COLOUR SPACES IN SCIENTIFIC RESEARCH

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Abstract

Colour is an individual visual perception that is dependent upon numerous factors. Colour cannot be measured directly unlike the mass of a body or its geometric characteristics (length, width, height). Using the key elements in the complex system of viewing/rendering/reproducing colour, which involves: the source of light, the coloured object, the observer (receiver), the paper presents the importance and standard of each component, highlighting the specifics of colour assessment, for additive and subtractive systems, including the particular steps of the direct RGB model and the opposite CMYK model. Based on preliminary complex mathematically processed data, the paper presents the algorithm for developing and structuring the various colour spaces that serve to represent colours: LMS, RGB, CIEXYZ, CIExy, CIELab – which has become a universal space that encompasses lightness L and two chromatic components, i.e. a - the green to magenta range and b – the blue to yellow, CIELuv – recommended for its uniformity, and HSB (hue, saturation, brightness) – typically used for dependent systems, etc. The paper emphasises the particular characteristics and gamut of each colour model. The variants CIEDE 1976, CIEDE 1994, CIEDE 2000 used in calculating colour difference are also provided. Moreover, an analysis of colour evaluation criteria is presented and, based on the conclusions, the adequate representation space is recommended. The author's personal contribution is limited to the colour spaces for three types of soil under humidity conditions; three types of leaves and grass, four types of gladioli and the colour of the red cabbage extract in connection with pH – which are all characterised by natural colour.

Key words: water, field, spaces, electromagnetic spectrum, spaces

The visible electromagnetic spectrum comprises electromagnetic radiation with wavelengths between 400 and 700 nm. In science, the 380-830 nm wavelength range is used.

Vi I A V G O R

In obtaining colour, additive mixing (light shows) or subtractive mixing (printed matter, colour paper).

Figure 1 **Additive mix of red (R), green (G) and blue (B), identical with RGB (red, green, blue)**

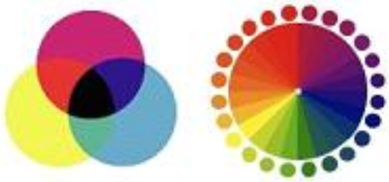

Figure 2 **CMYK subtractive mix - cyan (C), magenta (M), yellow - Y (yellow) and black-K (black).**

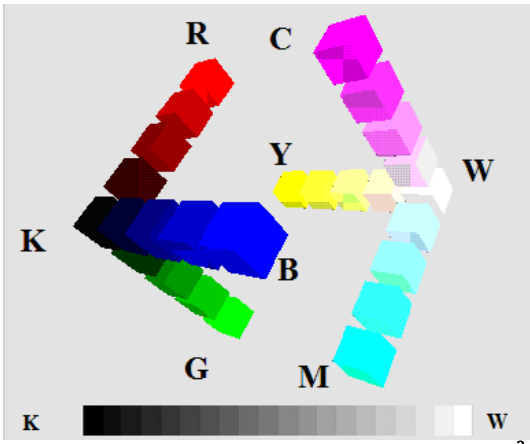

Figure 3 **The complementary RGB and CMYK[a] systems**

([a]*The gray colours on the K (black)-W (white) diagonal, termed non-coloured achromatic colours are characterized only by light.*)

Each mix uses the primary colours R,G,B, or C,M,Y(K), respectively.

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MATERIALS AND METHODS

Relations between additive and subtractive colour spaces

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix};$$

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}.$$

Table 1

Colour mixing

Additive colour mixing starting from the R,G,B primary colours			Additive colour mixing starting from the R,G,B primary colours		
Red + Green	->	Yellow	Cyan + Magenta	->	Blue
Green + Blue	->	Cyan	Magenta + Yellow	->	Red
Blue + Red	->	Magenta	Yellow + Cyan	->	Green
Red + Green + Blue	->	White	Cyan + Magenta + Yellow	->	Black

LMS, CIERGB Independent colour spaces and the imaginary space CIEXZY. Vector analysis.

The science of colour - colorimetry - operates with the LMS, CIERGB and CIEXYZ colour spaces that can be represented mathematically as vectors in 3D space. Due to trichromatic vision, a colour (C) may be represented by a vector whose magnitude is proportional to the light level, while orientation is linked to colour. At a random point C one can determine the contribution of primary colours (their individual share).

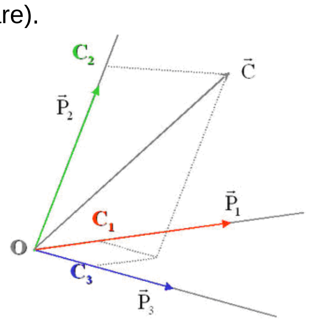

Figure 4 **Vectorial representation of a colour (C)**

The vector C is represented in the system of coordinates C_1, C_2, C_3, known as trichrome coordinates, in which the unitary vectors P1, P2, P3 are defined as representing the primary composing colours.

$$\vec{C} = C_1 \cdot \vec{P_1} + C_2 \cdot \vec{P_2} + C_3 \cdot \vec{P_3}.$$

Any random colour can be characterised by three tristimulus values (L, M, S), (R, G, B), (X, Y, Z), (L*, a*, b*), etc. For each colour space, the three-dimensional contour is defined in addition to its projection on the horizontal plane, known as locus.

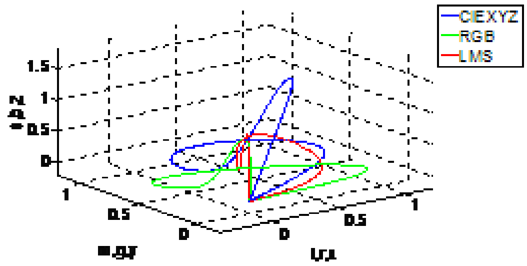

Figure 5 **Colour spaces**

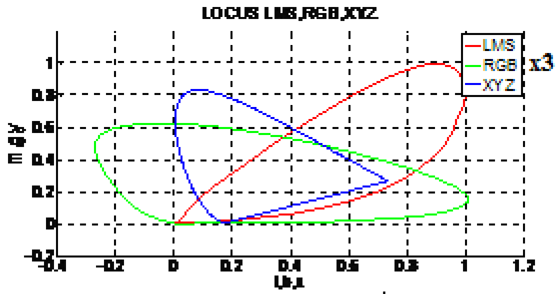

Figure 6 **Locus in the LMS, RGB[b], XYZ spaces**

LMS space is correlated with the spectral sensitivity of L, M, S-type cone[c] (Smith-Pokorny).

([b]*The RGB space has negative values, hence the need to resort to the imaginary CIEXYZ colour space.*)

([c]*Types of cones: L- sensitive to long wavelengths, 560–580 nm; M – sensitive to medium wavelengths, 530–540 nm; S – sensitive to short wavelengths, 420–440 nm.*)

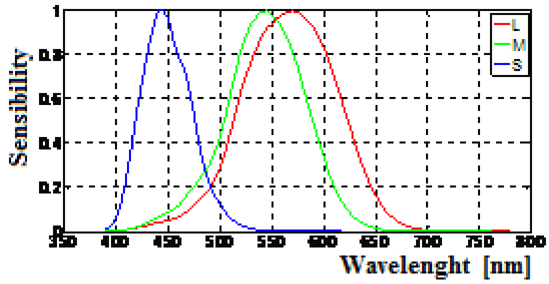

Figure 7 **Cone sensitivity**

In the CIExy locus can be positioned the monochromatic sources in the CIERGB space with the wavelengths: R = 700 nm, G = 546.1 nm, B = 435.8 nm.

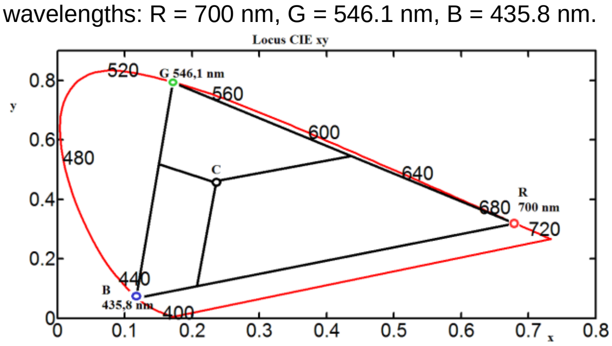

Figure 8 **The CIExy chromaticity diagram**

In the RGB triangle the Hermann Günther Grassmann colour composition laws apply, for example in the C(r,g,b) point:

C(r,g,b)=rR+gG+bB

Linear transformations can be performed between colour spaces.

RESULTS AND DISCUSSIONS

The CIEXYZ imaginary space - each point corresponding to a colour in the imaginary CIEXYZ space or in the corresponding CIExy locus is determined by means of the general algorithm which includes as known data: the spectral reflection / transmission curve, the illuminant's energy feature and standard functions of colour composition.

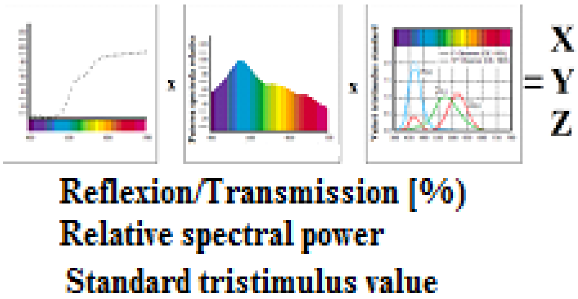

Figure 9 **Computation elements for the tristimulus X, Y, Z values.**

$$X = k \cdot \int_{\lambda=380nm}^{780} \Phi(\lambda)\, \bar{x}(\lambda)\, \tau(\lambda)\, d\lambda,$$

$$Y = k \cdot \int_{\lambda=380nm}^{780} \Phi(\lambda)\, \bar{y}(\lambda)\, \tau(\lambda)\, d\lambda,$$

$$Z = k \cdot \int_{\lambda=380nm}^{780} \Phi(\lambda)\, \bar{z}(\lambda)\, \tau(\lambda)\, d\lambda;$$

where:

$$k = \frac{100}{\int_{380}^{780} \Phi(\lambda)\, \bar{y}(\lambda)\, d\lambda},$$

normalisation factor (normalisation coefficient),

Φ(λ) – the relative spectral distribution of the energy of the standard light source (the illuminants A, B, C, D, E (equal distribution), F_1 – F_{12} - fluorescent);

$\bar{x}(\lambda), \bar{y}(\lambda), \bar{x}(\lambda)$ – standard colour composition functions (matching);

$\tau(\lambda)$ – The reflection/transmission spectral coefficient;

In the CIEXYZ colour space, the working values x, y, z are defined:

$$x = \frac{X}{X+Y+z};$$

$$y = \frac{Y}{X+Y+Z};$$

$$z = \frac{Z}{X+Y+Z} = 1-(x+y);$$

$$X = \frac{Y}{y} \cdot x;$$

$$Z = \frac{Y}{y} \cdot (1-x-y)$$

Derived colour spaces

The CIELAB space

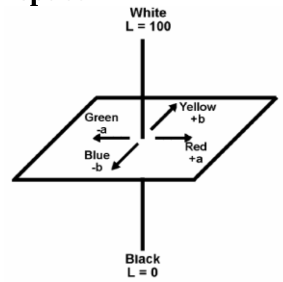

Figure 10 **Representation in the Lab space**

The Lab space is much more even than the XYZ space.

$$\begin{bmatrix} L \\ A \\ B \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -1 & 0 \\ 0 & 1 & -1 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

The luminosity L may also be represented in relation to the coordinates:

$$\begin{cases} u' = \dfrac{4 \cdot X}{X + 15 \cdot Y + 3 \cdot Z}, \\ v' = \dfrac{9 \cdot Y}{X + 15 \cdot Y + 3 \cdot Z}, \end{cases}$$

for the L′u′v′ space

or

$$\begin{cases} u^* = 13 \cdot L^* \cdot (u' - u'_0) \\ v^* = 13 \cdot L^* \cdot (v' - v'_0) \end{cases}$$

for the $L^*u^*v^*$ space.

Reflection/transmission spectra, CIEXYZ-1931, CIExy and CIELAB diagrams Wet and dry soils (A, B, C)

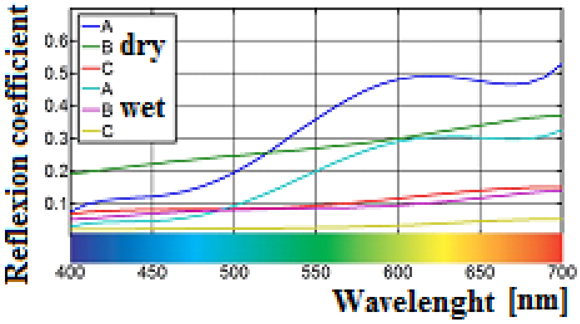

Figure 11 **Reflection curves of wet and dry soils**

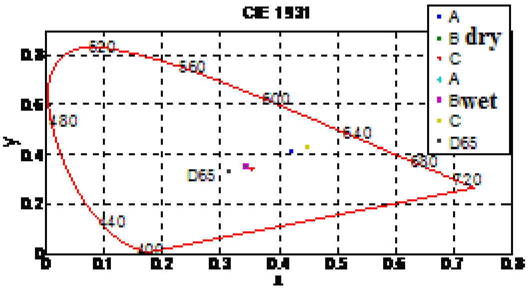

Figure 12 **Soil chromaticity diagram**

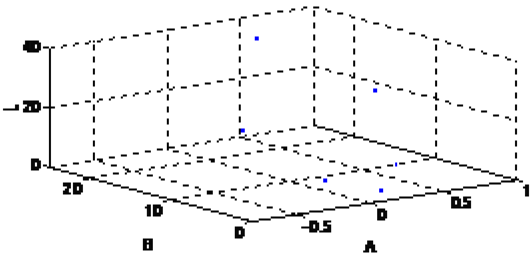
Figure 13.**Soil characteristics in the CIELAB colour space**

Leaves (F_1, F_2, F_3) and grass (I)

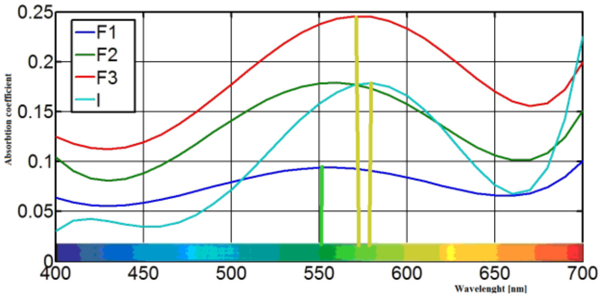

Figure 14 **Reflection curves of leaves and grass**

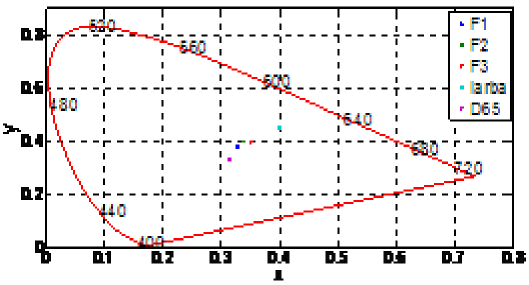

Figure 15 **Chromaticity diagram of leaves and grass**

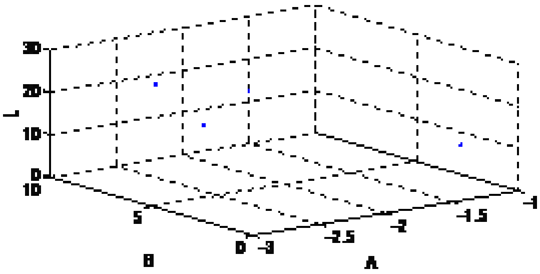
[Leaves (F1, F2, F3) and grass]

Figure 16 **The colour position of leaves and grass in the CIELAB colour space**

3.3. Gladioli[d] (A, B, C, D)

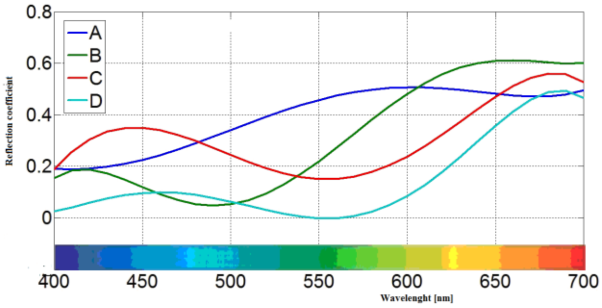

Figure 17 **Reflection curves of gladioli in different colours**

([d]*A-yellow, B – orange, C – pink-violet, D – red.*)

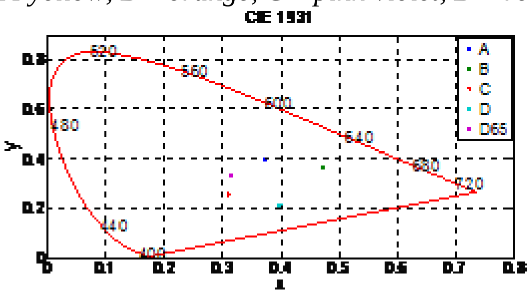

Figure 18 **The chromaticity diagram of gladioli**

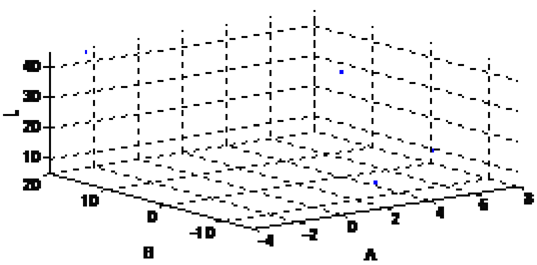
Figure 19 **The colour position of gladioli in the CIELAB colour space**

Red cabbage extract
(pH = 1, 3, 6 ,8,10)

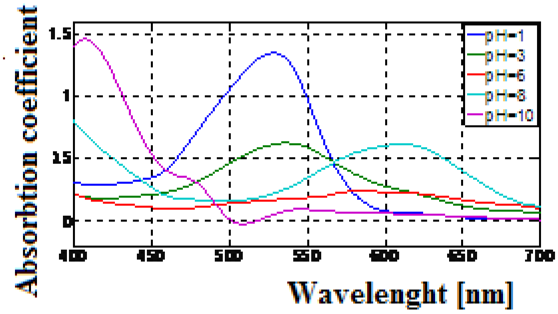

Figure 20 **The absoption coefficient of red cabbage extract**

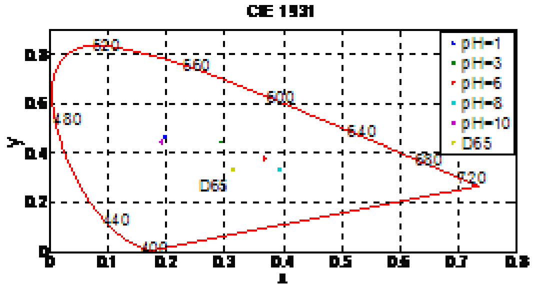

Figure 21 **The position of the red cabbage extract colour for various pH values**

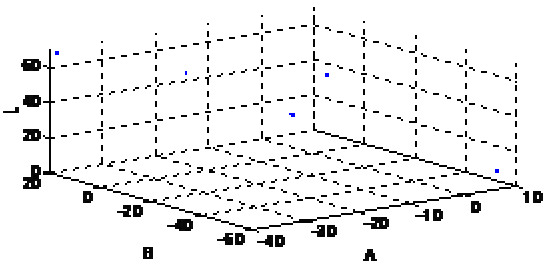

Figure 22 **The colour position in the CIELAB colour space of the red cabbage extract**

Specific colorimetric data

Wet and dry soils (A, B, C)

XYZABCD[e] =

36.6665	36.2303	14.3900
26.8713	27.5572	24.3281
10.1500	9.9074	8.7574
21.4148	20.5666	5.8403
8.5779	8.8151	7.6018
2.8892	2.7861	2.3114

([e]*The CIEXZY-1931 space.*)

xyzABCD[f] =

0.4201	0.4151	0.1649
0.3412	0.3499	0.3089
0.3522	0.3438	0.3039
0.4478	0.4301	0.1221
0.3432	0.3527	0.3041
0.4478	0.4301	0.1221

([f]*The position in the imaginary space CIExy-1931;z=1-(x+y).*)

Labsoil =

36.2303	0.4362	21.8403
27.5572	-0.6859	3.2291
9.9074	0.2426	1.1500
20.5666	0.8482	14.7263
8.8151	-0.2372	1.2133
2.7861	0.1031	0.4747

Colour difference from standard:

DE1976	DE1994	DE2000
20.5635	17.7742	6.9018
33.4816	31.6290	18.8235
17.2084	16.5178	11.9008
34.3150	32.5144	19.4894
39.6877	38.0842	23.0253

Leaves (F_1, F_2, F_3) and grass (I)

XYZF1F2F3I =

7.5411	8.6759	6.7583
13.5978	16.1239	10.6171
19.4994	22.0202	14.0616
12.2435	13.8465	4.5438

xyzF1F2F3I =

0.3282	0.3776	0.2942
0.3371	0.3997	0.2632
0.3508	0.3962	0.2530
0.3997	0.4520	0.1483

Lableaves =[8.6759 -1.1348 1.9176
16.1239 -2.5261 5.5068
22.0202 -2.5208 7.9586
13.8465 -1.6030 9.3027]

Colour difference from standard:

DE1976	DE1994	DE2000
8.3840	8.5901	4.8081
14.7134	14.8182	8.9611
9.0274	9.1154	4.4590

Gladioli (A, B, C, D)

XYZABCD =

41.7718	44.5882	26.3293
35.2506	27.3104	12.2087
25.1964	20.8456	35.1569
9.5053	5.0764	9.3372

xyzABCD =

0.3707	0.3957	0.2336
0.4715	0.3653	0.1633
0.3103	0.2567	0.4330
0.3974	0.2122	0.3904

Labgladioli =
44.5882 -2.8164 18.2589
27.3104 7.9402 15.1017
20.8456 4.3508 -14.3113
5.0764 4.4289 -4.2608]

Colour difference from standard:

DE1976	DE1994	DE2000
20.5960	19.3910	16.9038
40.9354	35.6722	30.4104
46.0615	44.2185	30.4772

Red cabbage extract
(pH = 1, 3, 6 , 8, 10)

XYZ =

29.6417	69.1753	51.4233
29.8914	45.0707	26.9924
18.5353	19.1798	12.7273
44.4480	38.1840	30.8594
16.4136	7.4934	62.0555

xyz =

0.1973	0.4604	0.3423
0.2932	0.4421	0.2647
0.3675	0.3802	0.2523
0.3916	0.3364	0.2719
0.1909	0.4442	0.3649

Labextract =
69.1753 -39.5336 17.7520
45.0707 -15.1793 18.0783
19.1798 -0.6445 6.4525
38.1840 6.2640 7.3246
7.4934 8.9202 -54.5621.

Colour difference from standard:

DE1976 DE1994 DE2000

34.2676	28.9263	23.6663
78.9717	64.0117	49.0395
104.2044	63.7949	49.6113
175.9544	90.8679	93.3073

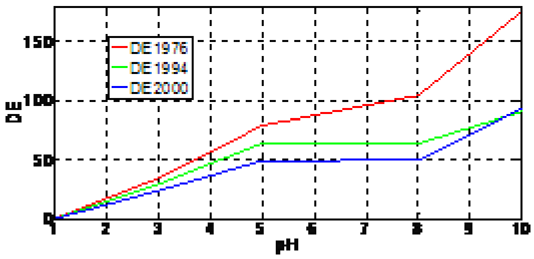

Figure 23 **Colour difference depending on pH for red cabbage extract**

CONCLUSION

Except for two samples (cabbage extract at pH 3 and pH = 10), the CIE xy points are located in the sRGB colour rendering space. This suggests the fact taht further direct methods of colour analysis may be employed.

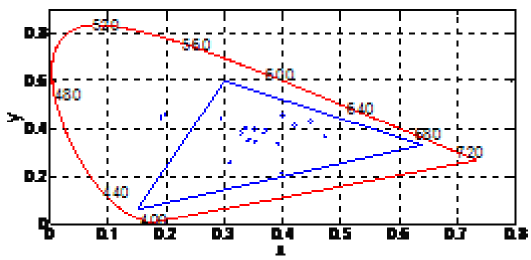

Figure 24 **Experimental data in the sRGB space**

Wet soils have lower L,A,B values than dry soils and less colour difference from standard.

Grass is significantly more yellow than leaves (the highest b+ value). Over time, leaves become increasingly greener (higher a- values).

In the CIELAB space, the a and b values cause a clear distinction between gladioli: a + - green, a- - red, b + - yellow, b- - blue.

In the CIEL*AB colour space, colours differ significantly based on their location.

By using the CIEDE2000 formula to compute colour difference uniform and limited differences between the coloured samples are obtained.

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