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Soil morphology as an indicator for assessment of drainage system efficiency in sugarcane cultivated lands, South Khuzestan, Iran

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Abstract

Land drainage is an operation which increases land production and ensures sustainable land use. Soil scientists attempt to arrive a scientific procedure for assessing the efficiency of drainage system, among the correlation between soil morphological characteristics, mainly soil color and redoximorphic features and water table behavior. The aims of this study were investigating the efficiency of drainage system through soil morphological and micromorphological characteristics and judge about the existence of episaturation or endosaturation, in Khuzestan sugarcane cultivated lands after years of artificial drainage. 5 pedons were dug and characterized based on their morphological and micromorphological features. The characteristics of redoximorphic features showed no considerable differences in drainage class between artificial drained field and virgin land. The only contrast was shallower ground water table in virgin lands. 4 pedons were classified as somewhat poorly drained and one as well drained. These drainage classes show that despite the existence of artificial drainage system, the problems haven't been eliminated yet. All pedons showed horizons with low chroma colours in deeper horizons and different types of redoximorphic feature. Micromorphological observations proved that the lands were involved in Endosaturation due to high ground water level.

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Introduction

Soil scientists usually estimate groundwater level fluctuation through the soil morphological characteristics, mainly the soil colour and mottles. Many soils with grey colour (low chroma) indicate saturated hydric condition and chemically reduced condition. Yellowish-brown to reddish soil colours represent aerobic and oxidizing chemical condition. Soils with ground water fluctuations show low chroma or grey colour with reduced condition and saturated zone. The Natural Resources Conservation Service, however, has adopted "redoximorphic features" instead of the traditional concepts of low chroma colours and mottling to provide morphological evidence for periodically saturated and reduced (Soil Survey Staff, 1992). Features of the oxidized forms of Fe and Mn include nodules and concretions, pore linings, and masses. Features formed by the dissolution and removal of reduced Fe and Mn include the "reduced matrix" (Neal et al., 1995). Redoximorphic features are more useful than soil colour for indicating soil saturation and reduction occurrences, because they provide specific evidence of where these processes operate in the soil, for

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example, pore linings form by oxidation of Fe along macro pores, indicate that the soil is reduced in the matrix but oxidized around macro pores, usually due to oxygen diffusion within the roots of hydrophilic plants (Fisher and Stone, 1991). Hassannezhad et al., (2008) investigated about the morphology and micromorphology of paddy soils under different soil moisture regime and ground water table in Northern Iran through the different redoximorphic features and their distribution patterns. Kodeva et al., (2010) estimated intensity and duration of waterlogging under rice crop by micromorphology and mineralogy. Vepraska et al., (1992) conducted a study about the development of redoximorphic features in constructed wetland soils. Most lands in south Khuzestan exhibit both grey and yellowish-brown colours with high saline ground water level. Reclamation activities, specially operating a drainage system at the depth of 2 meter and salt leaching were done and the lands had been prepared for cultivation. Despite the existence of artificial drainage system, some of these lands are facing with drainage problems and ground water fluxion now. Poor drainage leads to many problems. There are several obvious clues for assessment of soil drainage. Soil scientists used soil colours, layers with low chroma or grey colour and redoximorphic features as some indicators for drainage imperfections. The aims of this study were investigating the efficiency of drainage system through soil morphology and micromorphology characteristics and finding the existence of episaturation or endosaturation, in south Khuzestan sugarcane cultivated lands after years of artificial drainage.

Material and Methods

Study area and sampling

The study area was a sugarcane agro industrial unit, Amir Kabir, which is located between longitudes 31° 15' N and 31° 40' S, latitudes 48° 30' E and 48° 12' W, south Khuzestan, Iran. Table 1, shows some general information about the study region. Four pedons were in sugarcane cultivated lands and one in adjacent non-cultivated land, (Table 2).

Table1. General information of the study region

Area	Mean annual temperature (°C)	Mean annual precipitation (mm)	Physiography	Soil Moisture - temperature regime[a]
Amir Kabir	25	252	River alluvial plain	Aridic-Thermic

[a] Soil Survey Staff (2006)

Morphological features of each horizon and layer were described according to Soil survey staff (1998). Undisturbed soil samples of all diagnostic horizons were collected by means of Kubiena boxes. In order to measure soil bulk density core sampler was used.

Table 2. Information of studied soil profiles in Haft tappe series

Region	Soil series	Profile No.	Field No.	Coordinate South West	Years after drainage	Soil Classification[a] (Subgroup)
Amir Kabir	Karoon	1	6-9	240611E 3438859N	14	Typic Haplocalcids
		2	2-2	245660E 3441120N	19	Typic Aquicambids
		3	8-12	239665E 3438508N	14	Typic Aquicambids
		4	3-1	244484E 3439941N	14	Typic Aquicambids
		5	2-18	244631E 3442758N	Not drained	Typic Natriargids

[a] Key to Soil Taxonomy (2010)

Soil samples of all horizons were obtained in plastic bags and then the samples were air-dried and carefully passed through a 2 mm sieve to remove stones, roots and large organic residues before conducting laboratory analysis.

Laboratory analysis

Particles size was determined using hydrometer method (Gee and Or, 2002), Bulk density was determined using Core method (Grossman and Reinsch, 2002). Soil pH was measured in saturated soil using glass electrode (Mclean, 1982). Electrical conductivity was measured in saturated paste using conductivity meter (Rhoades, 1982). SOM was determined by using the Walkley and Black procedure (Jackson, 1975). CCE was measured by digestion in HCl (Nelson, 1982). CEC was determined using Sodium Acetate (NaOAc) at pH 8.2

(Bower and Hatchea, 1966). Gypsum ($CaSO_4$. $2H_2O$) was determined by precipitation in Acetone (Salinity Laboratory Staff, 1954). Undisturbed block of soil were taken by Qubiena boxes. All of the blocks were impregnated with a polyester resin after replacing water with acetone to avoid of structural modification. After air-drying, oriented thin sections with a thickness of 30 micro meters were prepared and were observed under a petrographic microscope (Motic BA300 POL). The micro morphological features were captured with a digital camera (Motic cam pro 252A). Finally the soils were classified to the subgroup level and assigned to a soil drainage class.

Results and Discussion

Abbreviated field descriptions and laboratory data of five representative soil profiles are presented in tables 3 and 4. All studied pedons had a 2-8 cm black organic buried horizon which is lying at varying depths between 150-180 cm in this region (Figure 1). This might relates to the past time native vegetation. Historical records revealed that the south Khuzestan native vegetation was canebrake. All studied pedons, except the first one met the requirements of somewhat poorly drained class. Pedon 1 had the requirements of well drained class (Soil Survey Staff, 1998). In well-drained class soils generally have high-chroma matrices to a depth of 150 cm and soil depth is at least 50 cm to bedrock and has a texture of loamy very fine sand or finer and redoximorphic features, if present, are 100 cm or more below the mineral soil surface (NRCS, 2010).

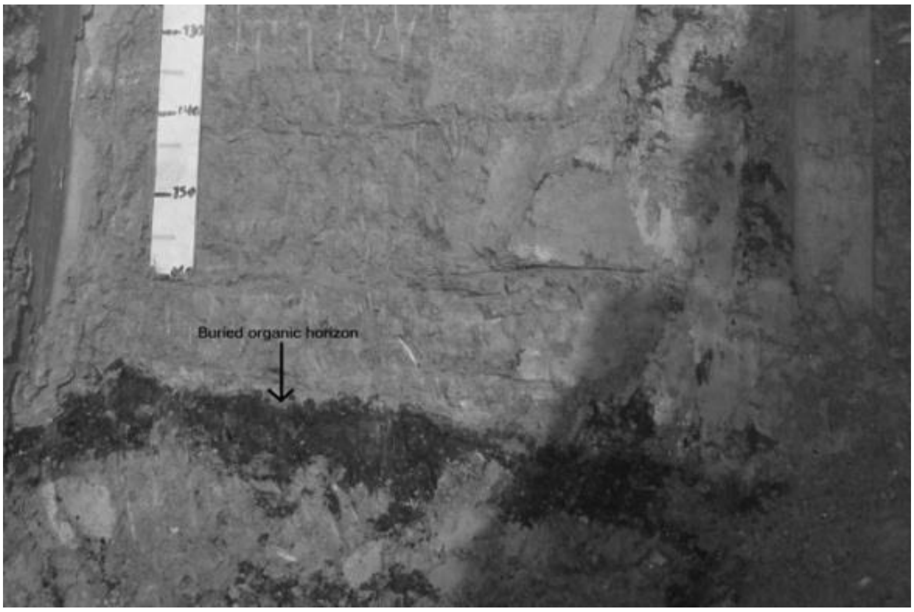

Figure 1. Buried organic buried horizon lies beneath the soils of study region.

Pedon1 fulfilled the texture requirement and had the chroma 3-4 in all horizons and showed no evidence of redoximorphic features to the depth of 60 cm, were seen in field with nacked eye. High-chroma Fe concentrations were observed in two underlying horizons and just few Iron depleted matrices with chroma, 1, were at the depth of 160 cm, (Table 3).

Somewhat poorly drained is not very poorly or poorly drained and has redoximorphic features at the depth of less than 40 cm below the mineral soil surface (NRCS, 2010). This drainage class has high-chroma Fe concentrations, Fe depletions or a combination of the two, within 30 cm of the surface. In this study, pedons which were classified as somewhat poorly drained had high chroma. Pedon 2 and 4 showed mottles even in surface horizons. Simonson and Boersma (1972) stated that the average depth to the uppermost horizon containing redoximorphic features increased from poorly drained to well-drained soils. Similarly featured soil horizons were saturated for approximately the same amount of time in any given month, regardless of soil drainage class. However, the authors found that the frequency of saturation of soil materials at a given height above the featured horizon varied by drainage class, with more frequent saturation of materials in somewhat poorly drained soils> moderately well-drained soils> well-drained soils (Genthner et al., 1998).

Table 3. Morphological characteristics of studied pedons.

Profile & field NO.	Horizon	Depth (cm)	Matrix colour	Mottle colour	Mottle Type[a]	Pores[b]	Texture[c]	Structure[d]	Drainage Class[e]	Remarks
1(6-9)	Ap	0-15	10YR 4/3	-	-	M v.f to f	L	P	WD	Common gypsum features.
	Bk1	15-35	10YR 4/4	-	-	M v.f to f	L	M		
	Bk2	35-60	10YR 4/3	-	-	M v.f to f	L	M		
	Bwg	60-110	10YR 4/3,7.5YR 5/4	7.5YR5/8	F 1 d	M v.f to f	Sl	F1sabk		
	Bwyg	110-160	7.5YR4/4,10YR 5/4	10YR6/8	C 2 d	M v.f to f	Cl	F1sabk		
2(2-2)	Ap	0-28	10YR 4/4	5YR5/8	F 1 f	F v.f to f	C	P	SPD	109-150 cm: buried organic horizon below this horizon.
	Bt	28-63	10YR 4/4,7.5YR 4/4	5YR5/8	F 2 d	C v.f to f	C	M		
	Bkd	63-90	7.5YR 4/4,10YR 5/3	5YR5/8	C 3 d	C v.f to f	C	F1sabk		
	Bwg	90-109	10YR 5/4,7.5YR 4/4	5YR5/8	M 3 p	Mv.f to f	C	F1sabk		
	Bg	109-150	10YR 3/1	5YR5/8	M 3 p	M v.f to f	C	M		
3(8-12)	Ap	0-20	10YR 4/4	-	-	M v.f to f	C	P	SPD	85-95 cm: Gley layer(10YR3/1), few gypsum.,110-150(cm): Common gypsum, buried organic horizon at the depth of 180cm,EC of ground water was 5.4 dS/m at the depth of 190cm.
	Btk	20-35	10YR 4/4	-	-	M v.f to f	Sic	M		
	Bk	35-50	10YR 5/4,7.5 YR 4/4	-	-	C v.f to f	Sicl	M		
	Btkg	50-75	10YR 5/4,7.5 YR 4/4	5YR5/8	F 1 f	M v.f to f	Sicl	M		
	Bkg	75-110	10YR 4/4,10YR3/1	5YR5/8	F 1 f	M v.f to f	Sic	M		
	Bg	110-150	7.5 YR 4/4,10YR 5/4	10YR6/8	C 2 D	M v.f to f	Sic	M		
4(3-1)	Ap	0-30	10YR 4/4,10YR 5/8	7.5YR 5/8	F 1 f	M v.f to f	Sicl	P	SPD	109-150(cm): Restricting clay layer with a varied depth from 8-10 cm.
	Bdg	30-60	10YR 5/4,10YR 5/8	7.5YR 5/8	F 1 f	Co v.f to f	Sicl	M		
	Bkgy	60-83	10YR 5/4,10YR 5/8	7.5YR 5/8	C 2 d	Co v.f to f	Sil	M		
	Bgy1	83-109	7.5YR 4/4,10YR 6/2	10YR 6/8	M 2 p	Co v.f to f	Sicl	M		
	Bgy2	109-150	10YR 6/2,2.5Y 6/2	10YR 6/8	M 2 p	F v.f to f	Cl	M		
5(2-18)	A	0-34	10YR5/4,7.5YR5/4	-	-	Co v.f to f	Cl	M	SPD	Salty crusts on surface. 98-150(cm): This horizon is completely gleyHigh saline ground water (EC[f]: 44.2 dsm^{-1}), at the depth of 150 cm.
	Cg1	34-70	7.5YR 4/4	5YR 5/8	F 2 f	Co v.f to f	Sic	M		
	Cg2	70-98	10YR4/4,7.5YR4/4	5YR 5/8	C 3 d	Co v.f to f	Sic	M		
	Cgy	98-150	5Y5/2,10YR 3/1	5YR 5/8	M 3 p	Co v.f to f	Cl	M		

[a] Mottle type. Abundance: F, few; C, common; M, many. Size: 1, fine; 2, medium; 3, coarse. Contrast: f, faint; d, distinct; P, prominent.

[b] Porosity. Abundance: M, many; Co, common; F, few. Size: v.f, very fine; f, fine.

[c] Texture: Sicl, silty clay loam; Cl, clay loam; Sic, silty clay.

[d] Structure: P, plow; M, massive; F1sabk, fine, weak, angular blocky.

[e] Drainage class: WD, well drained; SPD, somewhat poorly drained. [5]

Table 4. Results of laboratory analysis of studied pedons.

Profile & field No.	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk density (gr cm^{-3})	EC[a] (ds m^{-1})	pH	$CaSO_4.2H_2O$ (%)	$CaCO_3$ (%)	OC[b] (%)
1(6-9)	0-15	33.94	42.48	23.58	1.75	22.7	7.15	0.055	37.53	0.59
	15-35	41.94	36.48	21.58	1.70	2.4	7.46	0.004	38.63	0.04
	35-60	37.94	36.48	25.58	1.70	2.15	7.79	0.004	38.65	0.14
	60-110	69.94	20.48	9.58	1.59	2.95	7.80	0.004	34.88	0.20
	110-160	29.94	40.48	29.58	1.56	4.05	7.56	0.432	38.70	0.20
2(2-2)	0-28	12.42	0	87.58	1.65	2.40	7.51	0.004	39.78	0.53
	28-63	4.42	0	95.58	1.60	2.21	7.77	0.003	38.88	0.12
	63-90	0.42	0	99.58	1.76	1.69	7.78	0.003	39.35	0.21
	90-109	0.42	0	99.58	1.61	1.49	7.86	0.003	39.23	0.20
	109-150	0.42	0	99.58	1.58	1.59	7.86	0.005	38.23	0.33
3(8-12)	0-20	22.42	30	47.58	1.70	3.12	7.58	0.013	37.25	0.20
	20-35	2.42	38	59.58	1.66	3.12	7.99	0.004	37.33	0.21
	35-50	0.42	38	60.58	1.66	3.16	7.76	0.004	38.78	0.23
	50-75	0	39	61	1.62	2.80	7.64	0.003	39.03	0.22
	75-110	0	48.67	52.25	1.53	2.74	7.80	0.003	39.38	0.23
	110-150	0	48	53.58	1.55	2.45	7.86	0.003	38.53	0.22
4(3-1)	0-30	10.42	54	35.58	1.76	2.00	7.87	0.013	39.05	0.29
	30-60	8.42	56	35.58	1.82	1.97	7.88	0.003	38.75	0.27
	60-83	18.42	60	21.58	1.76	1.40	7.57	0.071	39.35	0.18
	83-109	16.42	48	35.58	1.69	3.50	7.69	0.750	39.15	0.10
	109-150	-	-	-	1.80	3.30	7.58	0.863	33.83	0.21
5(2-18)	0-34	26.42	36	37.58	2.70	16.66	7.76	0.151	38.80	0.23
	34-70	4.42	52	43.58	1.75	26.20	7.83	0.151	39.10	0.18
	70-98	4.42	54	41.58	1.78	25.20	8.08	0.027	39.43	0.23
	98-150	30.42	40	29.58	1.75	24.30	7.95	0.071	37.50	0.49

[a] Electrical conductivity., [b] Organic Carbon

The observation of redoximorphic features in studied pedons showed no considerable differences in drainage class between artificial drained field under cultivation and virgin land and the only contrast were the depth of ground water table which was shallower in virgin land (about 40 cm). These drainage classes show that despite the existence of artificial drainage system, the problems haven't been eliminated yet. In all pedons except the blank one water was ponded nearly at the depth about 180 cm above the drainage network, but in pedon5 ponded water was seen at shallower depth (about 150 cm). Different types of Fe accumulations of high chroma about 8, as variable shapes of Fe masses in soil matrix, pore linings or in other words impregnations of the matrix adjacent to the pores, Fe concentration on ped faces and redox depletion with generally value ≥ 4 and chroma ≤ 2, which is called gley mottles, were observed in the field (Figure 2a, b and c). These features were similar with Hassannejad (2008) observations. He reported brown spots and rusty mottles that showed oxidized condition. He also stated that during reoxidized conditions existed in the soil, Fe and Mn accumulated as coating in the voids, root channels and macropores, particularly in the root channels and other biopores caused by cultivation. After alternative redox processes, irregular soft masses were concentrated close to the pedosurfaces; Fe and Mn nodules were further formed as well (Hassannejad et al., 2008). The most common observed mottle colours in the field were 5YR 5/8 in all horizons of pedons 5, 2 and at the depth of 50-110 cm of pedon 3. Pedon 4 and 1 in order, frequently showed 7.5YR5/8 mottles at depth of 83 cm and 60-110 cm.

The mottles showed more contrast in horizons with lower chromas, as generally the mottles in deeper horizons of studied pedons with less chroma were prominent, however they are faint in upper horizons with more chroma. Contemporary redox colours may be the results of the iron minerals: Ferrihydrite (5YR), Lepidiocrocite (7.5YR), Goethite (7.5YR, 10YR), and Jarosite (2.5Y) and have value and chroma of 4 or more (NTCSH, 2007). All pedons had a gley horizon of low chroma, 1-2, generally at the depth of 150 cm (Table 3) which lies above and below the buried organic horizon and continue nearly to the depth of 2 meter, where the water starts to ponding (Figure 1).

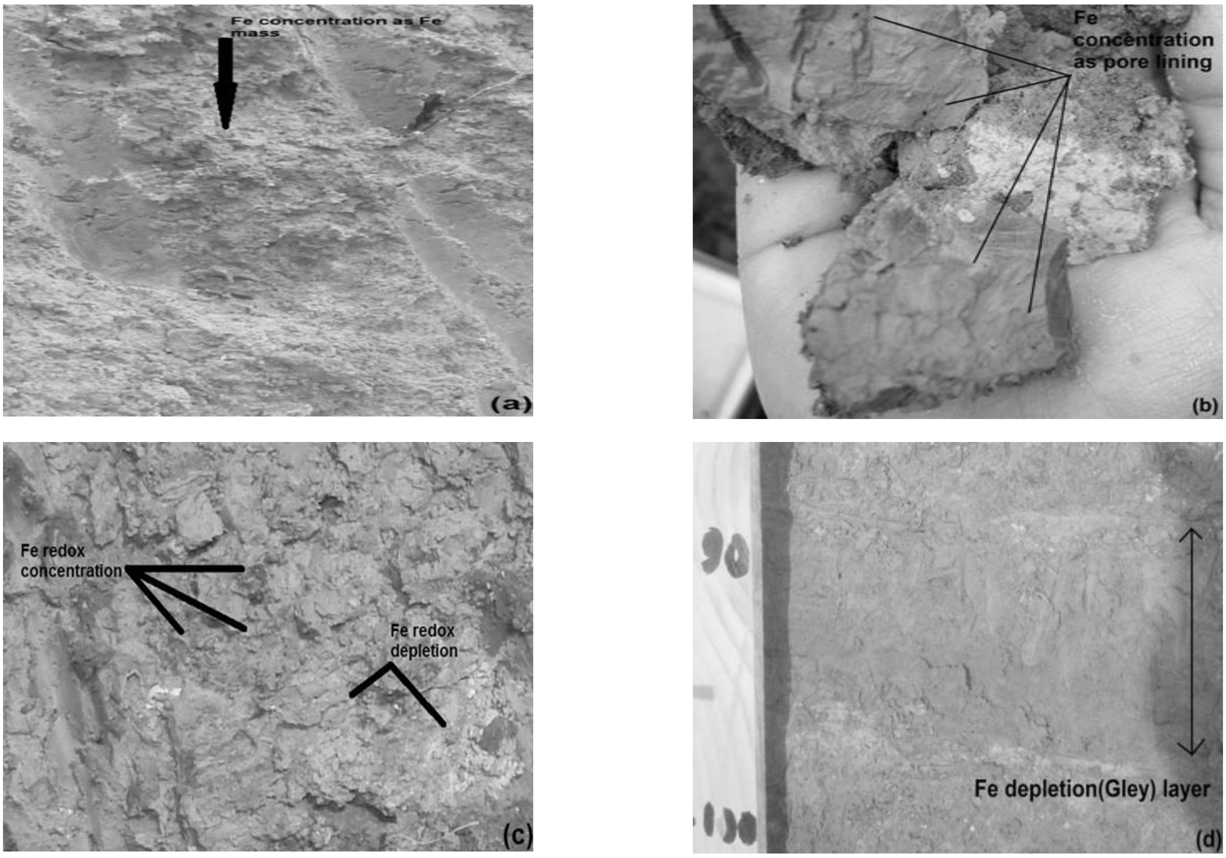

Figure2. Redoximorphic features as Fe mass (a)., Impregnation of Fe adjacent to pores (b)., Fe concentration on ped faces and redox depleted zones (c)., Fe depleted layer at the depth of 85-95 cm of pedon3 (d).

A thin low chroma Fe depleted horizon occurred at the depth of 85-95 cm on pedon 3 (Figure 2d). Daniels et al. (1971) reported that soil materials that were saturated about 25% of the year developed pale brown to very pale brown (10YR 6/3 or 10YR 7/3) mottles. Soils that saturated about 50% of the year developed light grey to light brownish grey (10YR 7/2 or 10YR 6/2) mottles at depths. Franzmeier et al. (1983) found that soil horizons dominated by chroma 1 or 2 colours were saturated for much of the year, and tended to occur in that portion of the soil profile subject to the most frequent wetting and drying. Horizons that had 3 chroma colours in the matrix, argillans, or mottles also were observed to be periodically saturated, while those that had matrix chromas of 5 or 6 and no mottles of chroma, 3 or less were seldom if ever saturated. Schelling (1960), stated the depth to the mean water table in soils of the Netherlands was reasonably estimated by the depth to specific grey redox depletions. It was believed that the depth to grey depletions was a more reliable indicator of the mean water table than were rust mottling. Zobeck and Ritchie (1984) found that the depth to 2 chroma depletions corresponded with the highest water table levels in well, moderately well, and poorly drained, fine-textured soils in Ohio. Thin section observations under microscope showed different types of redoximorphic features, especially in somewhat poorly drained pedons (Figures 3 and 4).

In Pedon 1, well drained, contrary to field descriptions, thin section observations also showed some redoximorphic features in subsurface horizons. Figure 3a, shows 100 to 300 μ Iron oxide nodules that were distributed in micromass of pedon1 at the depth of 35-60 cm. Related to the drainage class of this pedon, they are similar to anorthic or lithomorphic types of nodules which might be inherited from parent material. However in pedon3, Somewhat poorly drained, 42-62 cm, Fe oxide nodules distinguished as orthic nodules, based on Stoops (2003). Figure 3b, shows Fe oxide coating on the lower surface of a channel in pedon1. Hassannejad reported the least amounts of Fe-Mn nodules through the profile with the poorest drainage. He also mentioned the types of coating and hypocoatings in well drained and moderately drained pedons that have sharp boundaries relate to matrix and were distinct. For all studied pedons the ground water table seemed to indicate endosaturation. So confirmation of endosaturation should be done by surveying the field data and the types of redoximorphic features. Vepraska and Guertal (1992) stated that when a perched water table is present, saturation and reduction occur primarily along macropores while ped interiors remain oxidized. Thus, in such a scenario, Fe would be dissolved primarily along root channels and ped faces and translocate to oxidized ped interiors, where it would be precipitated as high-chroma Fe concentrations (quasi-coatings). It is called Episaturation. By contrast in soils with high ground water table in such a prolonged period of saturation presumably allows time for water to move into ped interiors. At this condition redox processes may continue throughout the peds. During this time period, the formation of high-chroma Fe concentrations could occur only in the capillary fringe, where there is presumably considerable microsite variation in the soil redox environment (Genthner et al., 1998). This is called Endosaturation.

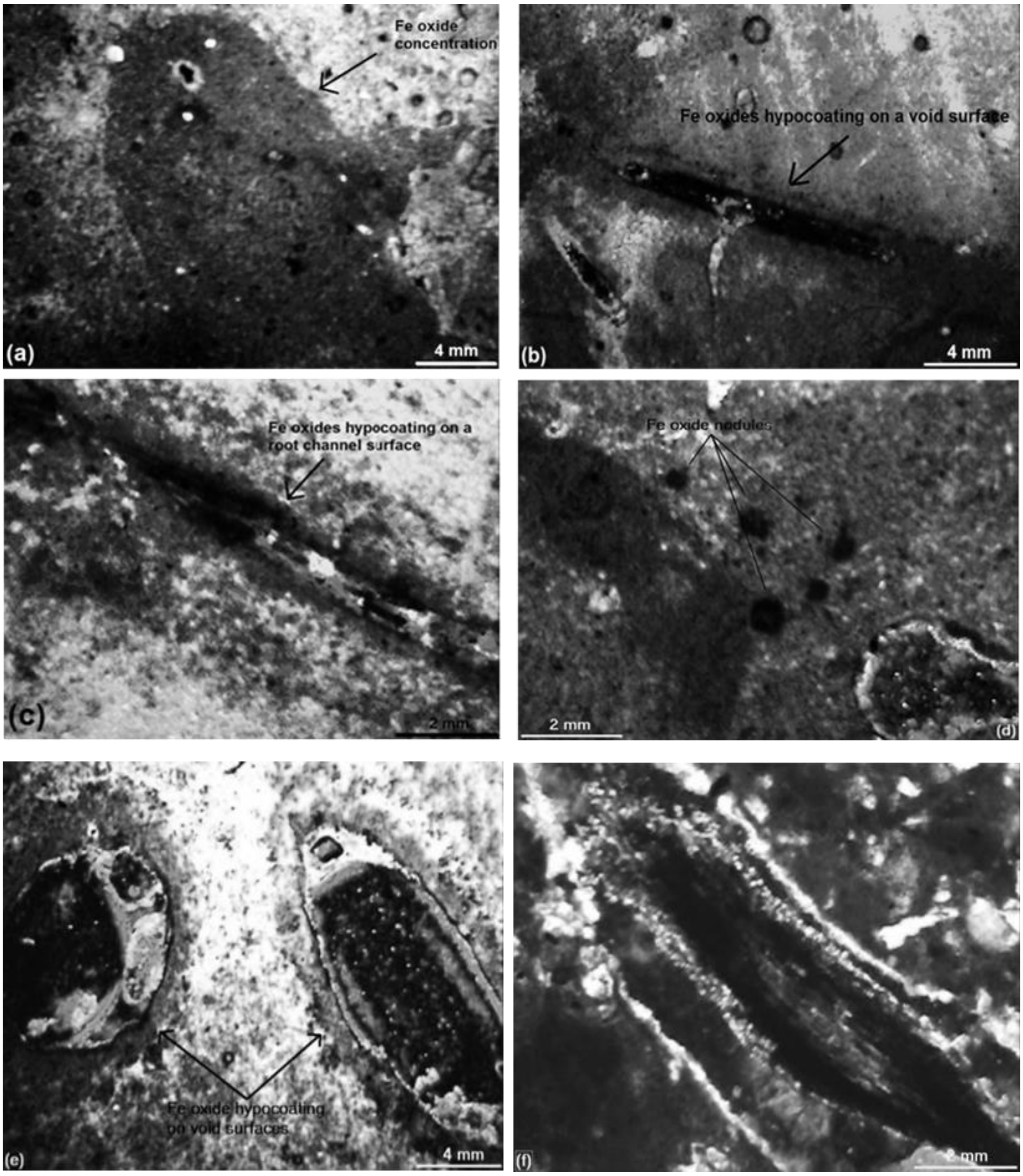

Figure 3. Strongly impregnative pedofeature of Fe oxides concentration in micromass., 30-60 cm, pedon 4, (a)., Internal hypocoating of Fe oxides on a void surface, which is developing to void infilling, 62-90 cm, pedon3, (b)., Internal hypocoating of Fe oxides on a root channel surface, which is developing to void infilling, 42-62 cm, pedon 3, (c)., Fe oxides orthic nodules in micromass, 42-62 cm, pedon3, (d)., Fe oxides external hypocoatings on void surfaces, 96-142 cm, pedon3, (e). A root channel with no redoximorphic features, 23-42 cm, pedon3, (f)., All in XPL.

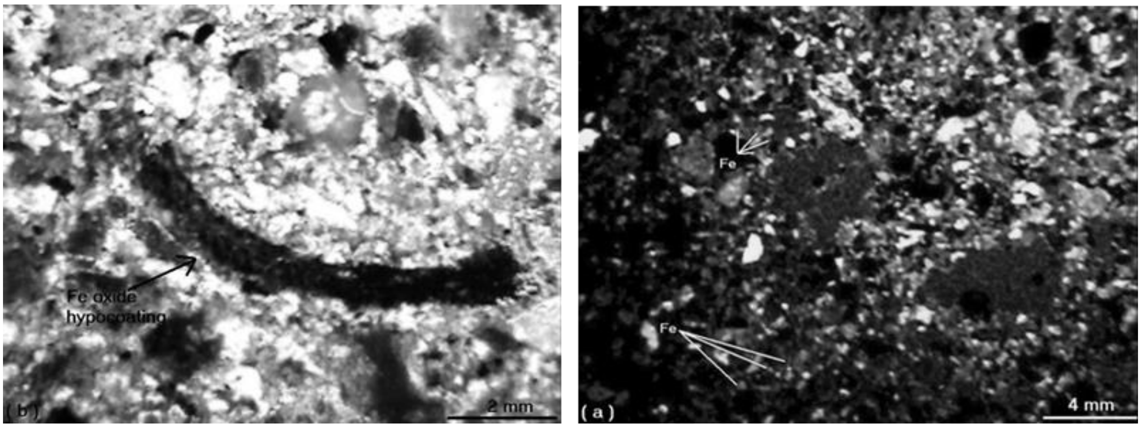

Figure 4. Small Iron oxide nodules, about 100-300 μ, distributed in micromass, 35-60 cm, pedon 1, (a). Fe oxides coating on lower surface of channel, (b). All in XPL.

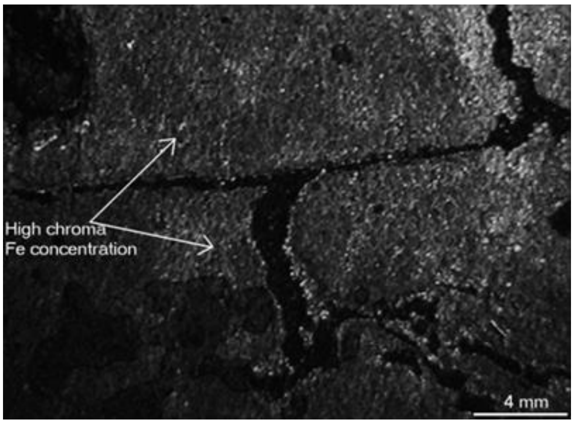

Figure 5. Subangular blocky microstructure and High-chroma Fe concentration around channel voids, 63-90 cm, pedon 2, XPL.

Vepraskas and Guertal (1992) stated that in the capillary fringe, Fe may move from reduced ped interiors to more oxygenated sites along roots channels and ped faces (hypo-coatings). In arid temperature regimes like Khuzestan as the temperature start to increase in spring and evapotranspiration tend to reach to maximum level in summer, soil macropores would be the first places, where drying occur. Aerated conditions would develop along root channels and ped faces, while ped interiors would remain saturated and reduced. At this condition Fe^{3+} would continue to diffuse from ped interiors to precipitate along soil macro pores. As the signs were seen in field study and were observed in thin sections (Figure 3b, c and e), even in well and somewhat poorly drained soils of this research, similar patterns of saturation occurred and oxidation frequently was observed around root channels and on void surfaces. Figure 3b and c illustrated hypocoatings of Fe on root channel surfaces. Old roots are completely decomposed and saturation condition in micropores causes the movement of Fe^{2+} to root channels with more Oxygen and oxidation of Fe^{2+} to Fe^{3+}. Since the Fe^{3+} is insoluble form, it doesn't move and concentrates in such places during periods of saturation. Also figure 3f, revealed the signs of endosaturarion. Fe oxides hypocoating around the voids showed reduced condition interior the peds which caused the migration of Fe oxides to macropores. The occurrence of some high chroma Fe concentrations at depths slightly above the shallowest Fe depletions may indicate that some Fe also diffuses upward along saturated macropores and is precipitated at the interface between oxidized and reduced portions of the soil profile (Genthner et al., 1998). Figure 3c, shows precipitated Iron oxides on external ped surfaces between oxidized and reduced part of horizon. Figure 3f, was captured from the subsurface Bt horizon of pedon 3 at depth of 23-42 cm. No sign of redoximorphic features were seen in the field. The thin section observations confirm this claim. Figure 4b, revealed that well drained pedons sometimes in the past faced to endosaturation and this is eliminated now, but the other pedons have been faced with this problem yet. Vepraska (1992) noted that diffusion of air and water through sandy soils is likely to be more random than it is through finer-textured soils with a well-defined network of macropores. We speculate that under these conditions, high-chroma Fe concentrations are likely to be weakly expressed and more ephemeral than in more strongly structured, clayey and fine loamy. The results of this study are in agreement with this hypothesis. Pedon 1, Well drained, had subangular blocky structure and texture of silty loam and clay loam at the depth where high chroma redoximorphic feature exists. This is the evidence of better diffusion of air and water. Pedon 2 with prevalent clay texture in all horizons also showed high chroma redoximorphic features in all pedon. Figure 5, reveals developed blocky microstructure in this soil profile which forms planar and channel voids, caused good diffusion of air and water and results high chroma Fe concentration.

Conclusion

Land drainage performance is one of the operations that increase land production and also ensures sustainable land use. The depth of installed underground drainage is one of the important factors which affect its efficiency. Soil scientists attempt to arrive a scientific procedure based on the correlation between soil morphological characteristics and water table behaviour, for operating a drainage system with the most efficiency. This method mainly is through the information they obtain from the relationship between ground water table and soil redoximorphic features, which give them important implications for assessment of drainage system efficiency. It is important that interpretations have an accurate understanding of the relationship between water table and the depth of soil color features. During this study in this region we observed an apparent correlation between the occurrence of certain redoxirnorphic features and the water table depth. The results showed the signs of endosaturation. We found the relationship between the water table and: (i) the depth of Fe depletions and Fe-depleted matrices, (ii) the depth to high chroma, 8, Fe concentrations.

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