
61	26	42 - 55	KS	C_{k1}	7.7	8.6	3.7	29.0	1.47
62	27	0 - 18	PH	A_1	6.1	10.9	3.8	31.0	3.43
63	27	18 – 40	PH	A_2	6.2	14.1	2.8	18.8	2.35
64	27	40 – 75	PH	A_3	6.4	10.1	3.8	18.9	1.27
65	27	75 – 108	PH	AC_1	6.4	6.2	5.2	21.8	0.98
66	27	108 – 139	PH	C_1	6.5	5.2	3.3	18.8	0.98
67	27	139 - 160	PH	C_{k2}	7.7	7.1	1.1	16.5	0.98
68	29	0 – 22	KS	A_{k1}	7.5	29.4	3.0	41.0	3.76
69	29	22 – 47	KS	A_{k2}	7.7	12.6	1.4	16.0	2.4
70	29	47 – 79	KS	A_{k3}	7.8	4.2	1.0	12.0	1.70
71	29	79 – 119	KS	AC_{k1}	7.9	4.2	0.8	9.0	1.3
72	29	119 - 140	KS	C_{k1}	7.9	4.2	0.7	8.0	1.2
73	30	0 - 27	CH	A_{k1}	7.0	32.9	1.5	42.0	4.7
74	30	27 – 45	CH	A_{k2}	7.0	14.7	2.3	26.1	3.38
75	30	45 - 65	CH	AC_{k1}	7.3	10.5	1.4	21.0	1.27
76	31	0 - 12	PH	A_1	5.8	49.7	2.0	28.0	6.13
77	31	12 -35	PH	A_2	5.2	34.3	0.9	22.0	1.56
78	31	35 - 55	PH	A_3	5.5	14.0	1.5	29.0	1.01

**Soil Types - CH = Chernozems; KS = Kastanozems; RG= Regosols; CL=Calcisols*

The pH (H_2O) in different loess types could be 9.5 but for loess sediments it is about 7.0. The reaction of the environment in loess sediments testifies to the diversity of geochemical conditions in which soil formation occurs. The main components that determine the alkaline reaction are $CaCO_3$ and $MgCO_3$. Loess of the Danubian plain contains up to 25% carbonates and their distribution in the vertical depth is unequal (Stoilov, 1984). The soil results show that pH could vary from 5.2 to 8.0 (Table 1 and Table 2) and the mean value is 7.4. The low values (about 6 pH) are typical for the highest points of our soil samples in A horizons. In these places rains wash out the carbonates and soil reaction goes down. Also in south, far from the river Danube, where are spread Phaeozems (PH) the carbonates are washed in deep horizons (C_k), mainly by organic acids under forest. Highest values of pH are typical for Kastanozems (KS) and Calcisols (CL), because of high percent of carbonates. The well-known fact is that most fertile soils are soils with pH between 6 – 7, because in that range there are most available nutrients (Fink, 1976). These soils are mainly Chernozems (CH) and Phaeozems. Higher pH values in the C horizon in most profiles are evidence of the strong influence of the loess and its alkaline reaction.

One of the reason that soils over loess are fertile is the fact that at a soil pH range of 6 to 8, the microbial conversion of NH_4^+ to NO_3^- (nitrification process) is rapid. Most annual crops tend to take up most nitrogen as nitrate. In acidic soils (pH less than 6), microbial activity is low, the nitrification process is slower in this case NH_4^+ is more available to plants (McKenzie, 2003). The amount of "mineral" nitrogen (the sum of ammonium and nitrate) is from moderate to low – ranging between 49.7 to 4.9 mg/kg and decreases in depth of the soil profiles (Penkov, 2005). The amount of nitrate nitrogen is two to three times lower than ammonium nitrogen, which is probably related to the time of soil sampling, at the end of spring (Hristov et al., 2009). The process of nitrification then proceeds slowly as the temperatures are still lower and the soil is not sufficiently warm (Pryanishnikov, 1965). Soil pH is very important factor in nitrogen fixation by legume crops. The survival and activity of Rhizobium bacteria declines as soil acidity increases. Deep soils such as Phaeozems, Chernozems and Kastanozems have more ammonium and nitrate nitrogen than shallow soils as Regosols and Calcisols.

Available phosphorus oxide (P_2O_5) and potassium oxide (K_2O) commonly referred to mobile phosphate, and potassium. Well known fact is that phosphorus moves little because of the low amount dissolved in the soil solution. Leaching losses of inorganic phosphorus are generally low. Research of the chemistry of soil inorganic phosphorus has shown a complex system of reactions and compound formation dependent on factors such as soil pH; type and amount of soil minerals, amount of phosphorus in the soil, and other soil factors (Diaz et al., 2011).

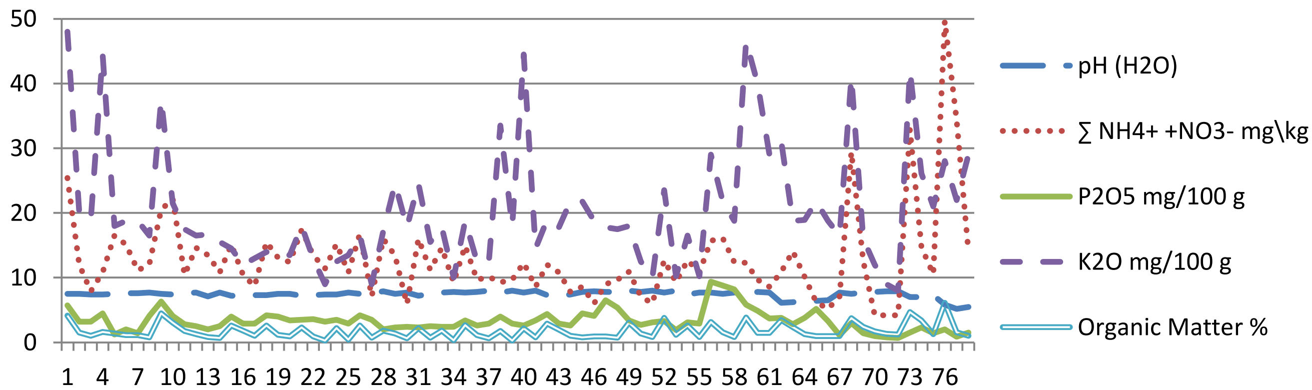


Figure 3. *Agrochemical values of the soils*

The amount of available phosphorus oxide (P_2O_5) in studied soils is low (Table 1, Fig. 3). The values are ranging from 0.7 to 9.40 mg/100g (Table 2), the median and mode are respectively 3.05 and 2.90. Therefore, by the amounts less than 5 mg/100g of soil, the plants will suffer a severe shortage of this element. In soils over loess the predominant form of mineral phosphorus is associated with calcium or magnesium minerals, because the loess is rich of carbonates, that is one of the reasons for the low amount of available phosphorus oxide (P_2O_5).

Potassium is very widely distributed in studied soils as a constituent of silicate minerals such as orthoclase and microcline, and certain forms of mica, muscovite and etc. Under the influence of various weathering factors (temperature changes and the influence of water) these and other potash-containing sediments are converted slowly to clay rich of potash. In terms of the potassium's stock (K_2O), studied soils are in better condition than mineral nitrogen and available phosphorus (Valchovski et al., 2015). Its quantity varies between 8 and 48 mg/100g soil, and in Phaeozems, Kastanozem and Chernozems this quantity is significantly higher than in Calcisols and Regoslos (Table 1 and 2).

Table 2. *Descriptive statistic of agrochemical properties*

	pH (H_2O)	*$\sum NH_4^+ + NO_3$-* **mg\kg**	*P_2O_5* **mg/100 g**	*K_2O* **mg/100 g**	*Organic Matter* **%**
Mean	**7.42**	**12.87**	**3.30**	**20.29**	**1.75**
Standard Error	**0.06**	**0.79**	**0.19**	**1.06**	**0.13**
Median	**7.50**	**11.30**	**3.05**	**18.00**	**1.36**
Mode	**7.70**	**10.80**	**2.90**	**18.80**	**1.14**
Standard Deviation	**0.56**	**7.01**	**1.67**	**9.40**	**1.15**
SampleVariance	**0.31**	**49.10**	**2.77**	**88.35**	**1.33**
Kurtosis	**4.96**	**10.63**	**3.17**	**1.59**	**2.02**
Skewness	**-2.14**	**2.74**	**1.43**	**1.43**	**1.38**
Range	**2.80**	**45.50**	**8.70**	**40.00**	**5.84**
Minimum	**5.20**	**4.20**	**0.70**	**8.00**	**0.29**
Maximum	**8.00**	**49.70**	**9.40**	**48.00**	**6.13**
Count	**78**	**78**	**78**	**78**	**78**
ConfidenceLevel(95.0%)	**0.13**	**1.58**	**0.38**	**2.12**	**0.26**

As it was mentioned the loess is rich of potash primary minerals such as micas and feldspars and secondary minerals such as illite (Koinov et al., 1998). Surface layers contain more potassium oxide (K_2O) than the subsurface horizons. In surface horizons under atmospheric influence, micaceous minerals and possibly feldspars slightly more weathered and these minerals release potassium more readily than the K-bearing minerals at the lower depths (Dubetz et al., 1981). According to Nikolova et al., (1995) in topsoil horizons Kastnozems, Chernozems and Phaeozems have very good reserves of K_2O (from 35 – 28 K_2O mg/100g soil) and Calcisols and Regoslos have moderate quantity.

Generally soils over loess are characterized by a surface layer that is rich in organic matter (humus), resulting in a well-aggregated structure with abundant natural grass vegetation (Hristov et al., 2017). Content of humus varies from 6.3 to 1.0 % in the upper part of soil horizons, decreases in depth to 0.29 % (Table 1 and 2). Usually humic type of humus prevail over fulvic and the type of humus is humic or fulvic-humic (Filcheva et al, 2014).

According to Artinova (2015) classification, Regosols and Clacisols have low organic matter content (1 – 2 %) and moderate humus content (2.1 – 3 %) in A horizon. Unusually uncultivated Chernozems, Kastanozem and Phaeozems have high (3.1% – 5 %) and very high content (over 5 %) of soil organic matter in surface horizons. The low content in Regosols and Calcisols is due to soil erosion, because typically these soils are spread over slopes and hills (Hristov et al., 2009; Hristov, 2014).

Table 3. *Correlation matrix of agrochemical properties*

	pH (H_2O)	*∑ NH_4^+ +NO_3-* **mg\kg**	*P_2O_5* **mg/100 g**	*K_2O* **mg/100 g**	*Organic Matter %*
pH (H_2O)	1				
∑ NH_4+ +NO_3- **mg\kg**	**-0.47**	1			
P_2O_5 **mg/100 g**	0.13	0.00	1		
K_2O **mg/100 g**	-0.21	0.42	0.29	1	
Organic Matter %	-0.28	**0.69**	0.14	**0.58**	1

Soils over loess are traditionally considered as richest soils due to their high content of soil organic matter (humus), available for crops nitrogen, phosphorus and potassium. According to correlation analysis (Table 3) there is positive correlation (**0.69**) between soil organic matter and available nitrogen (∑ NH_4^++NO_3^-). Similar situation is between organic matter and potassium oxide (K_2O) – **0.58**. The reasons for that is high organic matter content, favorable alkaline reaction, and high content of potassium rich minerals. As it was mentioned before soil reaction of the loess is good for available nitrogen and potassium, but not for available phosphorus oxide (P_2O_5) because phosphorus is bound with calcium or magnesium minerals.

Conclusion

Studied soils are characterized by a large diversity in their agrochemical properties – from a low content of available phosphorus oxide to some average and high values of mobile nitrogen, potassium oxide and organic matter content. As a whole there is shortage of phosphorus in all soil types.

Under favorable climatic conditions, loess could develop into fertile agricultural soil. Unusually uncultivated Chernozems, Kastanozem and Phaeozems have high and very high content of soil organic matter in surface horizons, and also high content of available potassium oxide. Shallow soils such as Regosols and Calcisols have low quantities of major nutrient elements as mobile nitrogen, phosphorus, potassium and total organic matter. Therefore, it is necessary to take actions for protections of such lands that would also limit the erosion and other degradations processes.

Loess alkaline reaction is also favorable for available nitrogen and potassium and the quality of soil organic matter. All these agrochemical features are beneficial for crops which grow very well over fertile soils over loess, such as Chernozems, Kastanozems and Phaeozems. Eroded and shallow soils as Regosols and Calcisols have low fertility and usually they are not cultivated.

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