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Assisting Non-Soil Experts to Identify Soil Types for Land Management to Support Restoration of Arid Rangeland Native Vegetation in Kuwait

Gerard Grealish[1,2], Robert W. Fitzpatrick[1,2], and Samira Omar Asem[3]

[1]Acid Sulfate Soils Centre, School of Earth and Environmental Sciences, The University of Adelaide, Adelaide, South Australia, Australia
[2]CSIRO Land and Water, Glen Osmond, South Australia, Australia
[3]Kuwait Institute of Scientific Research, Safat, Kuwait

Conventional soil survey information is often unclear except to specialists and experienced soil experts who are in short supply to meet user demands. An approach using a special purpose soil identification key and conceptual toposequence models was developed to assist non-soil experts with identifying soil types in Kuwait. The approach supports the restoration of Kuwait rangelands, where there is a need to assist revegetation success by removing uncertainty regarding soil conditions and targeting the planting of appropriate vegetation communities to the soil type. Legacy data from soil survey reports were available for reinterpretation. The soil identification key developed is in a matrix form and allowed soil types to be determined by the presence or absence of three recognizable soil features, which generally typify arid zone soils worldwide: hardpan, gypsum, and calcium carbonate. The soil type categories are descriptively named for ease of understanding by non-technical users, and were structured to align with the previously identified Soil Taxonomy classes to maintain linkages with the soil survey and other interpreted information. To complement the soil identification key, conceptual soil toposequence models presented the general soil distribution patterns in a visual format to aid understanding of spatial variation and soil type relationships. The approach is flexible and can be scaled with additional criteria as more knowledge is acquired regarding the relationship between soil types and vegetation communities, and while the detail is applicable to Kuwait the approach could be adjusted and applied elsewhere.

Keywords classification matrix, conceptual toposequence, legacy data, soil taxonomy, special-purpose soil classification

Introduction

Conventional soil survey information can be of limited use to non-soil specialists because of the scientific expertise required to understand and apply the soil information (Dudal, 1987; Yaalon, 1996; Sanchez et al., 2009; Fitzpatrick, 2004a,

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Address correspondence to Gerard Grealish, Acid Sulfate Soils Centre, School of Earth and Environmental Sciences, The University of Adelaide, Adelaide, South Australia, Australia. E-mail: Gerard.grealish@adelaide.edu.au

2013). Experienced pedologists are in short supply to meet user demands to reinterpret legacy data or conduct further field investigations to provide useable advice. Substantial soil information and accompanying soil maps are available in Kuwait (KISR, 1999) but requires soil specialists to interpret and apply for a specific purpose (e.g., to support native revegetation strategies). In response, we present an approach that aids the translation of such soil survey information into a form suitable for a non-soil-specialist audience. The approach is demonstrated to support restoration of rangeland native vegetation in the State of Kuwait.

Kuwait has suffered severe land degradation to at least 76% of the desert (Misak et al., 1999) noticeable by the destruction of the vegetation cover and soil erosion by wind and water. Degradation was caused by anthropogenic activities and military operations during the Gulf Wars from military vehicle traffic, excavation of fortifications, defensive structures, and digging of oil trenches (Brown, 2003; Khalaf et al., 2013; Omar et al., 2000; Omar et al., 2005). Land degradation has caused significant problems that include: loss of productive rangeland grazing areas; moving sands caused by land degradation encroach on buildings, roads, and oil facilities infrastructure and costs are incurred to remove the sand and for additional maintenance required because of the sand encroachment; and airborne particulates from the eroding desert surface may impact human health. To mitigate land degradation, Kuwait is planning to restore ecological function of rangeland areas by revegetation with local native species. To revegetate areas damaged by military activities in the desert, a large-scale restoration program will be to revegetate about 79 km^2 in different sized areas over about 1,680 km^2 protected from grazing (Omar, 2012).

Rangeland revegetation success not only depends on climate, topography, and management, but is strongly influenced by soil (Heady and Child, 1994). Soil information will remove a key source of uncertainty, as native vegetation distribution in Kuwait was strongly linked to soil type (Halwagy and Halwagy, 1974; Omar et al., 2001). Shahid et al. (2004) emphasized the significance of detailed prior assessment of soil types for planning. In these arid soils, water availability and salt accumulations are important soil properties and provision of soil information will reduce the risk of plant growth failure due to droughty conditions or inhospitable root conditions. Kuwait soils were mapped at a reconnaissance scale (1:100,000) at approximately 1 site per 200 ha, for the entire country covering approximately 17,000 km^2; site selection was made using a combination of free survey and transect survey approach; soils were classified into 23 soil types at the family level of Soil Taxonomy; that were mapped and included as major and minor components of 71 soil map units (KISR, 1999; Omar and Shahid, 2013). Map units were generally soil complexes making it difficult to predict soil types at a location for site specific management.

Limitations of Available Data

National soil surveys such as the Kuwait 1:100,000 scale survey (KISR, 1999) are conducted at a reconnaissance scale and provide general purpose soil classification and inventory of soil resources. This information is very useful for strategic broad-scale planning purposes, but there are shortcomings in their usability for site specific management that include:

1. Limitation of scale, to present soil distribution at the required level of detail.

2. Limitation to present soil variation that is effectively continuous and cannot be described perfectly by sharp boundaries (Webster, 1968).
3. Limitation to present individual soil property variation, as soil properties often vary at different rates and in different directions (Campbell, 1977), and, therefore, cannot be separated by a single map unit boundary.
4. Limitation of map unit purity, where soil inclusions that have sensitive soil properties that contrast with the named map components will have an impact on suitability (Valentine, 1981; Webb and Lilburne, 2005).
5. Limitation to provide quantitative information about soil properties, due to the classification process (Webster, 1968) that summarizes many soil properties making it difficult to then infer what a soil property value will be and representing that spatial variation (Valentine, 1983).
6. Limitation of general purpose soil classification, which depends heavily on morphological criteria that have poor covariance with practical relevant chemical, physical, and mineralogical properties (Fitzpatrick, 2013).
7. Limitation of pedological classification that is poorly understood and with generic soil types not necessarily useful for the application.

Digital soil mapping offers the opportunity to generate quantitative spatial information of soil variation (McBratney et al., 2003; Cook et al., 2008). But there are few examples of this approach being used at a routine project production level. Uptake is restricted by the practicalities of obtaining datasets, computer mapping infrastructure, skill set, and institutional capacity required. Additionally, users are not familiar with and would require time to be accepting of the outputs. At this stage digital soil mapping was discounted as an option for this immediate land management project.

Required Information

Experienced soil survey specialists with the time to cover the large tracts of land at the required detailed map scale are unlikely to be available and/or cost effective. The alternative is to develop tools for non-soil experts to use that would assist them with determining soil type and hence the native vegetation species to plant at a location. To implement land-use restoration, soil information requirements include:

1. Documented systematic approach that can be taught and under the supervision of a soil specialist allow teams to rapidly survey large areas at the required scale for planning purposes and then prior to planting allow areas to be verified to ensure the correct vegetation types are planted for the soil.
2. Linkages made between soil properties with the appropriate vegetation communities to ensure correct plants and seeds are targeted to appropriate soil type areas.
3. Guidance for non-soil experts to use for soil type identification.
4. Guidance on soil type distribution to assist non-soil experts to predict the general soil occurrence in the landscape.

Identifying Soils

Classifying soils provides a means for ordering soils into groups with similar properties that facilitates transfer of knowledge about the soil and land management performance (e.g., Wilding & Drees, 1983; Dudal, 1987; Yaalon, 1996; Fitzpatrick, 2013). Soil Taxonomy (Soil Survey Staff, 1999) and the World Reference Base (2006) are general purpose soil classification systems used to communicate soil information internationally. Soil Taxonomy was used in the Soil Survey for the State of Kuwait (KISR, 1999). However, for local users, Soil Taxonomy has limitations that include the reliance on laboratory analyses, specialized terminology, and structured use of words to classify and name soils (Drohan et al., 2010; Fitzpatrick, 2013). To improve the impact of soil survey data, the knowledge and ability of local people need to be taken into account (Sillitoe, 1998). Presenting this information in the form of a soil identification key linked to Soil Taxonomy allows local, nontechnical users to identify soils using a vocabulary that they are familiar with and would improve the uptake and use of soil data (Fitzpatrick, 2013). For example, Fitzpatrick (2004b, 2013) developed a special-purpose "pictorial soil identification key" for identifying categories and subcategories of submerged, disturbed, drained, burned and reflooded marshland soils in the arid southern Mesopotamian marshlands in Iraq to support land use planning. These soil subcategories were also correlated with Soil Taxonomy and the World Soil Reference Base by Fitzpatrick (2004b).

Soil Location in the Landscape

Conventional soil maps are produced based on the surveyors' understanding of soil classes and their distribution in the landscape. Milne (1935) describes a soil catena as a sequence of soils occurring on the same parent material and related to each other by topography. Topographic variation influences soil processes such as soil erosion and soil solute movement that impacts on the other downhill members of the soil sequence, thereby developing the linkage between soil types (Milne, 1935; Huggett, 1975; Conacher and Darylmple, 1977). Soil associations describe a geographic association of soil types rather than a process-based relationship (Conacher and Darylmple, 1977). A soil toposequence describes a soil association that can be defined in terms of topography, but does not necessarily imply the more strictly defined process based linkage of a soil catena.

Soil toposequence models provide a conceptual understanding of soil and landscape relationships on a hill slope (Huggett, 1975) and are developed by soil surveyors from observations and experience to assist them with delineating map units. Desert landscapes tend to be flatter but the variation can be still presented as a toposequence of what occurs based on sub-surface palaeo features similar to the so-called "reversed toposequences" or red-yellow-grey soil hydrosequences in parts of North Queensland, Australia (Coventry and Williams, 1984; Fitzpatrick, 1988).

While soil survey maps and map legends provide information on how soils vary across an area, soil toposequence models can be used to bridge the gap and graphically convey information and aid visual interpretation about soil variation in a form that non-soil experts understand (e.g., Grealish et al., 2013).

Aim

The aim of this work was to present legacy soil survey data in a format for non-soil experts that allow them to independently identify soil types to support their land management decisions and conduct revegetation of Kuwait rangeland. Not all soils are the same and the site soil properties need to be known prior to planting to improve the chance of revegetation success.

Method

The steps to develop the approach included:

1. Determine the vegetation communities and relate to soil properties and soil types.
2. Interpret legacy soil survey data, soil classification and maps.
3. Present information in a user friendly format.

The relationship between vegetation communities and soil types was established based on previous work. The approach then required an experienced soil surveyor to interpret conventional soil data and then distil the information into conceptual toposequence models and a special-purpose classification system using a soil identification key. The soil identification key was developed as a matrix for the range of soil types identified, and based on the presence or absence of particular soil features that could be recognized by non-soil experts. The constructed conceptual toposequence models consolidate the map unit information, and present the relationship of soil types to each other, the landscape and the vegetation communities.

Study Area

The State of Kuwait is situated at the north-western corner of the Arabian Gulf between latitudes 28°30 and 30°05 N and longitudes 46°33 and 48°35 E. The total land area is approximately 17,800 km^2. Climate is characterized by high temperatures during summer, short mild winters, strong sunshine, low humidity, and generally dry conditions. Daily temperatures range from 29°C to 45°C in July and 8°C to 18°C in January; rainfall averages 110 mm per annum, ranging from 20 mm in 1964 to 242 mm in 1976, and falling mainly between November and April; prevailing winds are from the northwest and southeast, with north westerlies more common in summer.

In general, the surface topography is flat to gently rolling desert plain, broken by occasional low hills, scarps, and wadis. The northern half of the country from the Jal Az Zor escarpment to the Wadi Al Batin and Iraqi border is a large old alluvial fan which consists of a series of channel deposits of sands and gravels. Geologically it is known as the Dibdibah Formation. Gypsum is commonly present with the gravels. The river system that generated this fan is no longer active but a relict remains as the Wadi al Batin. Most of southern Kuwait is covered with sand sheets and sand dunes with isolated calcareous sandstone outcrops along the Jal Az Zor Ridge. The sand sheets often form low ridges or hummocks, between the sand ridges are deflation areas with a firmer surface often protected by a fine gravel lag cover.

Most land outside the metropolitan area is owned by the state, with rangeland grazing by livestock the predominant land use covering almost three-quarters of the country, elsewhere there are oil fields and associated infrastructure.

Results

Vegetation Communities and Soils

Vegetation communities mapped by Halwagy and Halwagy (1974) recognized five community types. Later Omar et al. (2001) mapped the current status documenting eight community types, but noted that what was identified was not necessarily the optimal vegetation ecosystem for the landscape. The survey showed alteration in the distribution and the decrease of higher successionally shrubby vegetation communities, concluding that the landscape was severely degraded (Omar and Bhat, 2008).

From the information provided there were two dominant higher successionally vegetation communities in Kuwait, *Rhanterietum* and *Haloxyletum* that were widespread throughout the country but now occur in isolated areas (Omar et al., 2001). Areas range from severely degraded to the mid-successional vegetation communities that transition from the damaged states to climax state. The mid successional communities were *Cyperetum* or *Stipagrostietum* (Omar and Bhat, 2008).

The environmental conditions, which determine the distribution of the vegetation communities, are not well known. The general edaphic relationships described by Halwagy et al. (1982) were *Cyperus* associated with deep loose sandy soils; *Rhanterium* on shallow to moderately deep soil overlying gypsic or calcic layers; and *Haloxylon* commonly on shallow soils overlying a hardpan.

Given soil conditions suitable for the two main vegetation communities (*Rhanterietum* and *Haloxyletum*) are not well known, identification of soils at the higher great group level of Soil Taxonomy is best suited to discriminate out soil types for planning and planting purposes. Eight soil types were recognized in Kuwait at this classification level (Haplocalcids, Petrocalcids, Haplogypsids, Calcigypsids, Petroqypsids, Aquisalids, Torriorthents, and Torripsamments). Their general distribution is shown in Figure 1, with Table 1 listing their description and proportions.

Interpretation of data from KISR (1999) allowed the relationship between soil map units and vegetation units to be determined as shown in Table 1. *Rhanterium* vegetation communities were identified growing where the soil surface is somewhat stable with deep sand and loamy sand soils (Torripsamments), deep sand to sandy loam soils that have calcium carbonate in the subsoil (Haplocalcids), and may grow where the hardpan is below 50 cm and the soil is calcareous (Petrocalcids). For these same soils where the soil surface is mobile or degraded, *Cyperetum* vegetation communities occur. The *Haloxyletum* vegetation communities are primarily associated with soils containing gypsum (Haplogypsids, Calcigypsids) and where there are hardpans and gypsum (Petrogypsids).

Rhanterietum and *Haloxyletum* vegetation communities (or their transitional *Cyperetum* and *Stipagrostietum* communities) according to soil type would potentially cover 85% of the country, identification of these soil types will assist with the revegetation program to ensure the correct plants and seeds are matched to the soil types. Aquisalids occur on the coast and Boubyan Island and Torriorthents are minor in occurrence, these soil types were not considered further as they are unlikely to be locations for immediate rangeland revegetation.

Soil Identification Key

A summary of soil properties for each Soil Taxonomy class at the great group level is presented in Table 2. The table shows interpreted general ranges and categories generated from the soil survey report (KISR, 1999) and survey datasets, providing an overview of the soil property variations. The soil survey report should be referred to for actual soil profile data. Information in Table 2 indicates that for all soils the soil texture range is narrow, generally sand, loamy sand, or occasionally sandy loam. The soil colors are similar, generally around very pale brown (10YR 7/3) or

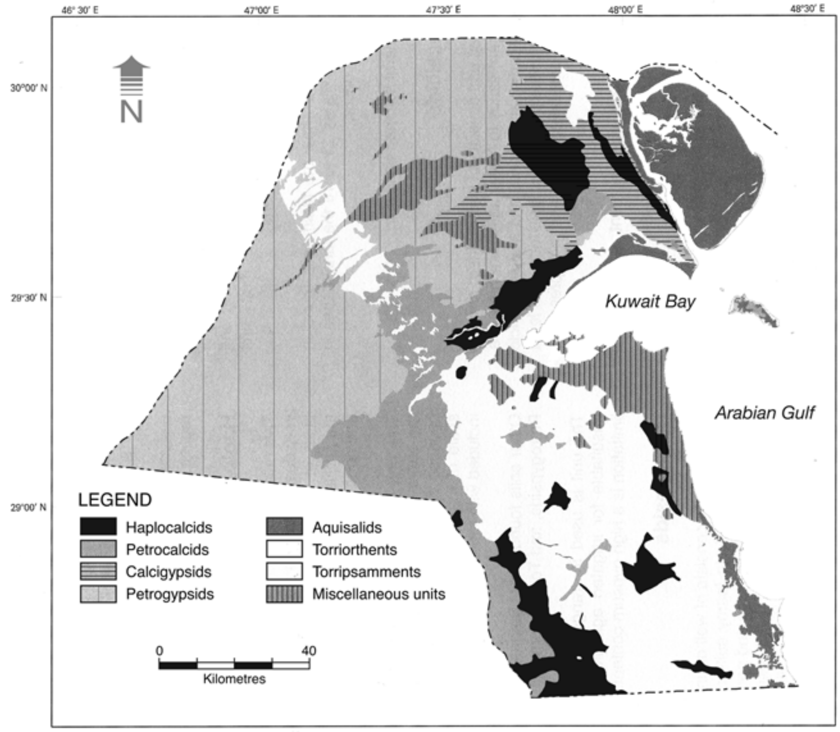

Figure 1. Soil distribution summary map at great group level (modified from KISR, 1999).

light yellowish brown (10YR 6/4 or 2.5Y 6/3, 6/4). The main differentiating characteristics are the occurrence of a hard pan with a consistence of rigid or extremely hard, compared with loose or slightly hard for the sandy layers, and the widely varying concentration of calcium carbonate and gypsum.

The soil identification key was established as a matrix that was complementary to and based on the Soil Taxonomy. To identify each soil type, the key used the presence or absence of three widespread and easily recognizable soil features, which generally typify arid zone soils worldwide: gypsum, calcium carbonate, and hardpan (Table 3).

The diagnostic criteria from Soil Taxonomy were followed but modified using "rule of thumb" that allowed non-soil users to routinely identify in the field the soil features. From our experience we found that for the Kuwait soils:

- Gypsum soil features (Gypseous) were recognized when any clear to white crystals that are gypsum (and in some areas possibly includes anhydrite or bassanite) were visible. If necessary this could be checked with field electrical conductivity test where reading is about 2 dS/m and in some cases up to about 4 dS/m.
- Calcium carbonate (Calcareous) soil features were recognized when there were $\geq$5% visible white soft masses or occasionally hard nodules or concretions. If necessary this could be checked with field HCl test where fizz will be a strong or violent reaction.

Table 1. Soil map units of Kuwait and associated vegetation units

Soil map unit	Description of dominant soil in the named map unit	Area, as % of total	Higher succession vegetation units	Mid-succession vegetation units
Haplocalcids	Deep, loamy sand or sandy loam with a layer containing carbonate masses	8	*Rhanterietum*/ (*Haloxyletum*)	*Stipagrostietum*
Petrocalcids	Sand, loamy sand or sandy loam overlying a calcic hardpan within 100 cm depth	11	*Rhanterietum*	*Stipagrostietum*/ *Centropodietum*
Calcigypsids	Deep, sand or loamy sand with a layer containing carbonate masses and a layer of gypsum	6	*Rhanterietum*/ *Haloxyletum*	*Stipagrostietum*
Haplogypsids	Deep, sand or loamy sand, with a layer of gypsum	<1	No information	No information
Petrogypsids	Sand or loamy sand overlying a gypsic hardpan within 100 cm depth	33	*Haloxyletum*	*Stipagrostietum*
Aquisalids	Poorly drained, sandy to clayey, with a high concentration of salts often near the surface	7	*Zygophylletum*/ *Halophyletum*/*Panicetum*	No information
Torriorthents	Deep, sand or loamy sand, with high content of shell fragments or occasional gravel	1	*Panicetum*	No information
Torripsamments	Deep, loose, sand or loamy sand	27	*Rhanterietum*	*Cyperetum*
Urban/Miscellaneous	Soils covered or significantly altered	>6	No information	No information

Note: Interpreted from KISR (1999) and Omar et al. (2001).

Table 2. Soil data ranges for the typical soil classes derived from survey datasets and reports KISR (1999)

Horizon designation	Depth cm	Munsell color dry	Texture Class	Gravel %	Bulk dens g/cc	Consis-tence	Efferves-cence	$CaCO_3$ % eq.	Gypsum %	ECe dS/m	pHs
Haplocalcids											
Ak	0–50	2.5Y 6/4	LS-SL	<15	1.5–1.8	L-S	VE-ST	5–15	<1	<4	7.4–8.4
Bk1	50–100	2.5Y 7/3	LS-SL	<15	1.5–1.8	L-SH	VE-ST	15–40	<5	<4	7.4–8.4
Bk2	100–150	2.5Y 7/3	SL	35–50	1.2–1.8	MH	VE-ST	5–40	<5	<4	7.9–8.4
Petrocalcids											
Ak	0–50	10YR 7/4	LS-S	<35	1.5–1.8	L	ST-SL	5–15	1–5	<2	7.9–8.4
Bkm1	50–100	10YR 8/2	–	–	–	R-EH	ST-VE	15–40	1–5	<2	7.9–8.4
Bkm2	100–150	–	–	–	–	–	–	–	–	–	–
Calcigypsids											
Ak	0–50	10YR 6/4	LS-S	<15	1.5–1.8	SH	ST-VE	5–15	1–15	2–4	7.9–8.4
Bky	50–100	10YR 7/3	S-LS	<35	1.2–1.8	SH	VE-ST	5–40	15–40	2–4	7.4–8.4
Cy	100–150	10YR 7/3	S-LS	<35	1.2–1.8	L	VS-NE	1–15	5–40	2–4	7.4–7.8
Haplogypsids											
Ak	0–50	2.5Y 6/4	S-LS	15–50	1.5–1.8	L-SH	ST	5–15	5–60	<4	7.9–8.4
By1	50–100	2.5Y 7/3	S	15–35	1.2–1.8	MH-SH	VS-NE	1–15	5–40	2–8	7.4–7.8
By2	100–150	2.5Y 7/3	S	15–60	1.2–1.8	MH	NE	1–5	5–40	2–8	7.4–7.8

Petrogypsids											
Ak	0–50	10YR 6/3	LS-S	<35	0.9–1.8	L	SL-ST	1–15	15–60	2–4	7.9–8.4
Bym	50–100	10YR 7/3	LS-S	<35	1.2–1.8	EH	NE	1–40	15–60	4–8	7.4–8.4
Bym/C	100–150	10YR 7/2	–	–	–	R	NE	1–15	15–60	4–8	7.4–7.8
Aquisalids											
Akz	0–50	2.5Y 6/4	S	<15	1.5–1.8	S	VS-SL	5–15	1–15	>16	7.9–9.0
Bkyz	50–100	2.5Y 6/4	S-LS	<15	1.5–1.8	S	SL	5–40	5–15	>16	7.9–8.4
Byz	100–150	2.5Y 7/4	S-LS	<15	1.5–1.8	S	SL	5–15	5–15	>16	7.4–8.4
Torriorthents											
A	0–50	2.5Y 7/3	LS-SL	35–50	1.2–1.5	SH	ST-SL	>40	>40	>16	7.4–7.8
C1	50–100	10YR 5/2	S	35–50	1.2–1.5	MH	VE-ST	>40	1–5	>16	7.4–7.8
C2	100–150	10YR 6/2	S	35–50	1.2–1.5	MH	VS-SL	>40	1–5	>16	7.4–7.8
Torripsamments											
Ak	0–50	2.5Y 6/4	S	<15	1.5–1.8	L	ST-VE	5–15	<1	<2	7.9–8.4
Bk	50–100	2.5Y 6/4	S	<15	1.5–1.8	SH	ST-SL	5–15	<1	<2	7.9–8.4
C	100–150	2.5Y 7/3	S	<15	1.5–1.8	MH	VS-NE	1–5	<1	<2	7.9–8.4

Texture Class: S, sand; LS, loamy sand; SL, sandy loam. Consistence dry: L, loose; S, soft; SH, slightly hard; MH, moderately hard; VH, very hard; EH, extremely hard; R, rigid. Effervescence: NE, non; VS, very slightly; SL, slightly; ST, strongly; VE, violently.

Table 3. Soil identification key presented using a matrix with the presence of each soil feature required to determine the soil type

Are gypsum soil features present?	**Are calcium carbonate soil features present?**	**Are hardpan soil features present?**	**Soil type name (Approximate Soil Taxonomy Great Group)**
Require all of the following: • Gypsum identified – where there are any white or opaque (gypsum) crystals visible (if necessary check with field EC test where reading is about 2 dS/m) • Layer $\geq$ 15 cm thick. • Not cemented. • Occurs within 100 cm of soil surface.	Require all of the following: • Calcium carbonate identified where there are 5% or more visible white soft masses or nodules (if necessary check with field HCl test, where fizz will be a strong or violent reaction) • Layer $\geq$ 15 cm thick. • Not cemented. • Occurs within 100 cm of soil surface.	Require all of the following: • Using an auger or shovel there is refusal to penetration due to hard layer (not coarse fragments) • Occurs within 100 cm of soil surface.	
No	Yes	No	Calcareous soil (Haplocalcid)
No	Yes	Yes	Calcareous over a hardpan soil (Petrocalcid)
Yes	Yes	No	Calcareous over gypseous soil (Calcigypsid)
Yes	No	No	Gypseous soil (Haplogypsid)
Yes	No	Yes	Gypseous over a hardpan soil (Petrogypsid)
Yes	Yes	Yes	Gypseous and calcareous over a hardpan soil (Petrogypsid)
No	No	No	Deep sandy soil (Torripsamment)

- Hardpan soil features were recognized when there was resistance to the auger (or shovel) penetrating deeper into the soil profile that was not due to coarse fragments. If possible check with auger and try to obtain a piece of the hardpan in the auger tip to determine if it is gypseous or calcareous.

From previous experience we found that with limited training non-soil experts can be shown how to obtain the required information by excavating the soil, taking depth measurements, observing for gypsum, calcium carbonate, a hardpan, and then using the soil identification key to determine the soil type. Essentially, if any gypsum is identified then there will be sufficient in the soil for gypseous soil types, whereas for calcareous soil types there needs to be obvious calcium carbonate concentrations.

Toposequence Models

Two conceptual toposequence models were generated, one for the southern part of Kuwait dominated by a sand sheet over the Fars and Ghars Formation sediments (Figure 2) and the other for the north which is an undulating old alluvial plain over Dibdibah Formation sediments (Figure 3). The conceptual toposequence models

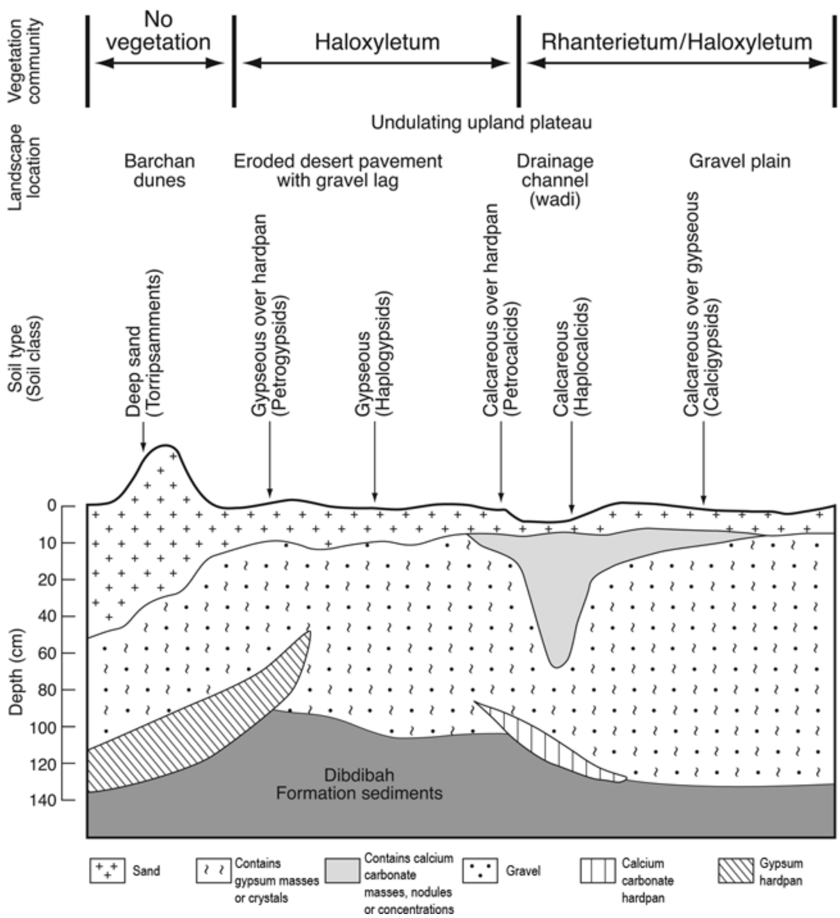

Figure 2. Conceptual toposequence model for soils in southern Kuwait.

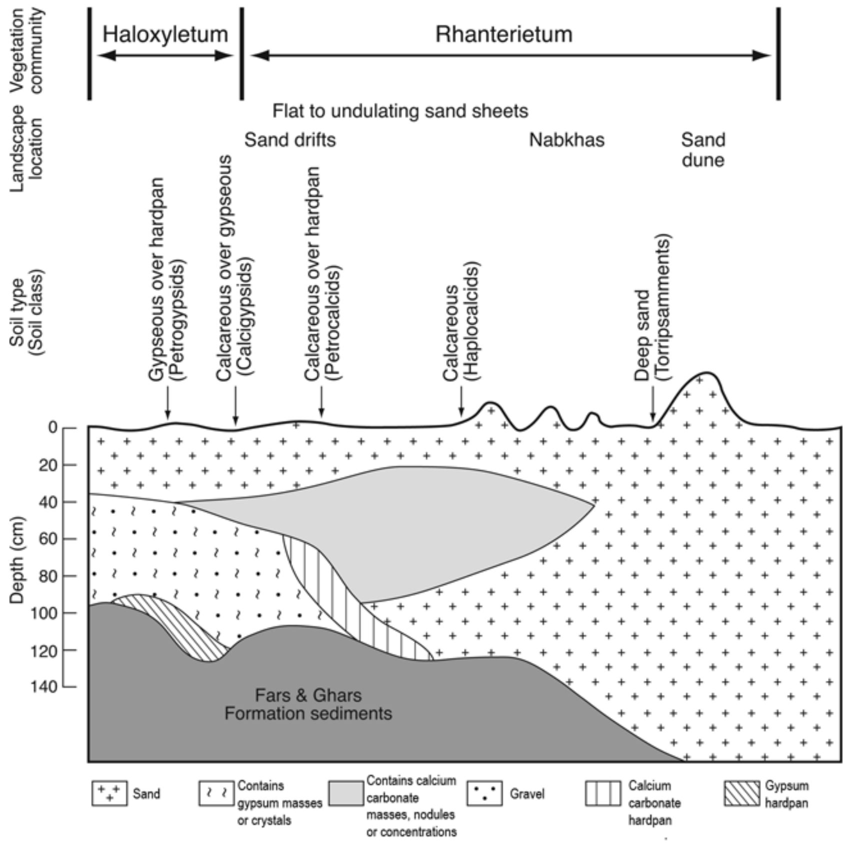

Figure 3. Conceptual toposequence model for soils in northern Kuwait.

show the relationship between soil types and the underlying trend of soil features and the primary plant communities' distribution.

The southern area (Figure 2) was dominated by deep sands that may contain calcium carbonate and to the west it was likely that hardpans occurred in the soil profile and occasionally gypsum. The northern area (Figure 3) is dominated by gypsum in the profile along with gravels from the Dibdibah Formation sediments. Hardpans were generally gypseous but some calcareous ones may occur. Where there are drainage depression channels it is likely that there are calcareous soils. The nature and degree of gypsum accumulations are discussed in relation to texture and gravel content that impacts on the downward movement of salt solutions, where increase in gravel content increases gypsum accumulation and crystalline forms (Verboom et al., 2003).

Discussion

This approach provides opportunity for an experienced soil surveyor to prepare the guidance required and work with a team of non-soil experts to survey the large areas to be restored, identifying suitable areas, determine the soil type, and select the appropriate vegetation species to plant.

Soil Identification Key

Soil Taxonomy was used for the soil survey for the State of Kuwait, the rigors of Soil Taxonomy as a technical soil classification system are necessary for ordering the soils and allocating a scientific name to facilitate transfer of knowledge about the soil and how vegetation will perform on similarly classified soils and provides links to land suitability assessments. Once a local soil has been classified, the complexities of the classification can be distilled down to a soil identification key using plain language that describes the local soils in a way that non-soil expert users can readily understand and use (Table 3). In this approach the soil identification key was developed for a special purpose, identification of soil types to target planting of vegetation communities. For other land uses in Kuwait, the soil identification key may need to be adjusted if a different set of soil features related to that management are required.

Developing the local soil identification key required good pedological knowledge and the ability to understand soil classification and its intent, along with testing and updating to simplify the questions to direct users to the correct soil type. Success requires that local users could easily obtain the information to answer the questions, and here we were able to restrict it to as few as three soil profile features: (i) soil depth to a hardpan; (ii) gypsum; and iii) calcium carbonate. The combination of presence or absence of the three soil features was able to uniquely identify the required soil type.

The soil types were named descriptively with familiar words to aid in their recognition and communication amongst non-technical people (e.g., gypseous or calcareous soils). Importantly, the soil types could also be matched to the Soil Taxonomy classes allowing further information about these soils to be determined and considered if required, for example soil properties such as infiltration rates and the evaluation of the soil suitability for irrigation, is provided in the soil survey reports and may be of value. Presenting information in this way facilitates the linkage and transfer of additional technical information to support decision making that may not otherwise have been accessed.

Most soils in Kuwait have undergone minimal pedogenesis, therefore they reflect the parent material that is sandy or gravelly with illuviation to different degrees of carbonates and/or gypsum into the soil profile. Soil color and soil texture are usually the first properties recorded in a soil morphological description and often are the only features of significance to a non-soil expert; however, for the arid soils in Kuwait they were not important differentiators. The differentiators in these arid soils were accumulations of salts, gypsum or calcium carbonate. From our field experience, training soil teams to consistently identify the white gypsum crystals and soft talc powder such as calcium carbonate masses and occasionally nodules, we found the rules of thumb in combination with limited in field guidance provided consistent results to categorize the soil type.

The structure of the soil identification key matrix would allow additional soil features to be included as their relevance to vegetation communities is identified during the restoration program. At this stage of development the knowledge linking soils and vegetation performance is at a broad level. Finer differentiation could be realized by including some of these suggested features: depths to hardpan, depth that gypsum occurs below the soil surface, concentration of gypsum in the profile, soil texture, gravel content, soil surface condition, and micro topography; all which can be linked to the Soil Taxonomy subgroup and family classes.

Toposequence Models

Landscape position played an important role in the prediction of soil type, and in this arid desert environment the differences are subtle, unlike a landscape with relief from hills where different slope positions can be recognized. The landscape position clues in Kuwait are often related to changes in the micro-topography, but these can be masked by the moving sands that blanket areas; therefore, topographic information could not solely be used to identify soil types. The conceptual soil toposequence models presented have deconstructed the complex soil survey map unit descriptions and show general soil features and soil type relationships as a simple visual graphic to provide some understanding of relationships. The soil type could then be verified by digging the soil and using the soil identification key matrix.

Conclusions

The approach provides guidance for non-soil experts to support the revegetation of Kuwait's rangelands using the soil identification key to determine soil type and conceptual soil toposequence models to provide an understanding of soil distribution. This approach first required an experienced soil scientist to interpret legacy soil survey data and represent the information in a user-friendly format. Once prepared, non-soil experts then can proceed with the work under limited supervision to make the land management decisions for revegetation.

The details presented are for local use in Kuwait but the approach provides information on the structure, process and type of outputs required to be implemented. A similar approach was successfully developed for tropical soils, with the special purpose targeted at management of agricultural crops (Grealish and Fitzpatrick, 2014). New areas will require experienced soil surveyors to develop an understanding of soil distribution and soil classification that can then be distilled in collaboration with local users to ensure the level of detail and its application is understood. There is the opportunity for non-soil experts to then independently determine soil distribution over an area with limited expert supervision.

The approach is flexible and can be scaled with additional criteria as more knowledge is acquired regarding the relationship between soil types and vegetation communities. This would likely occur during the implementation and research phase required for such a large revegetation program.

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