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Methodology for correlation of soil series in soil survey and mapping

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Abstract: The objective of soil survey and mapping is to organize soil observations and knowledge of soils to remember the most important characteristics of soils, establish environmental and other associated relationships, and to develop principles and guidelines for management of soil resources. In large and intermediate scale soil surveys, the soil series is the basic taxonomic unit employed in mapping soils. It is imperative that soil series be identified and established properly by following the criteria systematically as it is the most homogeneous and the lowest category in soil taxonomy. The standards for identifying and recognizing series have changed in the past and expected to change in the future because of inconsistent application of criteria, grouping soil profiles with wide range in characteristics, deficiency in setting up of differentiating characteristics and changes in criteria of taxa at higher categories and lack of proper soil correlation. This has led to recognizing many overlapping series with different series names. To overcome these problems, a simple method for use by the soil scientists for identification of soil series using soil profile data in the field is proposed here. Guidelines for soil characteristics like horizons, texture, gravel content, soil colour, drainage etc. that are used as differentiating characteristics for setting apart series are proposed. This would help in avoiding establishment of overlapping series or clashes when series are classified at higher category levels.

Additional key words : *Classification, polypedons, series criteria*

Introduction

The soil series is the basic taxonomic class employed in mapping soils at large (1:10000 or larger) and intermediate (1:100 000 or larger) scales in soil surveys. As a taxonomic class, the soil series is the most homogeneous category in Soil Taxonomy (Soil Survey Staff, 1992). Soil series is defined as a group of soils or polypedons having soil horizons similar in differentiating characteristics, and arrangement in the soil profile, except for the texture of the surface soil and developed from the same parent material (Soil Survey Division Staff, 1995). While recognizing series in the field, it is necessary to consider the scale and the degree of accuracy and precision at which the soil scientist observes and plots the boundaries between soil landscape units and soil mapping units. The ability and reference level of soil scientist also needs to be considered for their consistency to observe, determine and record soil similarities and soil differences (soil variability) in the field as the soil series have narrow ranges in their properties.

The criteria for differentiating soil series as defined by Marbut (1922) are both fundamental and independent of any classification system followed. Hence defining soil series helps in natural classification of soils in taxonomic units. This is in conformity with the observations made by Smith (1965). Mapping soils directly at higher category level without defining soil series will lead to erroneous mapping, lacking in the application of fundamental criteria of Soil Taxonomy. The standards for identifying soil series and recognizing the tentative and established series within a soil survey area have changed in the past and may change in the future. This was mainly due to the inconsistent application of the series criteria that was qualitative, and as such, uniform

application by different soil scientists was not possible; grouping soil profiles with wide ranges in respect of kinds and sequence of soil horizons, soil texture, soil depth, content of coarse fragments, mottling and drainage; deficiency in setting up of identifying and differentiating characteristics for soil series; frequent changes in criteria or limits of taxa in higher categories and lack of proper soil correlation. All of these have resulted in recognizing more series than are necessary. To overcome this problem of identifying and establishing many overlapping series by not applying the criteria consistently, a simple method for use by the soil scientists for establishment and correlation of soil series in the field is proposed here. This would help in proper establishment of soil series, soil correlation and classification thus eliminating chances of establishing too many as well as overlapping series with different names

Materials and Methods

Guidelines for correlation of soil series

The guidelines for correlating and establishing soil series in the field is as per the Memorandum on Soil Correlation (Shankaranarayana et al. 1984), Soil Series Criteria and Norms (Sehgal 1992) and Soil Survey Division Staff (1995). The major differentiating characteristics used for distinguishing soil series include all the differentiae of the higher categories (order, suborder, great group, subgroup and family) and those additional and significant characteristics in the series control section. The soil characteristics commonly used for differentiating soil series are the kind, thickness and arrangement of horizons and their colour, texture, coarse fragments, structure, mottling, reaction, consistence, content of carbonates and other salts, content of humus and minerology. The criteria for setting apart the series, based on these soil characteristics within the series control section, are given below. These may serve as guidelines and are subject to modifications.

Kinds of soil horizon	
O	horizon
A	horizon
E	horizon
B	horizon
C	horizon
R	horizon

Horizon sequence
Ap - C/Cr
Ap - C-R
Ap - Bw - Cr – R
Ap - Bg – Cg
Ap - Bk – Ck
Ap - Bt - Cr-R
Ap - BA - Bss – Ck/Cr
Ap – Bt – 2Bt – C, *any other*

Soil texture

Textural class	*clay (%)*	*Particle-size class**
Sand, loamy sand	<15	Sandy
Silt, silt loam	<18	Coarse-silty
Silty clay loam, silt loam	18-35	Fine-silty
Sandy loam, loam	<18	Coarse-loamy
Sandy loam, loam, sandy clay loam, clay loam, silty clay loam	18-34	Fine-loamy
Clay loam, sandy clay, silty clay, clay	30/35-59	Fine
Clay	>60	Very fine

*Only loamy particle-size class is to be used for *coarse loamy* and *fine loamy* classes if the soils are shallow (<50 cm deep). Likewise, only clayey particle-size class may be used for *fine* and *very fine* particle-size classes.

Coarse fragments

Gravel (%)	*Nomenclature*
0-15	Nongravelly
15-35	Slightly gravelly
35-60	Moderately gravelly/ skeletal
60-90	Strongly gravelly/ skeletal
>90	Fragmental

Soil colour

2.5Y, 5Y
10YR, 7.5YR
7.5YR, 5YR
5YR, 2.5YR
2.5YR, 10R

Soil structure

Single-grained
Granular, crumb
Subangular blocky, angular blocky
Prismatic, columnar
Platy
Massive

Calcareousness (content of carbonates

e – nil/slight effervescence
es – strong effervescence
ev – violent effervescence

Mottling

Mottled
Non-mottled

Soil depth

0-7.5cm	Very shallow (dl)
7.5-22.5 cm	Shallow (d2)
22.5-50 cm	Moderately deep (d3)
50-90 cm	Deep (d4)
>90 cm	Very deep (d5)

(I.A.R.I. 1970)

<10 cm	Extremely shallow
10-25 cm	Very shallow
25-50 cm	Shallow
50-75 cm	Slightly deep
75-100 cm	Moderately deep
100-150 cm	Deep
>150 cm	Very deep

(Sehgal *et al.* 1987)

<25 cm	Very shallow
25-50 cm	Shallow
50-100 cm	Moderately deep
100-150 cm	Deep
>150 cm	Very deep

(Soil Survey Division Staff 1995)

Soil drainage

Poorly drained, imperfectly drained
Moderately well drained
Well drained
Somewhat excessively drained
Excessively drained

Physiography

Hills, hill ranges
Uplands (pediplains, peneplains)
Valleys
Levees
Back swamps
Floodplains
Terraces, *any other*

Other soil characteristics like consistence, concretions/nodules, gleying or any other, that is significant in the series control section are to be used as differentiating characteristics for setting apart the soil series.

Results and Discussion

Methodology for correlation of soil series

The methodology for correlation of soil series using the guidelines from a number of soil profiles studied (Fig.1) for M.M.Kunta series is illustrated through a flow-chart (Fig.2). The procedure to be followed for grouping soil profiles to correlate soils series in brief is given below.

* Group soil profiles separately *as per the kind of parent material.* This is to be done by browsing through all the profile sheets studied up to that time in the survey area and segregating them into different kinds of parent material (rock types) identified,
* Pick all the profile sheets grouped under *one parent material at a time* for further segregation,
* Group soil profiles of a given parent material *as per physiography/landform* (as given in the guidelines on physiography / landform),
* Group soil profiles of a given physiography *as per the kinds of soil horizon, sequence and thickness of soil horizons* (as given in the guidelines on soil horizons),
* Group soil profiles of a given kind of soil horizon *as per soil depth class* (either I.A.R.I. 1970, Sehgal *et al.* 1987 or Soil Survey Division Staff 1995) or any other depth classes chosen for the survey area,
* Group soil profiles of a given soil depth class *as per particle-size (soil texture) classes* in the series control section (as given in the guidelines on soil texture),

* Group soil profiles of a given soil texture class *as per the content of coarse fragments* in the series control section (as given in the guidelines),
* Group soil profiles of a given coarse fragments content class *as per soil colour* (as given in the guidelines on soil colour),
* Group soil profiles of a given soil colour class *as per calcareousness* (as given in the guidelines on soil calcareousness),
* Group soil profiles of a given calcareousness class *as per the presence of mottling/gleying*,
* Group soil profiles *as per any other soil characteristic* that is relevant for setting up of a soil series.
* Repeat the above process for all the soil profiles studied and grouped under different parent materials to arrive at the series for each of the parent material identified in the survey area.

After correlating the soil series following the above methodology, the selection of typifying pedon for the established soil series and for working out range in characteristics from the number of soil profiles grouped under that series may be made following the methodology suggested earlier (Reddy 2000). The methodology envisages the systematic compilation and arraying of profile data for establishing the modal profile and for working out range in characteristics of soil series. The methodology in brief is as follows:

1. Pool all the soil profiles grouped under a given series; the number of profiles studied should be a minimum of 15 for a representative sample of soil properties.
2. Prepare sketch-diagrams (Fig.1) of all the profiles grouped under each series by using locally available fullscape ruled or graph sheet giving all the important morphological characteristics that are used as differentiating characteristics for correlating and establishing soil series.
3. Prepare a table (Table 1) showing all the morphological characteristics encountered in the survey area such as thickness of horizons, colour (moist), texture, structure, mottling, consistence, coarse fragments, concretions/ nodules, cutans / slickensides / pressure faces, reaction, content of humus, effervescence and drainage separately for each of the master horizons, *viz.* the surface (A horizon), the subsurface (B horizon) and the substratum (C/R horizon) or any other identified horizon vertically, and the profiles horizontally with two columns, one for mean/mode and the other for range in characteristics. Depending upon the morphological properties, Table 1 may be revised. Table 2 lists only those morphological properties which are encountered in this study area that are used for illustrating the methodology.
4. Enter all the morphological characteristics given in the sketch - diagram (Fig.1) for each of the three master horizons to Table 1.
5. Using Table 1, work out the arithmetic mean for those characteristics (thickness and coarse fragments) where values are in numerals and the mode for the most dominant notation or symbol for colour, texture and effervescence. The mode for the dominant notation or symbol for a given soil property was to be found by counting the number of times each is repeated in all the profiles and the one that repeats maximum.
6. *Criteria for establishment of the modal profile for soil series*- For establishing the modal profile, the soil characteristics of the series control section may be listed (Table 1) This is because the modal profile is selected based on those morphological features that are used as the differentiating characteristics in this section for correlating and establishing soil series. In general, a greater range of variance is allowed for the surface A-horizon which form the base for identifying phases of soil series. Examples are Mmk loamy sand, Mmk gravelly loamy sand or Mmk sandy clay loam, gently sloping.

Soil series are differentiated on all the differentiae of the higher categories (family, subgroup, great group, suborder and order) plus those additional and significant characteristics in the series control section. The soils grouped within a series are essentially homogeneous in

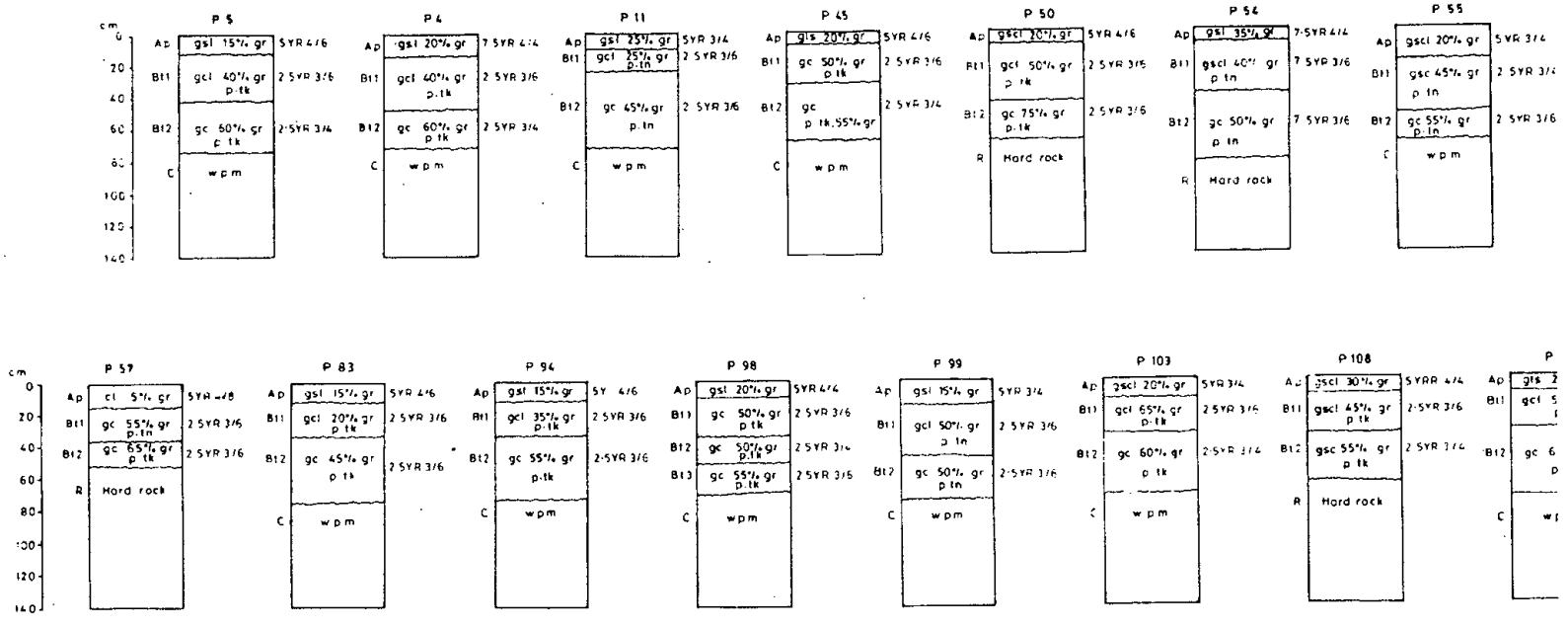

Fig. 1 . Sketch-diagram showing important morphological charactersitics of pedons

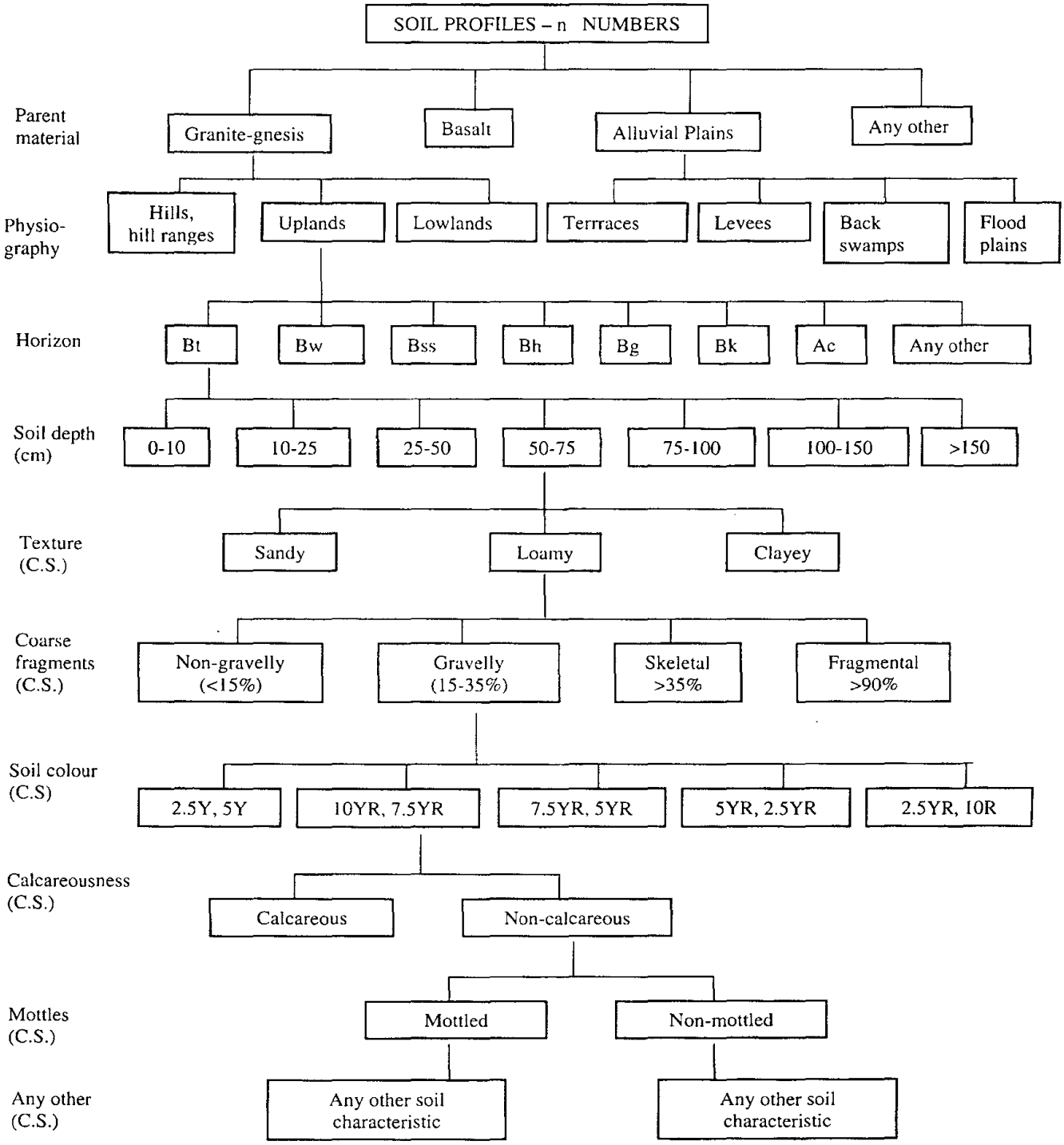

Fig. 2. Flow chart showing the methodology for identification of soil series and their correlation

Table 1. Range in characteristics of a representative soil Series (Mmk series)

Morphometric properties	Pedon numbers P4	P5	P11	P45	P50	P54	P55	P57	P83	P94	P98	P99	P103	P108	P143	Mean / mode	Range in characteristics
A-Surface horizon	0.14	0.12	0.10	0.08	0.08	0.08	0.20	0.15	0.12	0.12	0.10	0.15	0.12	0.10	0.10	176/15=12	0.08-0.20
Thickness (m)																	
Colour (moist)	7.5YR 4/4	5YR 4/6	5YR 3/4	5YR 4/6	5YR 4/6	7.5YR4/4	5YR 3/4	5YR 4/8	5YR 4/6	5YR 4/6	5YR 4/4	5YR 3/4	5YR 3/4	5YR 4/4	5YR 3/4	5YR 4/6,3/4	7.5YR 4/4 - 5YR 4/4,4/8
Texture	gsl	gsl	gsl	gls	gscl	gsl	gscl	cl	gsl	gsl	gsl	gsl	gscl	gscl	gls	gsl	gls-sl-gscl
Sttructure		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mottling	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coarse fragments (%)	20	15	25	20	20	35	20	5	15	15	20	15	20	30	25	300/15=20	15-35
Content of humus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Concr./nodules	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effervescence	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B-Subsurface horizon																	
Thickness (m)	0.58	0.60	0.61	0.61	0.60	0.74	0.50	0.36	0.63	0.62	0.62	0.60	0.60	0.65	0.65	897/15=60	0.36-0.74
Colour (moist)	2.5YR 3/4,3/6	2.5YR 3/6, 3/4	2.5YR 3/6	2.5YR 3/6	2.5YR 3/4	7.5YR 3/6	2.5YR 3/6,3/4	2.5YR 3/6	2.5YR 3/6	2.5YR 3/6	2.5YR 3/4,3/6	2.5YR 3/6	2.5YR 3/6, 3/4	2.5YR 3/6,3/4	2.5YR 3/6	2.5YR 3/6,3/4	2.5YR 3/4, 3/6
Texture	gcl-gc	gcl-gc	gcl-gc	gc	gcl-gc	gscl-gsc	gsc-gc	gc	gcl-gc	gcl-gc	gcl	gcl-gc	gcl-gc	gscl-gsc	gcl-gc	gcl-gc	gscl-gsc; gsc-gc
Structure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mottling	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coarse fragments(%)	50	50	35	50	60	45	50	60	35	45	50	50	60	50	55	745/15=50	35-60
Concr./nodules	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Content of humus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Reaction	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Effervescence	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cutans/slickensides	p.tk	p.tk	p.tn	p.tk	p.tk	p.tn	p.tn	p.tn	p.tk	p.tk	p.tn	p.tn	p.tk	p.tk	p.tk	p.tk	p.tk-p.tn
Solum depth (m)	0.72	0.72	0.71	0.69	0.68	0.82	0.70	0.51	0.75	0.74	0.72	0.75	0.72	0.75	0.75	1068/15=71	0.51-0.75
Horizon & sequence	Ap-Bt-C	Ap-Bt-C	Ap-Bt-C	Ap-Bt-C	Ap-Bt-R	Ap-Bt-R	Ap-Bt-C	Ap-Bt-R	Ap-Bt-C	Ap-Bt-C	Ap-Bt-C	Ap-Bt-C	Ap-Bt-C	Ap-Bt-R	Ap-Bt-C	Ap-Bt-C	Ap-Bt-C; Ap-Bt-R
Drainage	WD	WD	WD	SWED	WD	WD	WD	WD	WD	WD	WD	WD	WD	WD	SWED	WD	WD-SWED
C-horizon																	
Kind	GG	GG	GG	GG	rock	rock	GG	rock	GG	GG	GG	GG	GG	rock	GG	GG	GG-rock
Effervescence ($CaCO_3$)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2. Establishment of the modal profile for Mmk series

Morphometric Properties	Pedon numbers														
	P57	P50	P55	P45	P11	P4	P99	P5	P103	P83	P94	P98	P143	P108	P54
A-Surface horizon															
Thickness (m)	N	N	N	N	N	N	**N**	**Y**	Y	Y	Y	N	N	N	N
Colour (moist)	N	Y	Y	Y	Y	N	**Y**	**Y**	Y	Y	Y	N	Y	N	N
Texture	N	N	N	N	Y	Y	**Y**	**Y**	N	Y	Y	Y	N	Y	Y
Coarse fragments (%)	N	Y	Y	Y	N	Y	**N**	**N**	Y	N	N	Y	N	N	N
B-Sub-surface horizon															
Thickness (m)	N	Y	N	N	N	N	**Y**	**Y**	Y	N	N	N	N	N	N
Colour (moist)	Y	Y	Y	Y	Y	Y	**Y**	**Y**	Y	Y	Y	Y	Y	Y	N
Texture	N	Y	N	N	Y	Y	**Y**	**Y**	Y	Y	Y	N	Y	N	N
Coarse fragments (%)	N	N	Y	Y	N	Y	**Y**	**Y**	N	N	N	Y	N	Y	Y
Cutans	Y	Y	Y	Y	Y	Y	**Y**	**Y**	Y	Y	Y	Y	Y	Y	Y
Solum depth (m)	N	N	N	N	Y	N	**N**	**N**	N	N	N	N	N	N	N
Horizon & sequence	N	N	Y	Y	Y	Y	**Y**	**Y**	Y	Y	Y	Y	Y	N	N
Drainage	Y	Y	Y	Y	Y	Y	**Y**	**Y**	Y	Y	Y	Y	Y	Y	Y
C-horizon															
Kind	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N
	3Y,6	5Y,4	6Y,3	6Y,3	7Y,2	7Y,2	8Y,1	8Y,1	7Y,2N	6Y,3	6Y,3	6Y,3	6Y,3N	4Y,5	3Y,6
	N	N	N	N	N	N	N	N	----	N	N	N	----	N	N
	----	----	----	----	----	----	----	----	9	----	----	----	9	----	----
	----	----	9	----	----	----	----	----		----	----	----		----	----
	9	9		9	9	9	9	9		9	9	9		9	9

all soil profile characteristics except the texture of the surface or A horizon, and in such features as stoniness, thickness, soil slope, degree of erosion and topographic position where these features do not modify greatly the kind and arrangement of soil horizons in a series. In some situations, where the morphological features of the surface A-horizon are used as the differentiating characteristics for identifying soil series or their higher categories, those features of the surface A-horizon also need to be considered for establishing the modal profile. Examples of such situations where the features of the surface A-horizon forms part of the differentiating characteristics for correlating soil series and therefore need to be considered for establishing the modal profile are mollic, umbric, anthropic, plaggen and melanic epipedons. In such specific cases all the master horizons(A, B, C/R) are to be considered, whereas in all other situations only the subsurface B and C horizons are considered for establishing the modal profile.

7. *Establishing the modal profile for the series :* This is accomplished with the help of the profile data (Table 1) by comparing the mean/mode of each of the morphological characteristics under the column 'mean/ mode' against the values of each profile. If the profile values tally with that of the figures given in the column mean/mode, then **Y** (Yes) or **N** (No) are marked to indicate that the pedon value is either tallying or not tallying with that of the mean value/notation or symbol. It is needless to say that although marking *Y and N* are based on their tallying or not tallying exactly with that of the mean or mode which seems too fine a cutting of the values, in reality, it is not easy to make a hard and fast rule covering reasonable variations in morphological properties within the range of a soil series. If every single morphological feature in two soil profiles is to be identical to permit placing them in the same series, then every profile examined would be a separate series, for no two soil profiles are identical in all respects (Soil Survey Staff 1951). So some variation in every property must be allowed. Keeping this in view and based on the experience in several areas it has been proposed to have a maximum deviation of plus/minus of five per cent of the value of a given property to put under Y. It means that a particular property is marked as Y when either it exactly matches with that of the mean value, say 0.60m in thickness of B horizon or plus/minus five percent of 0.60 m which is 0.63 m or 0.57 m either way.

Repeat this process for all the profiles listed for consideration under that series. Then for each profile, evaluate how many soil characteristics is in agreement **(Y)** and how many are not **(N)**. The pedon (s) which satisfies the maximum number **(Y)** of soil characteristics out of the total number of characteristics used for evaluation is the modal profile that typifies the central concept for that series. Due weightage, however, is given to the key attributes that are critical for correlating soil series. It is because, at times, a particular morphological property of a soil may be a key and therefore, critical for its recognition as a soil series. For example in soils with Bt horizon, the thickness and the frequency of illuviated features are a keys for its recognition as soil series. Similarly, the presence of redoximorphic features indicating continuous or periodic saturation and reduction in some soils is the most significant feature based on which a series is identified. In such situations, the selection of the modal profile need not be a mere summation of Y's but with some discretion giving more weightage to the key morphological features like the Bt horizon, occurrence of intersecting slickensides, redoximorphic features, EC and ESP or SAR in salt-affected soils *etc*. This modal profile alone needs to be sampled for laboratory characterization and for writing soil series description; however for soil map unit characterization, apart from the modal profile, another two profiles representing the extreme values (allowed under range of variance for that series) on either side (highest and lowest) are also to be sampled for giving the range in characteristics of physical, chemical and morphological properties of series which are useful for making predictions of soil properties.

8. *Range in characteristics for each of the soil property for the soil series :* This can be done directly from the profile

data (Table 1) from extreme values of each profile and to enter them under the range in characteristics column. It gives the range of variance allowed for each soil characteristic for that series. Any value which is on a very extreme side and is unusual can be considered as either a misfit or an inclusion. If it is a misfit it can be excluded from that series and can be correlated with other series. Range in characteristics worked out are to be used for writing soil series description and for map unit characterization. The methodology can be automated if a computer is made available to the soil surveyor for use in the field while soil survey is in progress.

The methodology has been applied in red and lateritic, black and deltaic alluvial soil-scapes representing Alfisols, Ultisols, Vertisols, Inceptisols, Aridisols and Entisols in detailed (1:10,000 or larger scale) and reconnaissance (1:50,000 scale) soil surveys and soil resource mapping of states and of India (1:250,000 scale) where the soil map units were phases of soil series, association of soil series and association of soil families respectively for establishing the modal profile for series and families and for working out range in characteristics of soil series and soil families. Although the basic principles of the methodology suggested were applied in these different areas, the actual degree of detail with respect to various soil characteristics have been changed based on their significance for identification of soil series in varied soilscapes of the country. The proposed methodology is an open one in that it has provision for such modifications which are situation-dependent.

General Discussion

Medium intensity detailed soil survey of an operational research project (ORP) in M.M. Kunta watershed (Anonymous, 1985) in Ranga Reddy district of Andhra Pradesh on 1:5000 scale with phases of soil series as mapping units was carried out. Of the eight soil series mapped, M.M. Kunta (Mmk) soil series occurring extensively in the watershed has been chosen to illustrate the proposed methodology.

Out of 75 soil profiles studied, 24 were grouped under Mmk series. Only 15 profiles (Fig.1) are used for establishment of the modal profile for brevity. Sketch-diagrams of profiles in figure 1 give the most important morphological characteristics that were used as the differentiating characteristics for correlating soil series in the watershed. Table 1 gives the morphological characteristics for each of the master horizons (A, B, C) and the mean/mode and range in characteristics worked out using the data from 15 profiles. The modal profile which typifies the central concept for Mmk series has been selected by matching the values given in the column mean/mode (Table 1) against the values of each pedon and also giving due weightage to the key morphological features that are critical for identifying soil series.

It is seen from table 2 that profile numbers P5 or P99 satisfies a maximum number (8Ys out of 9) of soil attributes under consideration with due weightage given to key soil features whereas P54 and P57 satisfy the least number (3Ys out of 9) of soil attributes; it means that P5 and P99 satisfies the maximum number of key soil attributes that are critical for identification of soil series and therefore are selected as modal profiles typifying the central concept of Mmk series. In case two or more profiles enjoy the same number of Ys and Ns that include the key attributes, then any one pedon among them may be chosen as the modal profile representing that series. The profiles are so arranged (Table 2) on both sides of P5 and P99 to represent the range of variance allowed for Mmk series. The range in characteristics get widened as one moves away from the modal profile (P5 or P99) both towards left and right side, whereas it becomes narrower as one moves towards the modal profiles from both the sides indicating that profiles P103, P4 and P11 are almost similar to that of the modal profiles having narrow range in characteristics. The profiles (P83, P94, P98, P143, P 45, P 55, P 50) that are a little away from the modal profiles indicate wider range in characteristics. The profiles (P108 and P57) represent both the extremes of maximum and minimum values of range in characteristics allowed for the series; for example, the soil depth set for the series was a maximum of 0.75 m (P108 has 0.75 m depth) at one end and a minimum of 0.50 cm (P57 has 0.51 m depth) at the other.

Profile number P54 (Table 2) is a misfit under Mmk series and as such should not have been grouped under this series because of some differentiating characteristics like soil depth (0.82 m) and colour (7.5YR) that exceed the criteria set for Mmk series. Ideally this profile could belong to another series which has a soil depth of 0.75-1.00 m and soil colours in hue of 7.5YR in the control section. As there was no series identified in the watershed matching the attributes of P54 it was grouped under Mmk series as a *'soil variant'* or an 'soil inclusion'.

The modal profile (P5 or P99) thus selected for Mmk series only needs to be sampled for laboratory characterization of physical and chemical properties and for writing up soil series description and descriptive legend for soil mapping units. However, for characterization of soil map units, it is also necessary to sample another two profiles (P108 and P57) representing the extreme values that is the highest and the lowest allowed under the range of variance for Mmk series. This would help the soil survey user in getting the maximum amount of information about the properties of soils to locate the landscape for their accurate prediction and management.

Conclusion

The methodology presented herein will help soil scientists who are into soil survey and mapping in proper correlation and establishment of soil series more systematically and consistently. Proper soil correlation and establishment of soil series will help in soil correlation, standardization of soil legends, prediction of soil behaviour, soil-based agrotechnology transfer, preparation of optimum land use plans and planning further research in allied disciplines.

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