Relation between corolla coloring of herbaceous plants and some soil indices

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Abstract. Relation between corolla coloring of herbaceous plants of Central Europe with its ecological characteistics according to Landolt and Ellenberg (982 and 1164 species) was studied. Special attention was paid to the shades of antocyanin color. It was revealed that red-color species prefer at the average mare strongly acidic soils (mean pH=6), than blue–color ones (mean pH=7). Also the relation between corolla coloring and flowering season was registered.

Key Words: soil reaction, anthocyanins, season, corolla.

Introduction. Flowering or angiospermous plants are rather young group of higher plants, that appeared in Cretaceous period, quickly thrived in the middle-end of that period and from then have supremacy on firm land. Krupenikov (2008) states, that the chernozem formation in the world of soils as well as the development and supremacy of angiospermous plants in the world of plants are two progressive phenomena of Cenozoic era. In the process of their establishing and development they formed tight relationship and unity. The initial stage of this unity is the expansion of cereals and the formation on the vast territories of chernozem (the soil of storage type) by contrast with podzolic and ferralitic soils of dissipative type that had already existed. According to the prevailing now point of view monocots flowering plants originate from dicots (Takhtajan 1980). Then it is possible to suppose that the formation of dicots flowering plants is related with the dissipative types of soil, podzolic and ferralitic ones. They are characterized with acid reaction, weak accumulation of humus and removal of chemical elements (Krupenikov 2008).

Vacuolar anthocyanins, mainly determining flower coloring of dicots may serve to regulate the cell osmotic pressure and binding elements vital for plants Ca^{2+}, Mg^{2+}, K^+ that are removed at weathering and erosion of the dissipative type of soils (Yoshida et al 2009). Then the anthocyanin induction, caused by the corresponding environment factors becomes justified, as well as the predictability of the anthocyanins appearance from year to year in the periods of specific development stages and their bright expressiveness in special ecological niches (Chub 2008).

It is known that red color salts are formed when mineral and organic acids influence the anthocyanins. But in the presence of alcali in anthocyanin molecules rearrangement of double and ordinary connections between the carbon atoms takes place that results in the formation of new chromophore of blue color (Britton 1983; Chub 2008; Shoeva 2013). Color variation depends first of all on the level of hydroxylation and methylation of the benzol ring of the flavonoid molecule that in its turn is determined only by genetic reasons. But in the interspecies variation of corolla coloring besides the genetic component the modificational one is present. According to Rausher (2008), the genetic transitions from blue color of corolla to the red one are more possible than from red to blue. These transitions are related with switching over of anthocyanin synthesis with more hydroxylate to less hydroxylate forms. Then in acidic and strongly acidic environment as a result of color identity either along modificational or genetic components the mutations will not be eliminated by the selection but will be accumulated. As a result the species with red corolla will dominate on strongly acidic soils. So on the slightly acidic, neutral and slightly alkaline soils the proportion of blue corolla species will be higher than on the acidic and strongly acidic soils.

However the investigation results of other scientists do not allow to make univocal conclusions. Thus, Dorogonevskaya (cited by Nasimovich 1991) has shown that the soil acidity can influence flower coloring, but Kuptsov (cited by Nasimovich 1991), while studying the color changeability of *Tulipa schrenkii* Regel flowers did not find the relationship between coloring and soil-climatic conditions. Nasimovich (1991) supposed that the dependence of corolla coloring on the soil chemical composition has the quality of modification and reveals itself only when the plant gets into the soil with the chemical composition unusual for this plant. Yoshida et al (2009) report that the flower pigmentation depends not only on the structure and the pigment concentration but on pH in vacuoles where the anthocyanin combinations accumulate.

In this paper one more attempt is made to study the relationship between some soil forming factors (soil reaction, humidity, temperature and others) and coloring of herbaceous plants flowers that grow on the soil of this type.

Material and Method. As an object of investigation the flowering plants species of C layer were taken, represented in Ellenberg (1974) and Landolt (1977) ecological scales. The soil forming factors were considered basing on the data given in the scales. The acidity value according to Landolt scale was transformed (Table 4) into the acidity value according to Ellenberg scale basing on the formula found empirically:

$$B_E = 1.5\ B_L + 2.12 \qquad (1)$$

Jn the data base of http://www.plantarium.ru/ site, the color atlas of herbaceous flowering plants was composed. All the species depending on the corolla coloring were divided into five color classes: red, blue, green (including corollaless), yellow (including orange) and white. The flower coloring range of every species and the flowering beginning were specified according to Ciocârlan (2000) and Geideman (1986) field guides. The supposed anthocyanin corolla coloring (red and blue classes) were evaluated according to the more detailed scale (1 through 8 points, corresponding to the anthocyanin coloring change in the media with pH from 1 to 8). The data statistical processing was performed according to Excel 2003 program.

Results and Discussion. The floristic lists of Ellenberg and Landolt are represented by Central Europe vegetation (vegetation of Germany and Switzerland respectively). The species classification according to the soils acidity scale (Tables 1-2) has shown that the most numerous is the sample of plants preferring slightly acidic, neutral soils (62% according to Landolt and 61% according to Ellenberg) and slightly alkaline soils (22% according to Landolt and 24% according to Ellenberg). Thus more than 80% of herbaceous flora of Central Europe prefers moderate conditions of soils reaction – from slightly acidic to slightly alkaline. This result corresponds to the zone classification of soils acidity. The acidic soil reaction is set in under the conditions where the precipitation dominates over the evaporation (forests, tundra); neutral - the quantity of the precipitation and the evaporation is equal (pratal heath, typical savanna); alcaline - when the evaporation dominates over the precipitation as in deserts. The species composition distribution according to the flower coloring in the floristic lists of Ellenberg and Landolt was very similar. About one third of all the species composition is represented by the corollaless plants; the plants with hypothetic anthocyanin coloring make up also about one third, with blue color group being a little more numerous than the red one. The species groups with white and yellow corolla coloring are equal in both lists and in their sum make up about 40% of the species composition of Central Europe herbaceous flowering plants.

In general anthocyanin pigments determine red and blue corolla coloring, flavons and flavonols – yellow one, carotinoids – yellow-orange one, chlorophylles – green one. Each of these groups is represented by some pigments, that differ in chemical composition, and as a result in light absorption and coloring. The main pigments of the plants with green flowers are chlorophylles and carotinoids – photosynthetic, plastid pigments. It should be noted that chlorophylls are not stable in acidic media and as a result of change of complex bound magnesium for hydrogen form phaeophytin of brownish color. In the period of higher plants flowering the carotinoids play a special role, their content in the leaves becomes lower. At the same time it remarkably increases in anthers as well as in flower petals. It is known that carotin is resistant to alkali and heating, but is not resistant to acids, ultraviolet light and air oxygen. Under their influence it inactivates (Britton 1983). Thus, the floral envelope first of all has to protect anthers from the above mentioned factors.

Table 1

Distribution of herbaceous plants with different corolla coloring depending on soil reaction by Landolt (1977)

Soil pH points	Herbaceous flowering plants corolla coloring										ΣN
	red		blue		white		green		yellow		
	N	%	N	%	N	%	N	%	N	%	
1	12	54.0	0	0	1	4.5	7	31.5	2	9	22
2	24	14.4	17	10.2	28	16.8	74	44.4	20	12.0	163
3	73	9.5	136	17.7	132	17.2	254	33.0	126	16.4	721
4	54	21.6	62	24.8	61	24.4	11	4.4	62	24.8	250
5	0	0	4	50	4	50	0	0	0	0	8
∑	163	14	219	19	226	19	346	30	210	18	1164

Table 2

Distribution of herbaceous plants with different corolla coloring depending on soil reaction by Ellenberg (1974)

Soil pH points	Herbaceous flowering plants corolla coloring										ΣN
	red		blue		white		green		yellow		
	N	%	N	%	N	%	N	%	N	%	
1	3	37.5	0	0	0	0	4	50	1	12.5	8
2	9	29.0	2	6.5	4	12.9	10	32.2	6	19.4	31
3	8	19.5	4	9.8	4	9.8	18	43.9	7	17.1	41
4	7	11.0	5	7.9	11	17.5	27	43.0	13	20.6	63
5	12	17.9	8	11.9	18	27.0	21	31.3	8	11.9	67
6	13	11.5	19	16.8	28	24.8	31	27.4	22	19.5	113
7	27	9.1	53	17.8	53	17.8	107	36.0	57	19.2	297
8	31	14.6	48	22.2	34	15.8	51	23.7	51	23.7	215
9	7	12.3	16	28.1	12	21.1	10	17.5	12	21.0	57
∑	117	13	155	17	164	18	279	31	177	20	892

Vacuole flavonoid pigments – flavons and flavonols - protect flowers from ultraviolet light and air oxygen. Thanks to their ability to absorb the ultraviolet light (330 - 350 nm) and a part of visible light (520 - 560 nm) flavons and flavonols protect the plant generative organs from the ultraviolet light surplus.

The anthocyanins, taking part in water balance regulation, serve as a specific protectors when the cell is excessively acidulated or alkalized (Chub 2008; Shoeva 2013). Due to high electrofilicity of chromenilium cycle the structure, and as a result, the anthocyanins and anthocyanidins coloring is determined by their sensitivity to pH: in acidic media ($pH < 3$) the anthocyanins (and anthocyanidins) exist in the form of red pyrylium salts. When pH increases to ~4-5 the hydtoxide-ion is joined and colorless pseudobase is formed, if pH is increased to ~6-7 water removal takes place and the quinoid form of the purple color is created, which in its turn at pH ~7-8 removes proton with the formation of blue color phenolate and at last at pH 8-9 the phenolate of quinoid form of blue-green color is hydrolyzed with the break of quinoid cycle and the formation at $pH > 11$ the corresponding chalcons of yellow color which is preceded by the formation of colorless chalcons anion ($pH > 8$). Such anthocyanins transformations take place in vitro, while in vivo pH in vacuoles generally varies from 4 to 6, so the blue color appearance in the main cases can’t be explained only by the media pH influence. Yoshida et al (2009) in additional studies revealed that the anthocyanins in the intracellular (vacuolar) fluid are present not as free molecules, but in the form of complexes with molecules of flavons and metal ions, that determine the blue coloring of vacuole fluid. The mechanism of cytoplasma pH regulation is performed by the diffusion as well as by the tonoplast pumps, that pump the metal and oxygen ions from the soil to the cytoplasm and from the cytoplasm to the vacuole. These pumps may maintain the cytoplasm pH at the optimal level (Vorotnikov & Chkalov 2001; Yurin et al 2009).

It is known, that the soil reaction and the composition of exchange bases are mainly determined by Mg^{2+} and Ca^{2+} cations in the soil. H^+ and Al^{3+} ions, partially passing into the soil solution, can create significant acidity. Acidification may be so notable, that the soil solution pH reduces to 3.5. According to Nasonov & Alexandrov (1940), the shift of the media pH values only on 1-2 units leads to more than 10-fold change of the substance molecules concentration that are transported through the cytoplasmic membrane. The formation of the complexes with metals cations by anthocyanins, in its turn, influences the intracellular fluid coloring. Thus, the univalent K^+ cation gives the purple complexes, while the bivalent Mg^{2+} and Ca^{2+} ones give the blue complexes. According to Kaurichev et al (1989), Ca^{2+} concentration in A_1 soil horizon, and as a result the possibility of growing of the species with blue corolla coloring, is the greatest for the typical chernozem, dark-gray forest soil, dark-brown soil and the alkali solonetzes (Table 3).

Table 3

Ca^{2+}, Mg^{2+}, H^+, Al^{3+}, Na^+ cations concentration in different soil types

Soil type	*Concentration in A_1 soil horizon, meq/100 gm*			
	Ca^{2+}	*Mg^{2+}*	*$H^+ + Al^{3+}$*	*Na^+*
Sod-podzolic sandy soil	0.9	0.3	2.3	-
Low-loamy podzol	1.8	0.6	9.2	-
Red soil	1.9	4.3	12.1	-
Gray soil	11.9	1.5	-	0.7
Gray forest podzolozed soil	12.5	2.5	2.5	-
High-podzolic loam	13.9	1.1	14.1	-
Alkali solonetz	27.0	20.3	-	3.8
Dark-brown soil	27.6	5.5	-	1.0
Dark-gray forest soil	37.7	6.2	2.1	-
Chernozem	39.1	6.0	-	-

Kholopova's (1982) studying of the soil acidity seasonal dynamics and micro- and macroelements content has shown, that the fluctuations of micro- and macroelements content during the vegetation period can reach 1.5 to 10 times, especially in organogenic horizons. Dmitrieva et al (1958) have investigated the seasonal changeability of general humus and nitrogen forms, labile phosphorus and the acidity of the salt extract in the dark brown forest earth and in the soils under the broadleaved forests. It was determined, that in December and June the soil acidity increases, the difference between the less and the greatest values being 0.7 – 1.4 pH units. Levkina's data (1962), who studied the seasonal dynamics of the soils chemical characteristics under the bilberry scrub forest and the mixed herbs birch forest, have shown that Mg^{2+} and Ca^{2+} concentration in the soil increases with the decomposition of the soil organic component (the vegetation period beginning) and decreases with their removal by precipitation (June-July), while the hydrogen ions activity in the forest leaf litter horizon rises in summer months (June-September).

The analysis of the species with anthocyanin-colored corolla (red and blue classes) using the Ellenberg soil acidity scale was carried out for both Ellenberg's and Landolt's lists. The comparison of the soil pH average data for the species with red corolla and the species with blue corolla exposed the shift of the soil reaction to the acidic area for the species with red corolla and to the neutral area for the species with blue corolla (Table 4). This effect was significance for Ellenberg's list (German flora) at $p < 0.001$ and non significance for Landolt's list (flora of Switzerland). The first effect is shown graphically in Figure 1.

Table 4
Distribution of herbaceous plants with anthocyanin corolla coloring according to soil reaction scale

Source	*N*	*Average soil pH (in Ellenberg's points) for red-flower plants*	*N*	*Average soil pH (in Ellenberg's points) for blue-flower plants*
Landolt (1977)	163	6.074±0.138	219	6.484±0.276
Ellenberg (1974)	117	6.077±0.200	155	7.026±0.114

Comment. Landolt's points were recalculated to Ellenberg's ones by the formula (1).

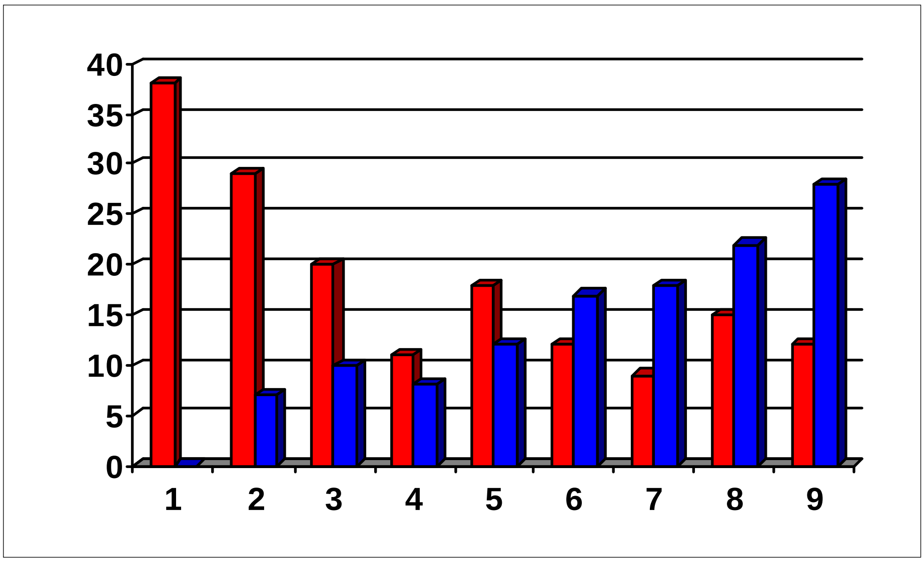

Figure 1. Distribution of proportion (%) of species with red and blue corolla (horizontal axis – Elenberg's soil pH points; vertical axis - proportion of species with red and blue corolla, %).

Conclusions. The distribution of the species according to the soil acidity scale has shown that more than 80% of Central Europe herbaceous vegetation prefer the moderate conditions of soils reaction – from slightly acidic to slightly alkaline.

The distribution of the specious composition of the Central Europe vegetation list according to corolla coloring has revealed, that the most numerous is the species group with green corolllaless flowers - 30.5%, the species group with the yellow corolla coloring makes up 19%, the white color species – 18.5%, the species with blue corolla - 18%, and the species with red corolla – 13.5%.

The comparison of soil pH average indices for the species with red corolla and the species with blue corolla has demonstrated the shift of the average soil reaction for the species with corolla to the slightly acidic area (pH = 6) and for the species with blue corolla to the neutral area (pH = 7).

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