DUS(Soil)—A Framework for Developing a Minimum Data Set of Soil Health Indicators and Management Guidelines for Farmers

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Abstract

Soil health information is still not widely used in decision making in agriculture. One of the reasons is the lack of a simple and effective method for selection of soil health indicators that have direct relevance to management decisions. A framework for soil health indicators selection and developing location-specific management practices that improve soil health are presented. The framework involves selection of a minimum data set of soil health indicators based on 'DUS(Soil)' criteria. In this framework 'D' represents Distinctness (indicators representing distinct functional soil processes), 'U' represents Utility (amenability for amelioration of the status of the indicator or altering its impact through management practices) and 'S' represents Simplicity (amenability for measurement in the field/small laboratories using simple protocols). This study also outlines a method for developing management guidelines for farmers based on the status of the selected soil health indicators. This involved classifying the status of each of the indicators into three classes. Thereafter, taking cognizance of the agroecological context, suitable field management schedules were developed for each class of the indicators, based on literature and local expert knowledge. The use of this framework was demonstrated by developing management guidelines for a coarse textured soil with optimum pH, low soil carbon, poor in water stable aggregates (highly slaking), optimum porosity and poor in soil macro fauna in Mandla district, Madhya Pradesh, India. The study showed that the framework is flexible, generic as well as simple and is useful to develop site-specific management guidelines logically, to overcome the soil quality constraints.

Keywords: DUS(Soil), soil health indicators, soil quality, agricultural soils

1. Introduction

Soil quality has been recognized as the foundation of sustainable agriculture. Soil degradation has been reported to be one of the main factors impacting crop yields, resulting in stagnating productivity (Bindraban et al., 2012). The deterioration of soil quality is a problem worldwide (Karlen & Rice, 2015) and more so in India (Bhattacharyya et al., 2015) because of the adoption of agricultural practices with focused emphasis on high productivity.

The impact of soil health is multidimensional. McBratney, Field, and Koch (2014) reported that soil has an important role in food, water and energy security, climate stability, biodiversity and ecosystem services, hence, soil is as equally important as these issues. Similarly, Keesstra et al. (2016) reported close linkage between soil functions and the Sustainable Development Goals especially goals under serial number 2, 3, 6, 7, 12-15. They have further discussed extensively the various issues arising due to the linkages.

Soil physical, chemical and biological properties are integral components of soil health and studies have been conducted to assess and index soil quality, considering the multiple soil functions (Karlen, Ditzler & Andrews, 2003; Moebius-Clune et al., 2017). However, the choice of indicators vary widely and many studies have reported different indicators to measure soil health and also criteria for scoring them (Andrews, Karlen, & Cambardella, 2004; Ganeshamurthy & Srinivasarao, 2009; Bünemann et al., 2018). The indicators of soil health have been identified by various methods ranging from simple expert opinion to statistical techniques such as Principal Component Analysis (Ghaemi, Astaraei, Emami, Mahalati, & Sanaeinejad, 2014).

However, the adoption of soil health evaluation practices by farmers has not been encouraging. One of the reasons could be that there is no general agreement on the best method to use to identify a set of soil health indicators suitable to a particular scenario or circumstance. Further, the results of soil health assessment *per se* were also observed to be not very encouraging (Roper, Osmond, Heitman, Wagger, & Reberg-Horton, 2017). They reported no significant correlation between soil health tests and crop yields, suggesting that soil tests should be calibrated to better differentiate soil management effects according to the intrinsic soil limitations. Almost similar observation for translating science into practice by identifying indicators that are useful to land managers had been made by Doran as early as in 2002 (Doran, 2002).

Therefore, this study proposes a simple framework for the selection of minimum data set of soil health indicators and for developing location-specific management practices based on the status of each of the selected indicators.

2. Materials and Methods

2.1 Selection of Indicators

For the selection of minimum data set of soil health indicators, a set of criteria akin to UPOV's Distinctness, Uniformity and Stability (DUS) criteria (UPOV, 2002), used to distinguish plant varieties was adopted. This was termed 'DUS(Soil)' wherein 'D' represents 'Distinctness' (indicators representing distinct functional soil processes), 'U' represents 'Utility' (amenability for amelioration of the status of the indicator or altering its impact through management practices) and 'S' represents 'Simplicity' (amenability for measurement in the field/small laboratories using simple protocols). This was accomplished by evaluating the indicators used in various soil health assessment studies reported in literature (Syers, Hamblin, & Pushparajah, 1995; Kinyangi, 2007; Karlen, Andrews, Wienhold, & Zobeck, 2008; Schindelbeck et al., 2008; Cardoso et al., 2012) for meeting the three DUS(Soil) criteria *viz.* Distinctness, Utility and Simplicity. Each of the indicators meeting the three DUS(Soil) criteria were further categorized into three classes based on practical utility for planning of strategic management options. The threshold limits for the different classes were fixed based on literature and expert knowledge.

2.2 Formulating Management Recommendations Using the Selected Indicators

To demonstrate the utility of the indicator set for developing location-specific management practices, information on the biophysical context *viz.* temperature profile, rainfall distribution, soil depth and physiography were collected from literature (Velayutham, D. Mandal, C. Mandal, & Sehgal, 1999) for Mandla district (80.38 E, 22.6 N) in Madhya Pradesh, India. Taking cognizance of the biophysical context, management guidelines for each class of each indicator was developed based on literature and expert consultations. Recommendations for different combinations of classes of the indicators were then derived by synthesis.

3. Results and Discussion

3.1 Selection of Indicators

The DUS(Soil) criteria envisages the selection of soil health indicators meeting the three criteria, namely Distinctness, Utility and Simplicity. The indicators thus selected are provided in Table 1 and the justification for their selection is provided below.

Table 1. Selected indicators and their threshold values for different classes

Sl. No.	Indicator	Classes			Reference/Remarks
1	Soil texture	**Coarse**	**Medium**	**Fine**	Adapted from Ritchey et al. (2015)
		Sand, loamy sand	Sandy loam, sandy clay loam, loam, clay loam, silt loam, silty clay loam, silt	sandy clay, silty clay, clay	
2	Soil pH	**Low**	**Optimum**	**High**	Anonymous (2010)
		< 6.5	6.5-7.5	> 7.5	
3	Soil carbon (%)	**Low**	**Medium**	**High**	Anonymous (2011)
		< 0.5	0.5-0.75	> 0.75	
4	Water stable aggregates	**High slaking**	**Moderate slaking**	**No slaking**	Adapted from Emerson (1967)
5	Soil porosity	**Low**	**Optimum**	**High**	Adapted from Pagliai and Vignozzi (2006)
		< 10% total porosity	10-25% total porosity	> 25% total porosity	
6	Soil macro fauna abundance	**Poor**	**Moderate**	**High**	Adapted from Ganeshamurthy and Srinivasarao (2009) and Islam et al. (2017)
		0 to < 3 earth worms or macro life per spade full of surface soil)	3 to 6 earth worms or macro life per spade full of surface soil)	> 6 earth worms or macro life per spade full of surface soil)	

3.1.1 Distinctness

Soil texture is the major determinant of the physical dynamics of soil water (Scott, Cole, Elliott, & Huffman, 1996; Fernandez-Illescas, Porporato, Laio, & Rodriguez-Iturbe, 2001) and this is one of its unique features. It is also an important factor determining the soil's erosion potential. Due to these distinct characteristics, soil texture was chosen as an indicator of soil health. The three distinct classes of texture identified were coarse, medium and fine texture soils (Table 1).

The second indicator meeting the 'Distinctness' criteria is the soil pH. Soil pH plays a unique role in soil health primarily in terms of determining availability of nutrients in view of its major role in affecting the chemical dynamics of soil nutrients. It also determines the soil biological diversity to some extent (Anonymous, 2010; Neina, 2019). Soil pH is also a determinant of soil structure especially at the extreme values. Information on these characteristics are important for developing appropriate management schedules and hence soil pH meets the distinctness criteria. This indicator was also categorized into three groups *viz.* low, optimum and high in view of the requirement of such information for strategic decisions like choice of crops, fertilizer type, designing cultivation practices, use of amendments etc.

Soil carbon influences many physical, chemical and biological properties of soil (Reeves, 1997; Murphy, 2015). One of its unique roles is as an integrator of many soil functional processes (Lorenz & Lal, 2016) and this perhaps is its most distinguishing characteristic. Due to this distinct feature, soil organic carbon (OC) was also identified as an important soil health indicator. The three classes of soil carbon, *viz.* low, medium and high, were fixed as per the classification used by the soil testing laboratories in India (Anonymous, 2011).

Water stable aggregates (WSAs), is an important indicator of the soil structure and thus the effective soil porosity, hence it was selected as the fourth indicator. Through its effect on soil structure, WSAs have strong interaction with the soil organic matter and thus on soil aeration, soil micro flora and crop growth (Albrecht, Angers, Beare, & Blanchart, 1998). WSAs were categorized into three classes *viz.* high dispersion, moderate dispersion and no dispersion types, based on ability to withstand the disruptive force of water (Table 1).

Soil porosity *per se* is the fifth soil health indicator selected as per the 'Distinctness' criteria because of its distinct characteristic as a quantitative indicator of the ratio of non-solid volume to the total volume and thus is a simple indicator of soil compactness. Soil porosity greatly influences root penetration and growth, water movement as well as many soil chemical and biological properties (Pagliai & Vignozzi, 2006).

Soil fauna is intricately linked to many ecosystem functions. Lavelle (1996), Kumar and Singh (2016), Briones (2018), and Sofo, Mininni, and Ricciuti (2020) have discussed the diverse functions of soil fauna. From their work it is apparent that the soil faunal communities are responsible for performing many activities according to which they have been classified as decomposers, shredders, predators, herbivores, fungal feeders and burrowers. The soil fauna also stimulate the growth and activities of microorganisms in the soil including bacteria, fungi, protozoa etc. Apart from this, soil fauna mix and aggregate soil, increase infiltration, improve water holding capacity, provide channels for root growth, shred and bury plant residue and all these favour microbial activity. Decrease in the abundance and diversity soil fauna would result in shifts in community structure and may also affect the resilience of soil ecosystems. Therefore, any shift or disturbance in soil fauna will negatively impact the ecosystem services. Hence, the soil macro fauna population was selected as the sixth indicator as a proxy of soil biological health. Both porosity and soil macro fauna were also categorized into three classes (Table 1) based on their utility for strategic decisions.

3.1.2 Utility

Among the six indicators meeting the 'Distinctness' criterion, soil texture and soil pH are the two indicators that represent the inherent soil quality. While amelioration of their status *per se* is quite difficult, their impact can be altered by the choice of appropriate management practices like type of tillage practices, dose and method of application of nutrients, irrigation management techniques etc, in the case of soil texture. For example different tillage practices have to be adopted for different textural soils for proper seedbed preparation and also ensuring soil conservation. Similarly adopting frequent light irrigation can mitigate the high water percolation losses in coarse textured soils. Split application of nutrients is another agro-technique to reduce leaching losses in such soils. Similarly, for the other soil textural classes different agro-techniques can be adopted to mitigate their negative impact to a great extent.

The importance of soil pH and the various functions it governs have been studied extensively and have also been reviewed (Anonymous, 2010; Miller, 2016; Neina, 2019). Briefly, it controls the solubility, mobility, and availability of nutrients. The availability of P, K, Ca and Mg are less in acidic soils due to fixation or leaching

out. Aluminium toxicity can also be an issue in acidic soils while in alkaline soils, volatilization losses of N can be an issue. Soil pH also influences the microbial population as a consequence of which mineralization in soils is affected. Thus, soil pH influences the availability and uptake of nutrients, hence macro and micronutrient management schedules and application soil amendment practices have to be adapted to its status. For instance, in soils that have slightly lower or higher pH than the optimum range, management through crop selection and selection of appropriate type of fertilizers to apply may suffice. However, for soils with pH values of < 5.5 or > 8.0, use of amendments also would be necessary. Thus, both soil texture and pH meet the utility criteria since their influence can be modified through management practices.

The other four indicators, namely, soil carbon, water stable aggregates, soil porosity and soil biota represent the dynamic soil qualities, hence, their status can be more easily altered through management practices. Soil carbon status can be improved by a variety of management practices like green manuring, addition of farmyard manure (FYM), residue management, zero tillage etc. while the status of WSAs can be improved through minimum tillage practices, as well as through the introduction of certain crops that promote soil aggregation, like ley farming and introduction of legumes in cropping systems, as well as by liming. In the case of soil porosity, its status can be improved primarily through appropriate tillage practices, while the status of soil biota are amenable for alteration through the addition of organic manures and products rich in microbial population like *jeevamrit*, as well as by ensuring low pollutant load in the soil. Thus, these four indicators also meet the utility criteria.

3.1.3 Simplicity

As regards the third DUS(Soil) criteria, *i.e.*, 'Simplicity', simple protocols for field assessment of all six indicators are available. Perusal of published literature shows that: (i) soil texture can be easily measured using the 'Feel' method (Ritchey, McGrath, & Gehring, 2015), (ii) soil pH can be measured using litmus paper (Warburton-Brown & Kemeny, 2015), (iii) soil carbon can be measured through a simple field method (Bowman, 1994), (iv) WSAs can be measured using the slaking test (Emerson, 1967), (v) soil porosity can be measured by the amount of water required for bringing the soil to saturation using a measuring cylinder (Anonymous, 2018) and (vi) soil macro fauna population can be estimated by visual observations and then rating it (Islam, Bhuiyan, Mohinuzzaman, Ali, & Moon, 2017). Thus, all the six indicators selected can be easily measured in the field/small laboratories and hence meet the simplicity criteria.

3.2 Formulating Management Recommendations Using the Selected Indicators

Management recommendations are formulated considering the contextual information on biophysical aspects of the region together with the status of the soil health indicators. The information on the biophysical aspects collected from the literature for Mandla are presented below.

3.2.1 Biophysical Context

The temperature profile and rainfall distribution of Mandla district extracted from New_LocClim (Grieser, Gommes, & Bernardi, 2006) are provided in Table 2. Perusal of the table shows that the yearly mean maximum temperature at Mandla is 31.7 $^{\circ}$C while the yearly mean minimum temperature is 17.1 $^{\circ}$C. The mean maximum temperature peak touches 41.2 $^{\circ}$C during May. As regards rainfall, Mandla receives a total annual rainfall of 1420 mm but more than 88% of that (1257 mm) is received in four months, from June to September. Thus, the rainfall is highly seasonal and pre-monsoon and post-monsoon showers are negligible.

The agro-ecological characteristics of the district have been described in detail (Velayutham et al., 1999). Briefly, it is characterized as hot, sub humid climate with red and black soils. The dry period occurs from February to May suggesting typic ustic soil moisture regime and the post-rainy period remains fairly dry. The mean annual soil temperature of more than 22 $^{\circ}$C qualifies the area to be hyperthermic soil temperature regime. Mixed red and black soils are the common soil types in the district. The gently sloping uplands in Mandla are of mixed red and black type soils with shallow depth. In the valleys, the soils are largely medium and deep black soils having high swell-shrink potential and are interspersed with patches of red soils on ridges (Orr, 2008; Nahatkar, Pahalwan, Vani, Sharma, Rathi, & Khare, 2021). The Length of the Growing Period ranges from 150-180 d. The main constraints due to the climatic, edaphic and physiographic features include difficulty in tillage operations due to poor temporal distribution of rainfall, narrow workable moisture conditions in the heavy, highly cracking clay soils in the lowlands and poor soil depth in the case of red soils in the uplands. Uncertainty in the onset of the rainy season, as well as the risk of drought due to prolonged dry spells, are also important constraints in the area. Another constraint is the risk of inundation of the cropped areas during the rainy season due to poor temporal distribution of rainfall and low infiltration rate in the heavy clay soils in the lowlands. Significant soil erosion especially in the uplands is another consequence of the edaphic, physiographic and rainfall distribution pattern in the region.

Table 2. Meteorological data of Mandla district (monthly means)

Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Rainfall (mm)	Sunshine hours (Fraction %)
January	26	8.8	25	71
February	29.2	10.1	16	74
March	33.7	14.1	35	74
April	37.9	19.1	12	71
May	41.2	24.2	8	71
June	37.5	25.2	151	49
July	30.1	23.2	456	24
August	29.2	23.1	433	25
September	30.2	22.2	217	46
October	30.5	17.6	45	69
November	28.1	9.8	1	77
December	26.6	7.8	21	76
Year	31.7	17.1	1420*	60.58

Note. * Total rainfall.

3.2.2 Tailoring Management Practices According to Soil Health Status

The recommendations that emerge considering the contextual information and the status of all six indicators *viz.* coarse texture, optimum pH, low soil carbon, poor WSAs (highly slaking), optimum porosity and poor soil macro fauna are given in Appendix A. Perusal of these recommendations show that they are holistic and practical. The status of each of the six indicators, as well as the biophysical context have been considered while developing the recommendations. *e.g.*, practices for control of both wind and water erosion including a whole set of agro-techniques like adoption of agroforestry, grassed waterways and having small plots with thick bunds have been suggested to control erosion in view of the high rainfall intensity. Similarly, management practices other than green manuring have been suggested to increase soil carbon (Appendix A) because Mandla does not receive sufficient pre-monsoon showers to support a green manure crop before the main cropping season. Besides, the coarse textured gravelly upland soils at Mandla are very shallow and this makes plough down of green manure crops difficult. The rainfall pattern also gets reflected in the recommendation of choice of the crops in the cropping system. Thus, consideration of the status of the indicators together with the biophysical context enables precise location-specific management options to be developed drawing on the expertise of local agricultural specialists and published literature.

The importance of soil health has long been recognized and serious efforts were made towards its assessment and management, however, success in its widespread adoption was limited. Ingram (2008) studied the information needs of farmers for sustainable soil management and found that they lack in-depth scientific knowledge, hence, they may not be able to implement complex practices. Griffiths et al. (2015) called for management decisions that improve soil quality/health to be taken at the individual field scale because they found that the effects of management practices were overridden by the soil properties. Even though serious efforts have been made to assess soil health, success in the widespread adoption of practices to improve soil health has been poor (Carlisle, 2016). According to Brown and Herrick (2016), it is highly challenging to ensure that land use and management are essential components of soil health. This could be due to the fact that studies commonly have provided information on sustainable soil management in a general way (Stockdale, Griffiths, Hargreaves, Bhogal, Crotty, & Watson, 2018) while the farmers require specific recommendations tailored to his situation.

This study proposes a simple, generic, flexible framework called DUS(Soil) for identifying a minimum data set of soil health indicators. The flexibility of the framework lies in the fact that the selection of indicators and the criteria for fixing the threshold limits of the indicators into different classes can be adapted to the research data relevant to the local situations. The study further shows that formulating management practices that consider the indicators' status together with the biophysical context allows the formulation of location-specific package of practices to overcome the soil quality constraints.

4. Conclusions

In this study a framework for a simple and generic method for selection of minimum data set of soil health indicators called DUS(Soil) was developed. Using this framework, six soil health indicators were identified: texture, pH, soil carbon, water stable aggregates, porosity and soil macro fauna. The study has also proposed a method for developing site-specific management practices based on the soil health indicator status, as well as the

biophysical context. This framework is flexible and is therefore expected to simplify the identification of minimum data set of soil health indicators for any agro-ecoregion. The procedure outlined for developing management schedules considering the biophysical context and the status of the soil health indicators is expected to lead to the development of management schedules relevant to the soil health status and having greater potential for adoption.

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Appendix A

Recommendations of management practices for soils of coarse texture, optimum pH, low soil carbon, poor WSA (highly slaking), optimum porosity and poor soil macro fauna at Mandla

Wind and water erosion can be a serious problem in coarse textured soils especially in slopes. Agroforestry practices should be adopted by growing fruit trees like tamarind, drumstick trees in the bunds surrounding the fields. The plot size may be kept small and row direction of the crops should be across the slope. Proper management of water lines with grassed water ways may be adopted to reduce water erosion.

As regards fertilization, preference may be given for slow release fertilizer application or split application of nutrients especially nitrogen.

Compaction is generally not a serious issue in these soils in the region, but surface crusting may be a problem in low organic matter and light textured soils. A light harrowing might help, or rotary hoes can be effective tools for fracturing crusted soils and allowing seedlings to emerge. When using a rotary hoe, the soil should be moist to dry. Application of 2.5 t/ha of phospho-gypsum on the soil surface to decrease surface crusting may also be adopted. Tank silt application (10 t/ha)/well decomposed manure (5 t/ha) or leaf litter application may also be considered if the soil texture is too coarse. All amendments must be applied during pre-monsoon period and must be mixed well with the soil after application.

In neutral soils, all forms of fertilizers can be used without risk. However, if the fields are on the slopes, then incorporation of fertilizers into soil or deep placement is recommended rather than broadcasting to avoid loss through surface runoff.

To improve water stable aggregates status, adoption of minimum tillage/zero tillage practices would be beneficial. Silvi-pastoral practices may also be adopted to introduce grasses in rotation. Preference may be given for local grasses like lemon grass, crops like *kodo* and *kutki* and legumes like horse gram, cowpeas, soybean and lentils for inclusion in rotation. Inoculation of soil with Microbial products like *Jeevamrit* both direct field application and in the nursery of transplanted crops may be adopted in the *kharif* season. Vermicomposts and vermiwash may be applied as frequently as possible.

Due to low organic carbon status and poor soil depth, tree lopping from trees grown along the hedges by adoption of agroforestry practices would provide necessary organic matter in these soils. Application of 10 to 25 t/ha of any available organic manures like FYM/well decomposed manure/leaf litter/biochar/tree loppings at the beginning of monsoon season is also recommended.

For improving the soil fauna status, it is recommended to leave the stubble of winter crops on the soil surface to act as stubble mulch to reduce soil temperature and avoid soil disturbance during summer months. At the onset of rains, recycle the residues by inoculation with biofertilizers containing N fixers and phosphorus solubilizing microorganisms. Though pollutants may not be a determinant of low soil biota status in Mandla soils in view of the low levels of agrochemical inputs, the pesticides usage may however be closely monitored. The above practices would encourage buildup of soil organic carbon and in turn encourage buildup of the soil biota population.

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