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Application of fertility capability classification in Kangayam grasslands representing dry semi arid climate of Tamil Nadu

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Abstract
Fertility capability classification (FCC) is a system meant for grouping the soils according to their fertility constraints in a quantifiable manner based on condition modifiers. The present study was carried out in the grasslands of Kangayam block falling in dry semi arid climate. The soils were mapped at 1: 10000 scale and classified into different taxonomic units. The fertility capability classification was applied to the nine major soils identified in the Kangayam grasslands. The major soil constraints identified through condition modifiers were dry soil moisture (d^+), low cation exchange capacity (e), basic reaction (b), alkalinity (n), gravel content (r) and low organic carbon content (m). The condition modifier d^+ was dominated in its occurrence followed by the condition modifier b (89.6%), e (56.7 %), r (64.2%), n (39.2%) and m (9.1%). The outcome signifies the limitations are varying with landform and soil properties. Hence, suitable management options should be arrived considering the extent and severity of each limitation for combating degradation as well as the productivity of grasslands.

Keywords: Condition modifiers, Fertility capability classification, Kangayam grasslands, Nutrient depletion, Soil moisture

Introduction

Grasslands in arid and semi arid region of India are under tremendous pressure due to natural and anthropogenic factors. Among the factors, over-grazing (Roy and Singh, 2013), soil erosion (Labriere *et al*., 2015; Dharumarajan *et al*., 2017), nutrient depletion (Hiernaux *et al*., 1999) and conversion into croplands and non-agricultural uses are the major causes of grassland degradation. Soil texture, thickness of the surface horizon, organic carbon and soil nutrients were used to assess the land degradation vulnerability of Kangayam grasslands and reported that lands with poor organic carbon is highly vulnerable for land degradation (Dharumarajan *et al*., 2017). Hence, soil fertility is an important factor which influences both crop and soil productivity. Land resource inventorization at large scale (1:10,000 or larger) is one of the method to characterise and identifies soil constraints and potential at farm or watershed level (Lalitha *et al.,* 2016). But direct interpretation of such system (soil taxonomy) for specific use is difficult and attempts were made to classify soils in comparison with the soil taxonomy system in order to produce interpretative soil units that are more specific for on-site crop production planning (Anusontpornperm *et al.,* 2009). Fertility capability classification (FCC) is one among the technical system which groups the soils according to their fertility constraints in a quantifiable manner based on condition modifiers was proposed by Buol *et al*. (1975) and modified by Sanchez *et al*. (1982). Fertility capability classification identifies number of soil properties that are important to the specific endeavor of growing crops and establishes for those properties critical thresholds that serve as dividers between groups of soils that have similar inherent fertility related properties (Jasper, 2004).

The Kangayam grassland is one of the earliest territorial divisions of the ancient home of the Tamils which is under degradation due to severe soil erosion, over grazing, loss of palatable plants, invasion of undesirable plant species, nutrient depletion and improper land management practices (Natarajan *et al*., 2008; Kumar *et al*., 2011). The area located in the rain shadow region of western Ghats and it is a drought-prone area, where pasture and grasses is the main land use and livestock rearing is the major occupation of the upland farmers. Almost every field in the Kangayam has the live hedge of *Balsamodendron berryi* which helps to secure the animals grazing inside the field and *Acacia* trees for fodder purpose. The study area has rich species diversity having 8 species of perennial grasses, 6 annual grass, 9 legumes and 16 forbs (Kumar *et al.*, 2011). This study was an embodiment with an objective of application of fertility capability classification system in Kangayam grasslands representing semi arid climate of Tamil Nadu.

Materials and Methods

Study area and its climate: The study area lies between 77°43'19" and 77°27' 06" East longitudes and 10°54'55" and 11°07'39" North latitudes in Tiruppur district of Tamil Nadu. The total area of grasslands in the block is 25,876 hectare. The mean annual rainfall (523 mm) exhibits variation over the years in the range of 90 to 788 mm. Rainfall is highly irregular and bi-modal which receives rainfall both from south-west (SW) and north-east (NE) monsoon. The pre-monsoon rains received during April-May contribute 125 mm to the average annual rainfall. The mean SW monsoon rainfall is 173 mm and ranges from 17 to 380 mm. The SW monsoon sets in by the first/ second week of June and extends to the first week of September. The NE monsoon starts by the second week of October and ends by second week of December and then tapers off. The average rainfall received during NE monsoon is 226 mm. January to March is the dry period, February being driest. The length of growing period is 10 weeks which starts from middle of September to the end of November. The elevation ranged from of 220 to 320 m above mean sea level. The study area falls under hyper-thermic temperature regime and classified under aridic (d^+) soil moisture regime which is too dry to grow a crop without irrigation.

Detailed soil mapping: Resourcesat-2 LISS IV imagery (5.8 m resolution) in conjunction with Survey of India Toposheets (1: 50,000 scale) was used as base maps for identification of different soils. Transects and profile locations were identified based on landform, slope characteristics and land use (Natarajan and Sarkar, 2010). The study area is divided into three different landforms *viz*., pediplain upper sector, pediplain lower sector and valley fringes. Profiles were opened in the selected locations in each landform and studied in detail for all their physical and morphological characteristics. The soil and site characteristics were recorded for all profile sites on standard proforma as per the guidelines given in USDA Soil Survey Manual (Soil Survey Staff, 2003). Profiles were grouped into soils based on identification characteristics. The major differentiating characteristics in the soils of Kangayam grasslands were soil depth, calcareousness (presence of $CaCO_3$) and soil texture.

Soil sample collection and analysis: Horizon-wise samples were collected from each soil profile for laboratory analysis. Particle size analysis was carried out by international pipette method (Piper, 1966); Soil pH and electrical conductivity (EC) were measured with 1: 2.5 soil: water ratio (Whitney, 1998). Organic carbon (OC) was determined by Walkley and Black (1934) method. Calcium carbonate ($CaCO_3$) equivalent (%) was determined by Piper method (1966). Cation exchange capacity was determined by neutral normal ammonium acetate method (Richards, 1954). The ESP was calculated using the formula given by USDA (Richards, 1954). The soils were classified according to soil taxonomy (Soil Survey Staff, 2003). Descriptive statistics were worked out using XLSTAT software.

Table 1. Descriptive statistics of the soil parameters in the surface and sub-surface soil

Parameters	Surface soil (0-20 cm)					Sub-surface soil (20-50 cm)				
	Average	Min	Max	SD	SE (m)	Average	Min	Max	SD	SE (m)
Sand (%)	74.09	41.67	86.90	12.70	3.66	66.18	29.01	79.08	13.40	3.87
Silt (%)	13.12	6.72	30.80	6.55	1.89	14.94	9.55	33.41	6.59	1.91
Clay (%)	12.78	5.73	27.51	6.36	1.83	18.85	11.35	37.58	7.07	2.04
Gravel (%)	27.75	13.65	50.00	10.53	3.04	30.64	22.64	39.13	5.85	1.69
pH	8.09	6.29	8.80	0.86	0.25	8.30	7.12	8.84	0.48	0.14
EC (dS m^{-1})	0.273	0.083	0.493	0.139	0.040	0.218	0.014	0.398	0.108	0.031
OC (%)	0.59	0.12	1.14	0.31	0.09	0.41	0.01	0.96	0.24	0.07
CCE	4.93	0.70	11.60	3.69	1.06	5.76	0.00	12.70	4.82	1.39
CEC (cmol(p+)kg^{-1})	7.21	2.00	13.90	3.96	1.14	9.61	4.83	17.50	3.46	1.00
Exchangeable Na (cmol(p+) kg^{-1})	0.39	0.02	0.91	0.36	0.10	0.29	0.01	0.97	0.30	0.09
Exchangeable K (cmol(p+) kg^{-1})	0.51	0.10	1.42	0.42	0.12	0.37	0.02	0.73	0.21	0.06

Fertility capability classification: Fertility capability classification (FCC version 4) by Sanchez *et al.* (2003) was used to classify the soils based on surface and sub-surface soil properties. The FCC system consists of three categorical levels. The first category type indicates texture of upper 20 cm of surface soil and substrata type indicates sub-soil texture between 20 to 50 cm depth. The second one condition modifiers were identified to indicate soil physical and chemical characteristics. The superscripts + or – were used to express the magnitude of condition modifiers. There were four type levels (sandy top-soils (S), loamy top soils (L), clayey top soils (C) and organic top soils (O), four substrata type levels (sandy sub-soils (S), loamy sub-soils (L), clayey sub-soils (C) and rock or other hard root restricting layer (R) and fifteen condition modifiers soil gleying (g), dry soil moisture (d), low CEC (e), aluminium toxicity (a), acidity (h), high P fixation (i), X-ray amorphous (x), vertic properties (v), low K reserves (k), basic reaction (b), salinity (s), natric (n), cat clay (c), gravel content (r) and slope (%). This classification system was applied to the soils identified in the grasslands to identify the soil constraints which affect the grassland production.

Results and Discussion

Soil properties: Major soils in the pediplain upper sector landform were aridic lithic ustorthents (ALU), loamy typic haplustepts (LTHp), loamy-skeletal typic rhodustalfs (LTR) and aridic haplustepts (AH). The soils of pediplain lower sector were coarse- loamy typic rhodustalfs (CTR), calcic haplustalfs (CH) and loamy-skeletal typic haplustepts (LsTHp) and fine loamy typic haplustalfs (FTH) and loamy typic haplustalfs (LTHf) were identified in valley fringe.

The descriptive analysis of the soil properties was also conducted (Table 1). Particle size distribution analysis revealed that dominant soil fraction was sand followed by silt and clay. The soil pH ranged from slightly acid (6.29) to strongly alkaline (8.80) and extreme soil reaction might be due to the presence of calcium carbonate in soil solum (Shalima Devi and Kumar, 2010). Organic carbon content varied from 0.01 to 0.86 per cent with an average of 0.36 per cent. Low vegetative cover, pasture grazing coupled with arid climate resulted in very low organic carbon content (Lalitha and Kumar, 2015). Calcium carbonate content ranged from 0 to 38.5 per cent and the wide variation was because of spatial variability, aridity and parent material. Cation exchange capacity was found very low in all the soil and it varied from 2.49 to 29.94 cmol (p+) kg^{-1} and it varying in accordance with clay content (Table 2).

Table 2. Relevant average values of soil properties for fertility capability classification

Soil series	Depth (cm)	pH	EC (dS m^{-1})	OC (%)	CCE (%)	CEC (cmol (p+) kg^{-1})	Ex. K (cmol (p+) kg^{-1})	ESP (%)	Sand (%)	Silt (%)	Clay (%)	Gravel (%)
Aridic lithic	0-20	8.65	0.583	0.43	6.55	2.7	0.17	20.4	86.27	7.65	6.06	14
ustorthents	20-50	8.48	0.113	0.63	1.57	4.8	0.32	8.1	74.05	9.64	15.97	23
Loamy typic	0-20	8.25	0.444	1.14	1.60	8.2	0.23	10.0	75.88	12.40	11.69	29
haplustepts	20-50	8.30	0.248	0.38	1.00	8.4	0.24	8.1	76.31	11.43	12.24	28
Loamy-skeletal	0-20	6.31	0.122	0.49	2.90	2.0	0.37	1.0	86.32	7.93	5.73	29
typic rhodustalfs	20-39	8.64	0.126	0.30	12.00	7.7	0.43	0.3	64.68	16.54	18.76	39
Aridic haplustepts	0-20	8.41	0.252	0.67	6.80	13.7	0.18	4.6	68.74	14.23	17.03	31
	20-50	8.58	0.277	0.39	12.70	13.5	0.25	3.0	67.65	13.47	18.86	33
Coarse- loamy	0-20	6.29	0.275	1.00	11.30	13.9	0.84	0.3	41.67	30.80	27.51	30
typic rhodustalfs	20-50	7.12	0.213	0.55	10.80	17.5	0.54	2.2	29.01	33.41	37.58	34
Calcic haplustalfs	0-20	8.64	0.265	0.57	6.10	4.0	0.60	0.8	79.77	9.70	10.51	41
	20-40	8.70	0.168	0.36	10.20	13.2	0.33	0.1	64.23	13.30	22.45	25
Loamy-skeletal	0-20	8.77	0.383	0.85	5.20	8.2	0.63	11.1	75.38	11.69	12.92	50
typic haplustepts	20-50	8.64	0.398	0.31	6.55	6.9	0.48	4.5	76.64	9.66	13.68	30
Fine loamy typic	0-20	8.24	0.493	0.71	11.60	5.0	1.42	0.6	62.58	18.49	18.91	18
haplustalfs	20-50	7.92	0.271	0.54	8.25	8.7	0.72	0.1	71.59	10.78	17.61	33
Loamy typic	0-20	8.03	0.197	0.12	0.70	3.4	0.37	1.5	86.90	6.72	6.36	14
haplustalfs	20-43	7.99	0.177	0.96	1.80	8.6	0.18	0.3	79.08	9.55	11.35	26

Table 3. Type, substrata and condition modifiers for fertility capability classification

Landform	Soil Series	Type/ Substrata	Modifiers	Check list b	d	e	m	n	r	Slope (%)	FCC unit	Area in hectares (% area)
Pediplain upper sector	Aridic lithic ustorthents (soil ALU)	L^+R	$bd^+emr^+n^-$	X	X	X	X	X	X	3-5%	$L^+Rbd^+emr^+n^-$ (3-5%)	1,417 (5.5)
	Loamy typic haplustepts (soil LTHp)	L^+R	$bd^+r^+n^-$	X	X	-	-	X	X	1-3%	$L^+Rbd^+r^+n^-$	2,252 (8.7)
	Loamy-skeletal typic rhodustalfs (soil LTR)	S^+L^+R	d^+e	-	X	X	-	-	-	3-5%	$S^+L^+Rd^+e$ (3-5%)	2,696 (10.4)
	Aridic haplustepts (soil AH)	S^+L^+R	bd^+r^+	X	X	-	-	-	X	1-3%	$S^+L^+Rbd^+r^+$	513 (2.0)
Pediplain lower sector	Coarse- loamy typic rhodustalfs (soil CTR)	S^+C	bd^+	X	X	-	-	-	-	1-3%	S^+Cbd^+	6,370 (24.6)
	Calcic haplustalfs (soil CH)	L^{++}	$bd^+er^{++}n^-$	X	X	X	-	X	X	1-3%	$L^{++}bd^+er^{++}n^-$	4,410 (17.0)
	Loamy-skeletal typic haplustepts (soil LsTHp)	L^{++}	$bd^+r^{++}n^-$	X	X	-	-	X	X	1-3%	$L^{++}bd^+r^{++}n^-$	2,067 (8.0)
Valley fringes	Fine loamy typic haplustalfs (soil FTH)	L	bd^+e	X	X	X	-	-	X	0-1%	Lbd^+e	5,217 (20.2)
	Loamy typic haplustalfs (soil LTHf)	SL	bd^+em	X	X	X	X	-	-	0-1%	$SLbd^+em$	934 (3.6)

Fertility capability classification (FCC): Based on the soil properties, the soils identified were further classified into different fertility capability units. The type, sub-strata type and condition modifiers were identified for each soil. The type of the soils was sandy and loamy top soil and substrata type were mostly clayey and loamy sub-soils. The condition modifiers identified were basic reaction (b; pH >7.3), dry condition (d; ustic moisture regime), low cation exchange capacity (e; CEC<7 cmol (p+) kg^{-1} of soil at pH 7), biological condition modifier (m; SOC is < 5 g C kg^{-1} soil within 20 cm depth) and gravel content [r; r^+ = 10–35% by volume of gravel size (2– 25 cm in dm) in 50 cm of the soil].

The FCC table (Table 3) showed that surface and subsurface soils of ALU were non-saline, loamy sand with soil moisture stress (d^+), basic reaction (b), low cation exchange capacity (e), deficient SOC (m), alkalinity (n), gravel content of 10-35 per cent (r^+), well drained very shallow soils, classified under the fertility capability unit $L^+Rd^+emr^+n^-$ and it occupies about 5.5 % of total geographical area. In soil LTHp, basic reaction (b), soil moisture stress (d^+) and gravel content (r^+) were identified as modifier and it occupies 2,252 ha of total geographical area (8.7 % of TGA). The LTR soils were non-saline, sandy topsoil and loamy subsoil texture with soil moisture stress (d^+), low cation exchange capacity (e), alkalinity (n), well drained shallow soils, classified under the fertility capability unit $S^+L^+Rd^+e$ (10.4 % of TGA). Soil AH comprise of b, d^+ and r^+ as condition modifier and sandy surface and loamy subsurface texture and accordingly FCC assigned as $S^+L^+Rbd^+r^+$ (2 % of TGA). These soils were developed from granite gneiss and occur on very gently sloping uplands (1-3 %) to gently sloping uplands (3-5 %) with moderate to severe erosion. The type and substrata, L^+R and S^+L^+R are being non arable due to serious limitations of rock outcrops and very high gravel content (Orimoloye, 2016). Among the FCC units in the pediplain upper sector landform, the FCC unit $S^+L^+Rd^+e$ occurs in large area (2,696 ha) followed by $L^+Rbd^+r^+n^-$ (2,252 ha) and other units. The soils were very shallow to shallow soil depth which is due to washing out of fertile top soil because of lack of proper soil conservation measures (Prasad, 2000; Bhattacharyya *et al.*, 2016). The less surface horizon depth and gravel content were the indicators of top soil loss due to severe sheet erosion which limits the availability of WHC and nutrients (Rajeshwar and Mani, 2014).

Table 4. The extent of soil condition modifier and the soil limitation of Kangayam grasslands

Soil condition modifier	Limitation	Area in hectare (% area)
d^+	Strong dry season: Dry soil moisture regime	25,876 (100)
b	Calcareousness	23,180 (89.6)
e	Low CEC/nutrient retention capacity	14,674 (56.7)
n^-	Alkalinity	10,146 (39.2)
r^{++}	Gravel content (> 35%)	6,477 (25.0)
r^+	Gravel content (10-35 %)	4,182 (16.2)
m	Low organic carbon content	2,351 (9.1)

Note: Each soil unit can have more than 1 condition modifier

The soils developed in pediplain lower sector were moderately shallow soil with loamy surface texture which favors easy infiltration of rainwater into the subsurface and clayey subsoil hade the capacity to hold more water and nutrients (Table 3). There were three FCC units identified in the pediplain lower sector landform and among that the extent of S^+Cbd^+ was found high in 6370 ha (24.6 % of TGA) followed by $L^{++}bd^+er^+n^-$ (17.0 % of TGA) and $L^{++}bd^+r^{++}n^-$ (8 % of TGA). All these soils had the soil modifier of basic reaction (b) and soil moisture stress (d^+). In addition soils of CH and soil LsTHp got condition modifiers of gravel content (r^+), low potassium reserve (k) and alkalinity (n) as additional soil modifier. The soil of 50-75 cm deep having capacity to hold more nutrients could be improved by adding required fertilizer nutrients and amendments for sodicity amelioration (Minh and Tri, 2016).

The soils of valley fringes were moderately deep to deep soil and the condition modifiers identified were dry soil moisture (d^+), low cation exchange capacity (e), basic reaction (b), gravel content of 10-35 per cent (r^+) and deficient SOC (m). The soil fertility capability unit arrived were Lbd^+e (20.2 % of TGA) and $SLbd^+em$ (3.6 % of TGA). As the soil condition modifier (e) indicated that the soils had low CEC and nutrient holding capacity, the soils should be fertilized with nutrients in split doses to improve the productivity (Dhar *et al*., 1993; Prasad *et al*., 1993). However, these soils were deep and had sufficient fine fraction (>20 %) in the 50 cm nutrient management along with assured supplemental irrigation could make these soils more productive.

The FCC units varied for each soil taxonomic units either in one or more than one soil condition modifier (Table 4). The variation might be due to the difference in slope, parent material, level of grazing and land management practices which influence the properties of soil (Rao and Jose, 2003). The strong dry season with influence on soil moisture regime stood prime factor which affected grassland productivity followed by calcareousness (89.6%), low CEC (56.7%), alkalinity (39.2%), strong (>35%) gravelliness (25%), moderate (10-35%) gravelliness (16.2%), and low organic carbon content (9.1%). Dry soil moisture regime could be effectively managed by following soil water conservation measures as well crop water budgeting (Lalitha *et al*., 2016). Since condition modifiers served as drivers for identification of soil constraints apart from indicating soil characteristics it could be used for prioritizing the problem based on its extent and severity as well as selection of appropriate management for increasing the soil productivity (Vasu *et al*., 2016).

Conclusion

Most of the identified soils were quite similar in FCC units in terms of soil and fertility management units. The soils were classified as sandy and loamy at the type level and clayey and loamy at the substrata level. The major soil constraints identified through condition modifiers were dry soil moisture (d^+), low cation exchange capacity (e), basic reaction (b), alkalinity (n) and gravel content (r). The application of fertility capability classification system facilitated for the generation of basic data which identified the limitation and also enabled better soil management for optimum grass and fodder crop production.

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