J. Agr. Sci. Tech. (2000) Vol. 2: 243-256

Genesis and Morphological Changes of Soils under Irrigated Date Palm in Southern Iran

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ABSTRACT

Macro and micromorphological investigations were conducted on selected Xerepts soils from southern Iran to identify changes in soil characteristics with time. Soil samples from similar pedons of four irrigated orchards ranging in age from 20 to 100 years were studied and compared with soil samples of a pedon of non-irrigated land. In addition to routine analyses, undisturbed blocks of soils from each horizon of pedons were prepared and used for micromorphological studies. Field data, micromorphological obsrevations and laboratory data, permitted an overview of changes in soil characteristics and their role in the pedogenesis. Changes observed include the type and distribution pattern of voids, translocation and accumulatin of $CaCO_3$, and the soil fabrics. Calcitic hypocoatings, and compound dense complete calcite infillings in vughs, and large voids were attributed to precipitation as induced by irrigation. There seems to be an increase in organic matter content with time. This needs to be further studid to establish condition for carbon sequestration and increased soil quality in arid regions.

Keywords: Calcitic hypocoatings, Irrigated date palm, Micromorphology, Xerepts.

INTRODUCTION

Soils the kind of under irrigation in Jahrom play a major role in all agricultural production in southern Iran. Long term hot and dry seasons in the area make agriculture entirely dependent, on irrigation with underground water. It is believed that progressive accumulation of $CaCO_3$, in soils of the study region is controlled by alternative processes of wetting and drying due to irrigation and evapotranspiration, respectively. Understanding soil developement under such conditions is therefore important for sustainable agriculture.

Soil development in arid and semiarid regions is best characterized by several pronounced time-dependent changes, including: decrease in particle size toward silt and clay texture; color changes; increase in plasticity, stickiness and hardness; translocation and accumulation of solutes (carbonate, gypsum,...); decrease in porosity; Ca and Mg enriching in exchange sites (Harden, 1982). Ahmed (1977), pointed out significant changes in soil properties such as decalcification of the upper and calcification of the lower parts of the newly reclaimed calcareous soils in Egypt.

Under flood irrigation, where water is allowed to pond on the soil surface, transport down preferential pathways should be unimpeded and deep movement of solutes is expected (Jaynes and Rice, 1993). McFadden *et al.* (1991) proposed that preferred movement of water in noncapillary pores may perhaps act to favor open system behavior in medium and coarse-textured soils. As shown in part by the studies of Arkley (1963), soil-water balance, combined with available water-holding capacity, plays a critical role not only in determining the mass of carbonate that can be dissolved and redistributed in the soil, but also determines the pattern of carbonate redistribution with depth over the

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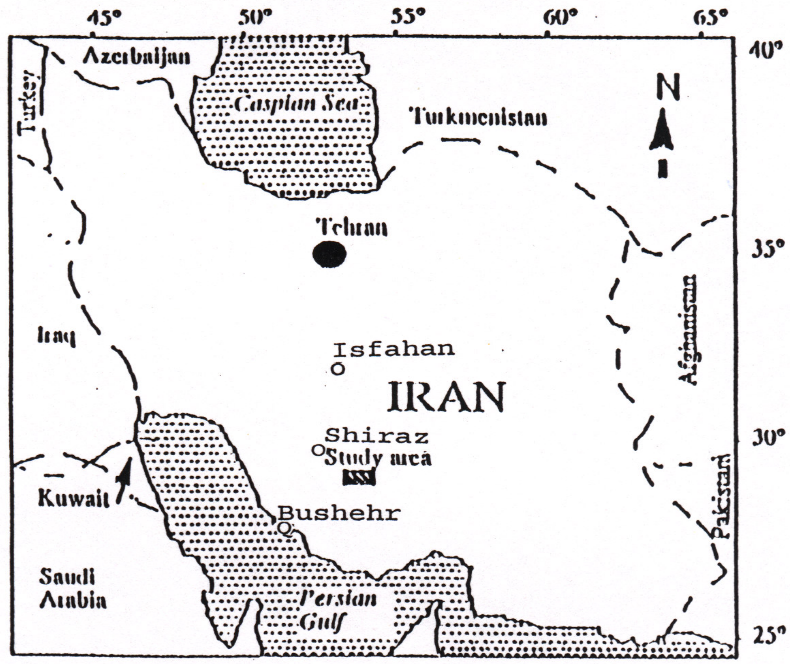

Figure 1. Location map of Jahrom.

duration of soil development.

Monger *et al*. (1991) stated that pedogenic calcite is most transient in zone 1 (surface layer), because this zone is subjected to most frequent wetting. They concluded that dissolved and suspended calcite was carried into the soil by percolating water. As the soil water was absorbed by roots or evaporated, calcite precipitated on root surfaces and on sand and silt particles as calcitans. Calcite was channeled into macropores during its downward movement, which resulted in hypocoatings and eventually nodules. Development of various pedogenic features, such as channels, cutans, pedotubules and secondary carbonates in soils of arid Australia, is due to major processes of dissolution, leaching and recrystallization (Chen, 1997).

Sequential accumulation of carbonate in desert soils is reported by Gile *et al*. (1966). Repeated wetting and drying of soils caused distribution of $CaCO_3$ and clay particles within the soils of irrigated date palms in Saudi Arabia (Khalifa *et al*., 1989). Effects of several wetting and drying cycles on the formation of micritic hypocoatings on void walls is also described by Thompson *et al*. (1991).

Becze-Deak *et al.* (1997) reported that various forms of small scale secondary $CaCO_3$ accumulations have a potential to contribute to the understanding of the evolution of the environment and studies of such accumulations focus on micromorphological observations. Thus, micromorphology has been used as a tool for better understanding of pedological processes in soils, including soils from arid regions. Determination of both macro and micromorphological changes in soil characteristics with time and induced by irrigation were the main objectives of this study.

[DOR: 20.1001.1.16807073.2000.2.4.7.9]

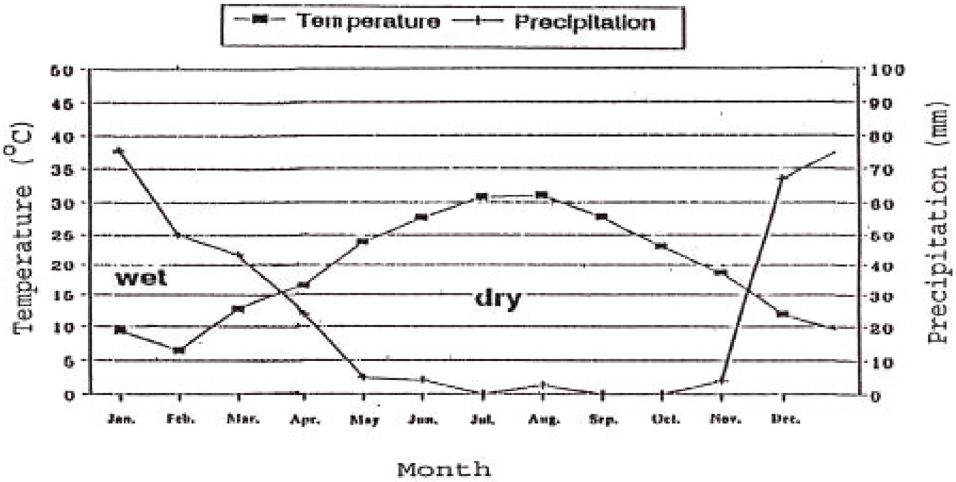

Figure 2. Gaussens omberothermic diagram of Jahrom.

MATERIALS AND METHODS

Jahrom, the study area, occurs in a date palm *(Phoenix dactylifera)* production region in Fars Province, Iran (latitudes 28° 30′ N and 28° 36′ N and longitudes 53° 21′ E and 53° 33′ E (Fig.1). Geology of the area consisted of the Quaternary alluvial deposits overlying a Mio-Pliocene conglomerate (Geology Organization of Iran, 1981).

The climate is characterized by a dry and a wet season. The wet season begins from December through March and the dry season from April to November (Fig. 2). Because of the low annual rainfall (200 mm), date palms, the principal fruit, has to be irrigated by pumped underground water once a week during the dry season.

Four pedons were sampled in flood-irrigated orchards and the fifth in a non-irrigated area. According to the information obtained from land owners and documents of permission for digging wells, four nearly level orchards of various ages were selected for the study. The ages are 20, 30, 40, and 100 years and the corresponding orchards were called site 1, 2, 3 . and 4, respectively. Four different wells supply water for the four orchards.

Both disturbed (bulk) and undisturbed soil samples were collected from the horizons A, B, and C in each pedon. Physico-chemical analyses were carried out on the bulk samples of soils (Jackson, 1975). Particle size analysis was determined using sedimentation and sieving procedures (Days, 1965) using sodium pyrophosphate as dispersant. Exchangeable cations Ca, Mg, K, and Na were determined by displacement with NH_4OAc (Chapman, 1965). Organic carbon was determined by wet combustion method (Jackson, 1958). Calcium carbonate equivalent was determined by HC1 (U.S. Salinity Laboratory Staff, 1954). Soil profiles were described (Soil Survey Manual, 1993) and classified according to Soil Survey Staff (1998).

Undisturbed soil samples were taken from each horizon using large Kubiena boxes (8x l0x 12 cm). Oriented soil blocks were air-dried and then impregnated under suction with epoxy resin. Thin sections of 6x8 cm were prepared according to the method described by Fitz Patrick (1984).

Micromorphological studies were carried out using a polarizing microscope. Nomenclature of observed pedologicäl features and fabric elements followed those proposed by

Bullock *et al*.(1985).

RESULTS AND DISCUSSION

On the basis of morphological characteristics (Table 1) and physico-chemical properties (Table 2) of the soils studied, the soils were classified as Entisols and Inceptisols. The soils were carbonatic (>40%). Soil color was dark yellowish brown (10YR 4/6) for the non-irrigated soils to yellowish brown (10YR 5/4) in soils under irrigation (Table 1). Subsurface horizons (B), with subangular blocky structure were found in pedons of the irrigated orchards. With the exception of the higher electrical conductivity (EC= 2.23 dSm^{-1}) of the water at site 2, all other chemical properties of the irrigation waters were more or less similar at the four selected orchards (Table 3).

All the soils were well drained and unsaturated within significant depth of the soil surface. The irrigation cycles are preceded by hot and desiccating conditions from April to September. The relatively dry soil conditions favour dispersion of clay and carbonate particles upon wetting (Thorp *et al.,* 1959 ; Daniels *et al.,* 1967). The moisture fronts are able to move freely through the solum carrying suspended particles. Dry conditions prevail after the wetting sequences thereby facilitating deposition of clay and carbonate particles in the lower horizons.

$CaCO_3$ impregnations of the soil matrix around pores have been observed in the field and with the microscope in many sections. Micromorphological studies of all irrigated soils showed some progressive differences among profiles with time (Table 4) In soils, they take the form of accumulations of a few millimeter thick coating pores, which are a few millimeters in diameter. Observations with the microscope showed that these impregnations are composed of micritic crystals. Such hypocoatings are due either to evaporation of a Ca-rich solution from the soil matrix (Brewer, 1976) or to precipitation from soil solution percolating along the pores and penetrating into the soil matrix (Brewer, 1976; Courty and Fedoroff, 1985; Courty, 1990; Kemp, 1995). Thompson *et al.* (1991) described micritic hypocoatings on void walls as a result of several wetting and drying cycles. Under crossed polarizers, micritic coatings or infillings and locally hypocoatings associated with channels and ped surfaces were visible. Similar findings are reported by Becze-Deak *et al.* (1997). Aggregates were rounded or blocky subangular. Interaggregate porosity (Interpedal pore) consisted of packing voids and planes which interconnect voids or vughs. There were many channels related to the biological activity. Calcium carbonate accumulated through many cycles of partial solution and reprecipitation. Amount and distribution of calcium carbonate differed among profiles and with ages of the Jahrom date palm orchards as also observed by Khalifa *et al.* (1989) and Becze-Deak *et al.* (1997).

The coarse fraction of soils consisted mainly of calcite and quartz grains. Solution cavities around sand-size grains were common. The fine fraction of groundmass consisted of a mixture of silicate clay minerals and carbonates. Precipitation of micritic calcite is observed on void walls and ped surfaces.

The micromorphology of pedons suggests that much of the carbonate has been subjected to dissolution and subsequent redeposition. Processes of dissolution, leaching and recrystallization have caused various pedologic features to be developed in arid Australia (Chen, 1997). Weakly oriented mixtures of calcite and silicate clay are occasionally observed in pedons 1 and 2. These oriented pedofeatures are called calci-argillans by Sehgal and Stoops (1972). Crystal size of individual calcite grains, as evidenced by birefringence under high magnification, is mostly of silt size, but varies from clay to sand size. This form of calcite particles in site 0 is quite different from those in other sites, where these crystals were oriented in the same striated patterns as clay particles. Thus a combination of crystallitic and one of the striated subgroups

[DOR: 20.1001.1.16807073.2000.2.4.7.9]

Table 1. Classification and characteristics of soils of the study area.

Site [a] No.	Horizon	Depth (cm)	Color	Texture [b]	Structure [c]	Consistency [d]	Boundary [e]	Remarks
			Lomay skeletal, carbonatic, thermic, typic xerofluvents.					
0	A	0-12	10YR4/6	1	pl	fr	c	Few filaments of $CaCO_3$.
	A/C	12-30	10YR4.5/6	1	m	fr	c	Few filaments and concretions of $CaCO_3$.
	C	30-80	10YR5/6	sl	m	fr	-	Few filaments of $CaCO_3$ and > 50% gravel.
			Sandy loam, carbonatic, thermic, calcic haploxerepts.					
1	A_p	0-20	10YR4.5/6	sl	gr	fr,s	c	Few, fine, segregated, soft masses of $CaCO_3$.
	B_w	20-65	10YR5.5/6	sl	sabk	fr,s	d	Few to common, medium, segregated filaments of $CaCO_3$.
	B_k	65-95	10YR6.5/4	gsl	sabk	fr	c	Few, medium, segregated filaments of $CaCO_3$, 50% gravel.
			Loamy, carbonatic, thermic, typic calcixerepts.					
2	A_p	0-30	10YR5/4	1	pl	fr	g	Few, fine, segregated, soft masses of $CaCO_3$.
	A_B	30-60	10YR4.5/4	1	m	fr	c	Few to common, medium, segregated filaments of $CaCO_3$.
	B_k	60-100	10YR5/4	1	abk	fr	c	Some powdery pocket lime.
			Loamy, carbonatic, thermic, typic calcixerepts.					
3	A_p	0-30	10YR5.5/3	cl	gr	fr	c	Few gravels.
	B_w	30-55	10YR4.5/4	cl	sabk	fr	g	Few to common mottling.
	B_k	55-91	10YR3.5/4	1	sabk	fr	g	Few to common thick roots, some powdery pocket lime and concretion.
	C	91-140	10YR4.5/4	sl	m	fr	-	> 20% gravel
			Loamy, carbonatic, thermic, typic calcixerepts.					
4	A_p	0-28	10YR6.5/3	1	gr	fr	c	
	E	28-61	10YR5.5/4	cl	sabk	fr	g	Common thick roots, powdery pocket lime.
	B_k	61-92	10YR5.5/4	1	sabk	fr	g	Powdery pocket lime, concretion and nodules of $CaCO_3$, concentration of clay minerals.
	C	92-140	10YR5.5/4	1	m	fr	-	Few gravels.

[a] 0= Non-irrigated land; 1, 2, 3, and 4 = 10, 20, 40, and 100- year old orchards respectively.
[b] 1= loam; sl= sandy loam; gsl= gravelly sandy loam; cl= clay loam.
[c] pl= platy; m= massive; gr= granular; sabk= sub-angular bloky; abk= angular blocky.
[d] fr= friable; s= sticky.
[e] c= clear ; d= diffuse; g= gradual.

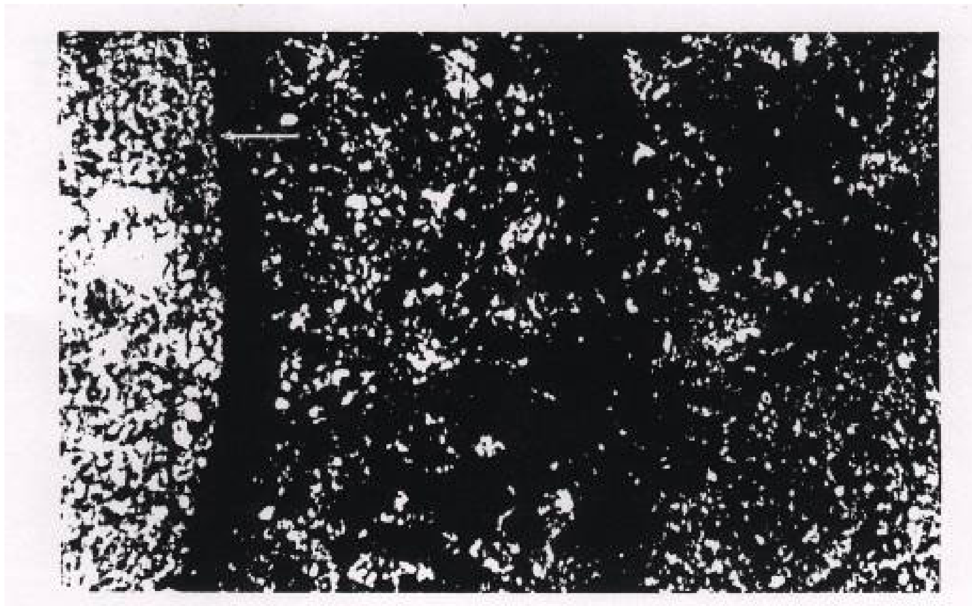

Figure 3. Coatings on the wall of pores with parallel orientation at B_k horizon, site 4. cross-polarized light. 40X.

(Bullock *et al*., 1985) is used. Calcite crystals in older orchards were disseminated throughout the soil matrix in surface horizons as scattered clusters of calcite in void spaces between coarse grains and as grain coatings, i.e. calcitic coatings (Monger *et al*. 1991). Calcitic crystalline coatings juxtaposed on clay coatings on the wall of voids progressively became thicker with increasing ages of orchards (Table 4).

The soil fabrics at site 4, the 100 year old orchard, have the form of grain cutans and coatings on the wall of pores with parallel orientation (Fig. 3). Baghernejad and Dalrymple (1993) showed that simple physical washing down of colloidal calcium carbonate could produce such coatings namely calcitans. We observed, indeed, silty clay coating with many calcitic detrital grains in the deeper horizons of the irrigated soils (Fig. 4). As shown in Table 2, organic matter content of the soil surface horizons increases as the age of orchards increases. With regard to the high $CaCO_3$ contents of the soils, the formation of organic matter-calcium carbonate complexes is possible. Sharma *et al.* (1997) indicated that incomplete leaching of $CaCO_3$ in Punjab soils is due to the formation of organic matter-calcium carbonate complexes that the percolating water could not dissolve.

Soil horizons at site 4 show calcitic coatings around skeleton grains (micritic, Bal, 1975) and to walls of water conducting voids within which calcite crystals form well-oriented layers. This is in agreement with results obtained by Monger *et al*. (1991). They believe that coatings form in soils because infiltering calcite-laden water is absorbed by particles within the macropore wall by capillary movement.

As Gile *et al.* (1966) described sequential accumulation of carbonate in desert soils, calcitic hypocoatings were observed especially in the horizons with the largest total amounts of calcium carbonate (59%), as for example the deeper horizons of the soil occurring at site 4 (Table 4). Some compound dense complete calcitic infillings in vughs were observed (Table 4). As shown by Chadwick *et al*. (1987) large voids were the main sites for calcite precipitation, because

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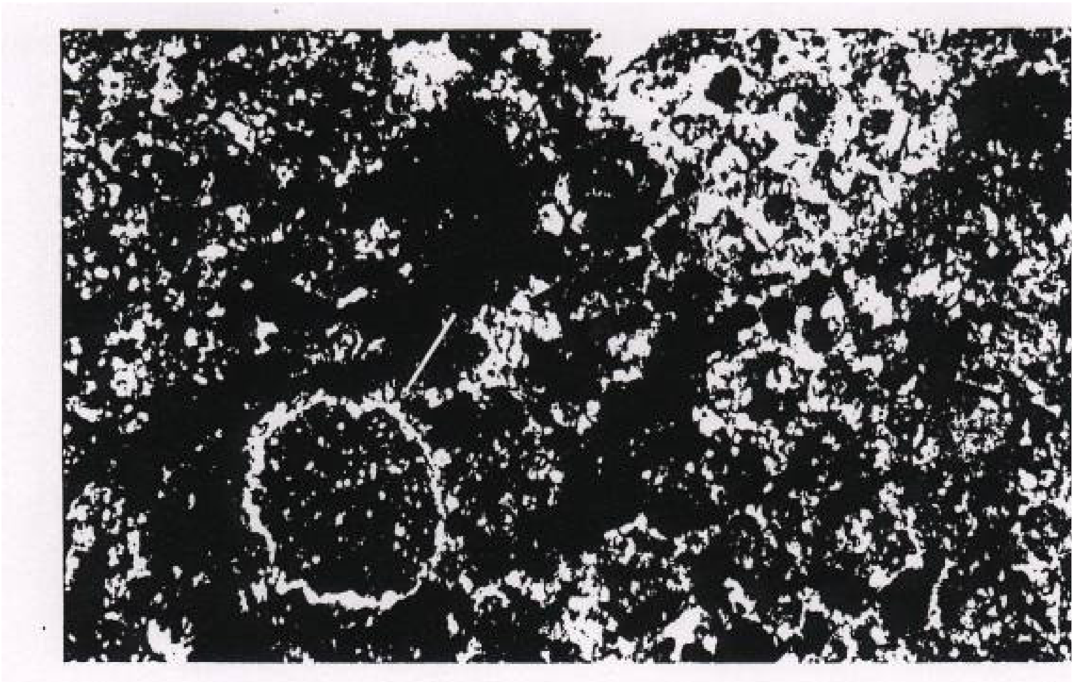

Figure 4. Silty clay coatings with many calcitic detrital grains at B_k horizon, site 4. cross-polarized light. 40X.

large voids dry more rapidly than smaller ones and are usually in more direct contact with lower atmospheric concentrations of CO_2. Likewise, their study indicated that calcite has a preference for self-nucleation, and calcite plugs large voids by preferential precipitation on previously deposited calcite crystals.

Carbonates were washed away from surface horizons of the profile at site 4 (Fig. 5). As shown in Fig. 5, carbonates of the groundmass around the channels are washed to the water conducting channels and partly infilled with sparitic calcite. This is in agreement with results obtained by Rabenhorst *et al*. (1991). Progressive changes in void types was observed in soils (Table 4). Compound packing voids with unoriented, random and unreferred distribution pattern at site 1, were changed with time to interconnected, irrigular, unoriented, random, unreferred distributed vughs; to round or elongated, regular, unoriented, random, unreferred distributed channels; and to irregular, straight to curved, random, unreferred distributed planar voids at sites 3 and 4 (Fig.6).

CONCLUSIONS

Field data, completed with micromorphological observations and laboratory data, permitted an overview of the distribution of various types of accumulations (mainly $CaCO_3$) and their role in the pedogenesis. Accumulation of $CaCO_3$ and silicate clays had caused reduced porosity, increased clay cutans and carbonate coatings, and channel infillings. These changes are evident in the formation of calcitans, argillans, and calcite sparitic infillings.

Distribution of the various accumulations in orchard soils can give important indications about some events of changes in the environment. Changes in the moisture regime, i.e. transition from non-leaching environment of the not-irrigated soil (Site 0) to leaching environment of the irrigated orchards (Sites 1 to 4), is detected through the dissolution features or by observation of the related distribution of the secondary

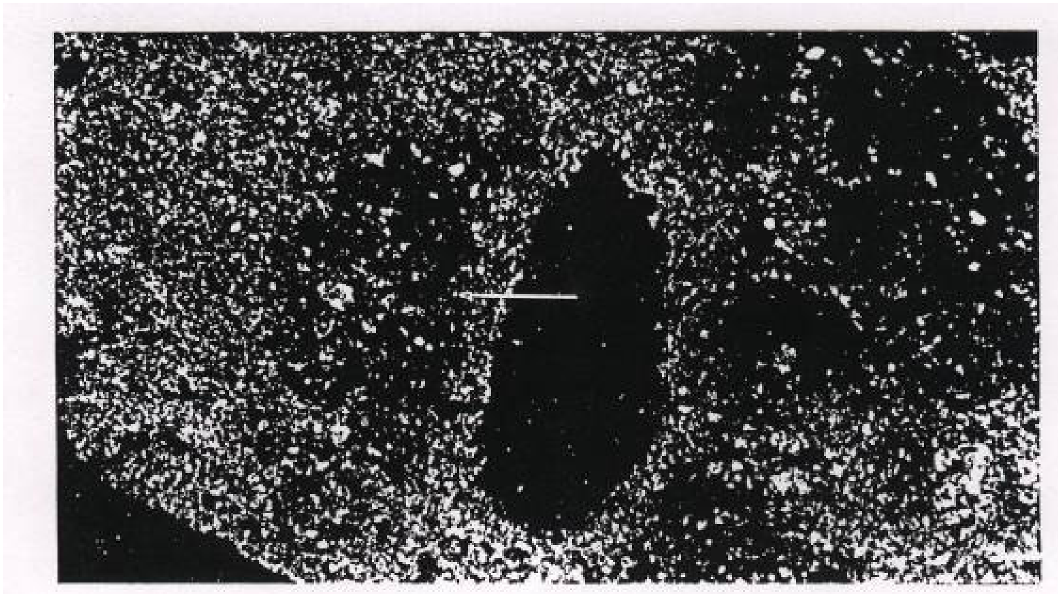

Figure 5. Carbonate depletion features and sparitic calcite infillings at E horizon, site 4. cross-polarized light. 40X.

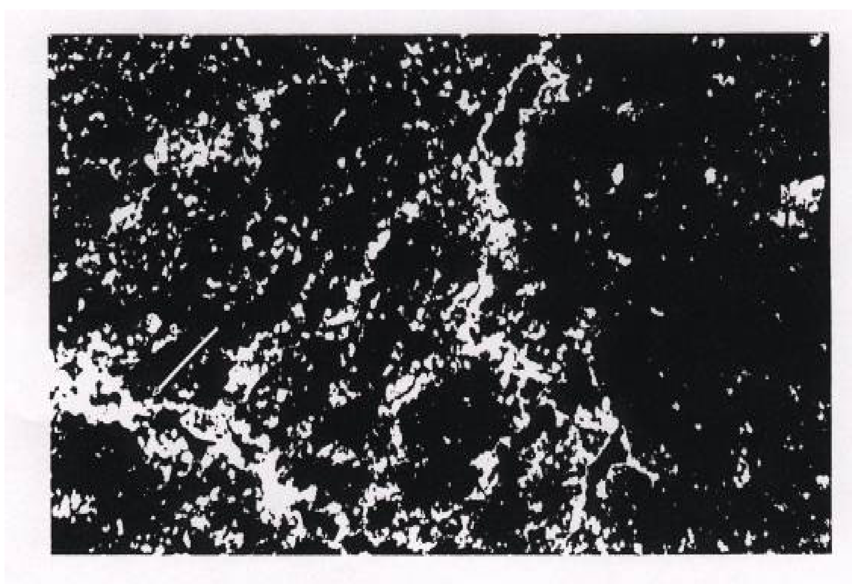

Figure 6. Planar voids with some calcitic coatings at B_k horizons, sites 3 and 4. cross-polarized light. 40X.

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carbonates. Differences in micromorphological features among the soils studied indicate that progressive changes are occurring and getting greater under continued irrigation. Clogged voids resulted by such changes, may cause low infiltration rate and affect the agricultural sustainability of the area.

ACKNOWLEDGEMENT

The author wishes to thank Shiraz University Research Council for funding this research project (No: 73-AG-820-464).

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تکوین و تغییرات مورفولوژیکی خاکهای نخلستانهای تحت آبیاری جنوب ایران

چکیده

در این تحقیق خصوصیات خاکهای زرپت (Xerepts) تحت آبیاری نخیلات منطقه جهرم مورد بررسی قرار گرفت و تغییر ویژگیهای ماکرو و میکرومورفولوژیکی آنها مشخص گردید. بدین منظور نمونه های خاک از پروفیلهای حفر شده در ٤ باغ با سنین مختلف از ۲۰ تا ۱۰۰ سال که از ابتدا تحت آبیاری غرقابی بوده اند تهیه گردید. ویژگیها و خصوصیات این خاکها با یکدیگر و همچنین با نمونه های خاک که از اراضی بدون آبیاری (شاهد) تهیه شده بود در مزرعه و در آزمایشگاه مقایسه شد. از هر افق در هر پروفیل بلوکهای دست نخورده خاک گرفته و از آنها مقاطع نازک خاک تهیه شد و سپس مطالعات میکرومورفولوژی بر روی آنها صورت گرفت. تغییراتی در نوع و توزیع حفره های خاک و همچنین انتقال و تجمع کربنات کلسیم در آنها مشاهده شد. تفاوت و تغییر فابریک خاکها مرتبط با طول مدت (سالهای) آبیاری باغها تشخیص داده شد. در خاکهای باغهای مسن تر پوششهای کلسیت روی دیواره حفره ها بیشتر بود و همچنین پرشدگی حفرات

درشت توسط رسوبات کربنات کلسیم بیشتر صورت گرفته بود به حدی که موجب انسداد آنها شده بود.

[DOR: 20.1001.1.16807073.2000.2.4.7.9]