

SOIL PHYSICAL HEALTH INDEX (SPHI) : ITS INDICATOR PARAMETERS IMPACTING CRITICAL SOIL PHYSICAL PROCESSES

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ABSTRACT

The present study was carried out to identify key physical soil health indicators and to develop indices of soil physical health in the Biswanath District of Assam in the year 2022-2023. The study area extends from latitude 26°35' to 27°00' N and 92°50' to 93°50' E longitudes, covering an area of 14,15,000 ha. A total of 180 number of geo-referenced surface (Upto 30 cm) soil samples were collected from five (1) rice-fallow (RF); (2) rice-potato (RP); (3) rice-rabi vegetables (RR); (4) fallow-rapeseed (FR) and (5) fallow-black gram (FB) based cropping systems. The principal components analysis (PCA) is used to screened the minimum data Set (MDS) indicators for computing soil physical health index (SPHI). The identified MDS indicators included clay content, microaggregate formation, total porosity, volume expansion, and permanent wilting point, with average scores of 0.47, 0.72, 0.87, 0.70, and 0.74 respectively. The calculated SPHI for the district ranged from 0.49 to 0.93, with an average of 0.61, indicating physical health status ranging from good to very good. The current study strongly recommends maintaining soil moisture, optimizing soil aggregation, improving soil porosity, are not only helpful for maintaining soil physical health but also sustaining yield of cropping system

(Key words: Soil health indicators, soil physical health, geo-referenced, principal component analysis)

INTRODUCTION

India's position on the Global Hunger Index (GHI) has witnessed a concerning decline, plummeting from 94th in 2020 to 111th out of 116 countries in the 2023 report. This downgrade reflects a distressing hunger situation within the country amid a backdrop of various calamities. The latest GHI projections indicate that 47 nations, including India and the global community as a whole are unlikely to achieve the target of attaining a low level of hunger by 2030. The deterioration in India's ranking underscores the urgency of addressing the complex challenges contributing to food insecurity within the nation. According to Lepcha and Devi (2020), soil parameters are considerably impacted by land use, soil depth and season. Conserving soil and water and keeping long term soil productivity depends primarily on cropping systems including crop diversification, crop rotation and intercropping and related agronomic practices used in agriculture (Vukicevich *et al.*, 2016). It calls for comprehensive strategies and collaborative efforts to

counteract the factors leading to this setback in the fight against hunger. The sobering reality portrayed by the Global Hunger Index serves as a poignant reminder of the collective responsibility to prioritize and accelerate efforts to ensure food security, not just within India but globally. Therefore, to eradicate the hunger from the globe study of soil health is utmost important.

The distinction between the terms "soil health" and "soil quality" is intricately linked to the perspective of the user, with scientists favouring the term "soil quality" and growers or farmers finding resonance in "soil health." For scientists, "soil quality" encompasses the soil's ability within a landscape to sustain biological productivity, uphold environmental integrity, and promote the well-being of plants and animal (Doran and Parkin, 1994). This perspective emphasizes a holistic assessment of soil attributes and their contributions to the broader ecosystem. There is need for soil management techniques that can increase soil fertility and crop productivity (Thakare and Ingle, 2010). Conversely, for growers and farmers, "soil health" takes precedence as the defining concept. It is characterized by the soil's capacity

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to support a specific purpose in relation to its potential, as indicated by inherent soil qualities. This perspective acknowledges the practical usability of the soil for agricultural activities and places emphasis on the soil's intrinsic attributes in relation to its suitability for cultivation.

Soil physical health is a critical aspect of overall soil health, playing a pivotal role in supporting plant growth and ecosystem functioning. It refers to the physical properties and structure of the soil, influencing its ability to retain water, provide aeration, and facilitate nutrient exchange. The productivity of soils is low usually low due to light texture ,low organic matter content ,low water retentively ,acidic soil reactions (Kundu, 2017). Assessing soil physical health involves examining various indicators that collectively reflect the soil's capacity to sustain plant life and promote environmental sustainability. The Soil Physical Health Index (SPHI) serves as a comprehensive metric for evaluating the overall physical well-being of soil in agricultural contexts. It is a composite index that combines various soil physical properties, providing a holistic perspective on the soil's capacity to support plant growth and ecosystem functions. The Physical indicators give information on the hydrologic characteristics of the soil, such as water entry and retention, which affect the availability to plants. Some indicators affect rooting volume and aeration status, which are associated to nutrient availability (Singh *et al.*, 2016). The various physical indicators are soil texture, soil and rooting depth, bulk density, soil porosity and pore size distribution, plant available water content (PAWC), penetration resistance, saturated hydraulic conductivity, soil structure, aggregate size and stability, field infiltrability, organic C, soil surface cover etc. These indicators are used only in certain situations and locations when determining the soil health (Cherubin *et al.*, 2016).

Attempts at indexing the soil health indices have been made from time to time (Katyayal *et al.*, 2016). However, the varied parameters employed by different researchers at different times underscore the lack of universality among soil health indices. This diversity in approach highlights the challenge of establishing a standardized set of parameters applicable across contexts. Moreover, the integration of spatial data onto a Geographic Information System (GIS) platform has become a prevailing practice for data presentation (Bhuyan *et al.*, 2023). Recognizing these considerations, the present investigation aims to contribute to the understanding of soil physical health in the District of Biswanath, Assam. By addressing these concerns, the research endeavours to provide valuable insights into the soil physical health status of the Biswanath District. Through a nuanced examination of diverse parameters and the utilization of GIS for comprehensive data visualization, the study seeks to contribute to a more holistic and regionally relevant understanding of soil health. This approach acknowledges the dynamic nature of soil health assessment and aims to bridge the gap in achieving more universally applicable soil health indices

MATERIALS AND METHODS

Study Site

The research site for this study was situated in Biswanath district, Assam, characterized by an elevation ranging from 48 to 849 meters above mean sea level. Covering a total area of 14,15,000 hectares, the district spans across the geographic coordinates of 26°35' to 27°00' latitude and 92°50' to 93°50' longitude. Positioned between the formidable river Brahmaputra and the Himalayan foothills of Arunachal Pradesh, the district predominantly features flat terrain. It falls within the North Bank Plain Zone (NBPZ) of the agro-climatic zone and constitutes the hot and humid alluvial plain of Assam. The unique geographical and climatic characteristics of this region make it a pertinent and distinctive site for the conducted study.

Soil sample collection

The investigation into the Biswanath District involved a comprehensive survey, focusing on the assessment of five prominent cropping systems cultivated under actual farmers' field conditions. These systems were identified as (1) rice-fallow (RF), (2) rice-potato (RP), (3) rice-rabi vegetables (RR), (4) fallow-rapeseed (FR), and (5) fallow-blackgram (FB). The cultivation cycle commenced with rice crops sown from June to October/November, followed by the subsequent cultivation of crops like potato, rapeseed, and blackgram as *rabi* crops during the period from November to February. For the purpose of soil analysis, samples were systematically collected from each site subsequent to the harvest of the respective cropping systems, specifically during the months of March and April. The sampling process was carried out at random locations, ensuring a comprehensive representation across an area spanning 4.5 to 5 km². The depth of soil samples extended to 0-30 cm to capture a holistic profile of the soil composition. In total, a meticulous collection of 180 soil samples was undertaken, forming the basis for subsequent detailed analysis. This methodical approach to soil sample collection aimed to provide an accurate and representative dataset for a thorough examination of the soil characteristics in the Biswanath District.

Processing of soil sample

The processing of soil samples for various parameters involved a systematic procedure. Initially, the collected soil samples underwent grinding using a wooden hammer, and the resulting material was then passed through a 2 mm sieve. Subsequently, the processed soil samples were carefully stored in polyethylene bags, ensuring proper labeling both inside and outside the packet. Additionally, bulk soil samples were obtained using core samplers and in larger masses. Specifically, undisturbed core samples of soil were utilized for determining key soil properties such as bulk density and saturated hydraulic conductivity. This approach ensured the preservation of the soil structure in its natural state, allowing for accurate assessments of these essential parameters.

Laboratory analysis of soil sample

The physical properties of soils were determined

following standard procedures. The details of the methods are highlighted in Table 1.

Table 1. Procedures used for analyzing physical properties of soils

Parameters	Methods	References
Particle size analysis (%)	International pipette method	Piper (1966)
Hydraulic conductivity (cm hr ⁻¹)	Constant head method	Klute and Dirksen (1986)
Field capacity (%)	Pressure plate technique	Richards (1948)
Permanent wilting point (%)	Pressure plate technique	Richards (1948)
Available water content (%)	Keen-Rackzowski box method	Richards (1948)
Water holding capacity (%)	Core method	Piper (1966)
Bulk density (g cm ⁻³)	Pycnometer	Bodman (1942)
Particle density (g cm ⁻³)	Wet sieving method	Black <i>et al.</i> (1965)
Soil aggregate (%)	Summation method	Yoder (1936)
Mean weight diameter (mm)		Van Bavel (1949)

Statistical analysis

The evaluation of soil physical health in the study involved employing Principal Component Analysis (PCA) to identify the most pertinent indicators. These selected indicators were then transformed into combinable scores using the linear scoring method (Andrews *et al.*, 2004). The Soil Physical Health Index (SHI) was subsequently calculated using the formula:

$$SHI = \sum_{i=1}^n w_i s_i$$

where, s_i represents the indicator score, and w_i denotes the weighted factor assigned by the Principal Components (PCs) analysis.

For the statistical analyses, the computations were conducted using the Python programming language within the Jupyter Notebook tool. Additionally, spatial variability analysis was undertaken using Geographic

Information System (GIS) software, specifically ArcGIS v.10.3

RESULTS AND DISCUSSION

The soil physical health index is determined three basic steps: Selection of physical soil health parameters as minimum data set (MDS) indicators; transformation of MDS indicators into combinable scores; and integration of indicator scores into soil health indices.

Selection of soil physical health parameters as minimum data set (MDS) indicators

Principal Component Analysis (PCA), a method that involves linear combinations of variables to reduce data dimensionality, was utilized for selecting the most suitable Minimum Data Set (MDS) indicator among the chosen soil parameters in the study area (Table 2). The first five PCs with higher eigen values were selected because of maximum variation in the dataset (Andrews *et al.*, 2004).

Table 2. Principal components, cumulative variance for the first five PC

	PC1	PC2	PC3	PC4	PC5
Eigen value	7.05	2.73	1.41	1.07	0.98
Variability (%)	47.00	18.25	9.45	7.17	6.59
Cumulative (%)	47.00	65.26	74.72	81.89	88.49
Weighted factor	0.53	0.20	0.10	0.08	0.074

The variables bold-faced in Table 3, including sand (-0.901), clay (0.966), maximum water-holding capacity (-0.892), and available water (-0.874) for PC-1, microaggregate (0.955) for PC-2, total porosity (0.909) for PC-3, permanent wilting point (0.826) for PC-4, and volume expansion (0.772) for PC-5, were considered highly weighted eigenvectors and thus were initially chosen for the MDS. Mastro *et al.*, (2008) reported that identification of 'highly weighted' variables involved defining them as having the highest weight under a specific PC and absolute factor

loading values within 10 per cent of the highest values under the same PC. However, to avoid redundancy, a thorough examination was conducted. Except for clay, all other eigenvectors from PC-1 were excluded from the MDS due to their high and significant correlations with each other (Table 4). The selection process considered multivariate correlation matrices, and after applying significance thresholds at 0.05 per cent and 0.01 per cent, the variable with the highest loading factor was retained in the MDS. Following this rigorous procedure, the final set of indicators

retained as part of the MDS included clay, microaggregate, total porosity, permanent wilting point, and volume expansion.

The Minimum Data Set (MDS) indicators, including soil texture (clay), aggregation (microaggregation), total porosity, volume expansion, and permanent wilting point, are interconnected and significantly influence root

development, as well as water and air movement in the soil. The favourable physical soil properties, coupled with effective management strategies, contribute to uniform crop strength, ensuring soil establishment and sustainability. This underscores the importance of adopting organic amendments, such as composted manure, to enhance and maintain soil health for sustainable agriculture practices.

Table 3. Factor loading for the first five PC

	PC1	PC2	PC3	PC4	PC5
Sand (%)	-0.901	-0.008	-0.031	0.070	0.091
Silt (%)	-0.884	0.039	0.101	0.091	-0.103
Clay (%)	0.966	-0.022	-0.038	-0.207	-0.062
Hydraulic conductivity (cm/hr)	0.827	-0.160	0.002	0.157	-0.184
PD (gm/cm ³)	0.837	-0.062	0.283	0.054	0.245
BD (gm/cm ³)	0.752	0.235	-0.548	0.096	0.028
Total porosity (%)	-0.097	-0.328	0.909	-0.066	0.194
Maximum water holding capacity (%)	-0.892	0.045	-0.064	0.204	0.224
Volume expansion (%)	-0.419	-0.025	-0.228	0.358	0.772
FC (%) at 0.3 bar	-0.820	0.088	-0.017	0.330	-0.245
PWP (%) at 15 bar	0.336	-0.076	0.228	0.826	-0.271
Available water (%)	-0.874	0.104	-0.076	0.099	-0.164
Microaggregate (%)	0.022	0.955	0.183	0.036	0.087
Macroaggregate (%)	-0.022	-0.955	-0.183	-0.036	-0.087
MWD (mm)	-0.210	-0.831	-0.138	0.083	0.113

Table 4. Pearson correlation coefficient of PC1

Variables	Sand (%)	Clay (%)	MWHC (%)	AW (%)
Sand (%)	1.000**			
Clay (%)	-0.933**	1.000**		
MWHC (%)	-0.815**	0.724**	1.000**	
AW (%)	-0.785**	0.751**	0.745**	1.00**

*p<0.05

**p<0.01

Transformation of MDS indicators into combinable scores

The average scores of the Minimum Data Set indicators were compiled in Table 5. The combinable scores were calculated by using the linear scoring method (Andrews *et al.*, 2004). The retained MDS indicators were subjected to normalization, where dimensionless values ranging from 0 to 1 were assigned to each indicator. Subsequently, these indicators were ranked either in ascending or descending order, depending on whether higher values were deemed 'good' or 'bad' in the context of soil function. For the 'more is better' approach, each examination was divided by the highest examined value, receiving a score of 1. Conversely,

for the 'less is better' approach, the lowest examined value was divided by each examination, also yielding a score of 1. In the current study, microaggregate and total porosity were considered under the 'more is better' approach, while the 'higher is better' approach was applied up to a threshold value for clay and volume expansion. The average scores were found as 0.47, 0.72, 0.87, 0.70 and 0.74 respectively. This comprehensive scoring system facilitated the evaluation and comparison of the selected soil indicators based on their normalized scores, providing valuable insights into the overall soil physical health and function in the study area (Vasu *et al.*, 2016).

Table 5. Scores of the MDS indicators

Indicators	Minimum score	Maximum score	Average score
Clay (%)	0.310	1.000	0.478
Microaggregate (%)	0.507	1.000	0.724
Total porosity (%)	0.765	1.000	0.875
Permanent wilting point (%)	0.495	1.000	0.749
Volume expansion (%)	0.569	1.000	0.708

Integration of indicator scores into soil physical health indices (SPHI)

The Soil Physical Health Index (SPHI) was computed by multiplying the scores obtained from the linear scoring method for each observation with the weighted factors derived from PCA results. These SPHI values were calculated for each indicator parameter, as outlined in Table 6. Subsequently, the SPHI values for each sample were summed up, and the average SPHI for the entire district was calculated and visually represented in the map (Fig. 1). The SPHI for individual samples, categorized by cropping

system, ranged between 0.49 to 0.93, with the mean SPHI for the district determined to be 0.61. The soil health index's range varied from 0 (indicating the worst condition) to 1 (representing the best condition). Based on this scale, the soil physical health in the studied district was classified as follows: <0.20 = Poor, 0.20 - 0.39 = Moderate, 0.40 - 0.59 = Good, 0.60 - 0.79 = Very Good, and >0.80 = Excellent. The SPHI range for the studied district falls within the Good to Excellent level, emphasizing the positive impact of organic manures, particularly composted manure, in reclaiming and enhancing soil physical health.

Table 6. Soil physical health indices (SPHI)

Sample	SPHI	Sample	SPHI	Sample	SPHI
1 (R-F)	0.67	61(R-F)	0.60	121(R-F)	0.57
2(R-F)	0.74	62(R-F)	0.62	122(R-F)	0.56
3(R-F)	0.76	63(R-F)	0.60	123(R-F)	0.56
4(R-F)	0.79	64(R-F)	0.57	124(R-F)	0.55
5(R-F)	0.73	65(R-F)	0.55	125(R-F)	0.56
6(R-F)	0.71	66(R-F)	0.54	126(R-F)	0.55
7(R-F)	0.72	67(R-F)	0.57	127(R-F)	0.53
8(R-F)	0.78	68(R-F)	0.59	128(R-F)	0.51
9(R-F)	0.75	69(R-F)	0.55	129(R-F)	0.52
10(R-F)	0.78	70(R-F)	0.55	130(R-F)	0.51
11(R-F)	0.75	71(R-F)	0.54	131(R-F)	0.52
12(R-F)	0.74	72(R-F)	0.55	132(R-F)	0.53
13(R-F)	0.76	73(R-F)	0.57	133(R-F)	0.54
14(R-F)	0.77	74(R-F)	0.58	134(R-F)	0.54
15(R-F)	0.81	75(R-F)	0.59	135(R-F)	0.54
16(R-F)	0.83	76(R-F)	0.58	136(R-F)	0.53
17(R-F)	0.87	77(R-F)	0.58	137(R-F)	0.54
18(R-F)	0.86	78(R-F)	0.58	138(R-F)	0.53
19(R-F)	0.93	79(R-F)	0.57	139(R-F)	0.54
20(R-F)	0.88	80(F-R)	0.56	140(R-F)	0.52
21(R-F)	0.82	81(F-R)	0.56	141(R-F)	0.51
22(R-F)	0.87	82(F-R)	0.56	142(R-F)	0.53

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23(R-F)	0.86	83(F-R)	0.55	143(R-F)	0.51
24(R-F)	0.80	84(F-R)	0.56	144(R-F)	0.52
25(R-F)	0.83	85(F-R)	0.56	145(R-F)	0.51
26(R-F)	0.79	86(F-R)	0.55	146(R-F)	0.51
27(R-F)	0.75	87(F-R)	0.55	147(R-F)	0.53
28(R-F)	0.78	88(F-R)	0.56	148(R-F)	0.52
29(R-F)	0.76	89(F-R)	0.56	149(R-F)	0.53
30(R-F)	0.74	90(F-R)	0.57	150(R-F)	0.51
31(R-F)	0.73	91(F-B)	0.57	151(R-F)	0.52
32(R-F)	0.73	92(F-B)	0.58	152(R-F)	0.52
33(R-F)	0.70	93(F-B)	0.58	153(R-F)	0.53
34(R-F)	0.73	94(F-B)	0.57	154(R-F)	0.53
35(R-F)	0.71	95(F-B)	0.58	155(R-F)	0.53
36(R-F)	0.75	96(F-B)	0.59	156(R-F)	0.52
37(R-F)	0.70	97(F-B)	0.58	157(R-F)	0.53
38(R-F)	0.70	98(F-B)	0.58	158(R-F)	0.54
39(R-F)	0.72	99(F-B)	0.57	159(R-F)	0.55
40(R-F)	0.72	100(R-F)	0.57	160(R-F)	0.56
41(R-F)	0.73	101(R-F)	0.57	161(R-R)	0.55
42(R-F)	0.74	102(R-F)	0.56	162(R-R)	0.58
43(R-F)	0.74	103(R-F)	0.58	163(R-R)	0.58
44(R-F)	0.69	104(R-F)	0.56	164(R-R)	0.58
45(R-F)	0.70	105(R-F)	0.56	165(R-R)	0.57
46(R-P)	0.70	106(R-F)	0.53	166(R-R)	0.56
47(R-P)	0.70	107(R-F)	0.54	167(R-R)	0.58
48(R-P)	0.69	108(R-F)	0.56	168(R-R)	0.57
49(R-P)	0.66	109(R-F)	0.49	169(R-R)	0.58
50(R-P)	0.67	110(R-F)	0.52	170(R-R)	0.54
51(R-P)	0.65	111(R-F)	0.51	171(R-R)	0.54
52(R-P)	0.67	112(R-F)	0.52	172(R-R)	0.53
53(R-P)	0.66	113(R-F)	0.51	173(R-R)	0.53
54(R-P)	0.67	114(R-F)	0.60	174(R-R)	0.52
55(R-P)	0.66	115(R-F)	0.62	175(R-R)	0.56
56(R-P)	0.66	116(R-F)	0.63	176(R-R)	0.52
57(R-P)	0.64	117(R-F)	0.62	177(R-R)	0.55
58(R-P)	0.64	118(R-F)	0.56	178(R-R)	0.53
59(R-P)	0.67	119(R-F)	0.56	179(R-R)	0.50
60(R-P)	0.61	120(R-F)	0.60	180(R-R)	0.50
Range			0.49-0.93		
Average			0.61		

R-F : Rice-fallow (RF), R-P: Rice-potato (RP), R-R: Rice-rabi vegetables (RR), F-R: Fallow-rapeseed (FR), F-B: fallow-blackgram (FB)



Fig. 1. Spatial distribution of soil physical health indices (SPHI)

Based on the study, it can be concluded that clay, microaggregate, total porosity, volume expansion and permanent wilting point were the most sensitive MDS indicators affecting soil physical health.

REFERENCES

- Andrews, S.S., D. L. Karlen and, C.A. Cambardella, 2004. "The soil management assessment framework: a quantitative soil quality evaluation method". *Soil Sci. Soc. Am. J.*, **68**: 1945-1962.
- Bhuyan, S., D.K. Patgiri, S.J. Medhi, D Chutia and M. Sandilya, 2023. "Spatial Distribution of Soil Nutrient Status of Biswanath District, Assam, North East India". *Int. J. Plant Soil Sci.* **35**(8):145-157.
- Black, C.A. 1965. "Methods of Soil Analysis: Part I, Physical and Mineralogical Properties, American Society of Agronomy, Madison, Wisconsin".
- Bodman, G.B. 1942. "Nomograms for Rapid Calculation of Soil Density, Water Content, and Total Porosity Relationships." *Agron. J.* **34**(10): 883-893.
- Cherubin, M.R., D.L.Karlen, C.E.P.Cerri, A.L.C.Franco, C.A.Tormena, C.A.Davies and C.C.Cerri, 2016. "Soil quality indexing strategies for evaluating sugarcane expansion in Brazil". *PLoS ONE*, **11**(3): e0150860.
- Doran, J.W. and T.B.Parkin, 1994. "Defining and assessing soil quality. In: Defining Soil Quality for a Sustainable Environment". *SSSA*, **35**: 3-21.
- Katyal, J.C., S.P.Dutta and D.Golui, 2016. "Global Review on State of Soil Health". *Bulletin of the Indian Society of Soil Science*, **30**: 01-33.
- Klute, A., 1965. "Laboratory measurement of hydraulic conductivity of saturated soil, Methods of Soil Analysis Part-I. American Society of Agronomy, Inc".
- Kundu, M.C, 2017. "Nature of acidity in some soils of red and laterite belt of West Bengal". *J. Soils and Crops*, **27**(1): 39-44.
- Lepcha ,N.T. and N.B.Devi, 2020."Effect of land use, season and soil depth on soil microbial biomass carbon of Eastern Himalayan" . *Econ .Process* ,**9** :65.
- Masto, R.E., P.K.Chhonkar, D. Singh, and A.K.Patra, 2008. "Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol". *Agric. Ecosyst. Envt.* **118**: 130-142.
- Piper, C.S. 1966."Soil and Plant Analysis. University of Adelaide, Australia".
- Richards, L.A. 1948. Porous plate apparatus for measuring moisture retention and transmission by soils. *Soil Sci.* **66**: 105-110.
- Singh, S.N. and R.P.Singh, 2016. "Nutrient status of red soils of Vindyan region of (district Mirzapur ,Uttar Pradesh)". *J. Soils and Crops*, **26** (2): 199-202.
- Thakare, S.K. and S.N.Ingle, 2010."Studies on soil properties of Jalgaon District". *J. Soils and Crops*, **20** (2) : 301-306.
- Van, Bavel. C.H.M. 1949. "Mean Weight-Diameter of Soil Aggregates as a Statistical Index of Aggregation". *Soil Sci. Soc. America J.* **14**: 20-23.
- Vasu, D., S.K.Sing, S.K.Ray, V.P.Duraisami, P.Tiwary, P.Chandra, A.M.Nimkar and S.G.Anantwar, 2016. "Soil quality index (SQI) as a tool to evaluate crop productivity in semi-arid Deccan plateau, India". *Geoderma*. **30**:282-304
- Vukeceovich, E., T. Lowery, P. Bowen, J. R. Urbez-Torres and, M.Hart, 2016."Cover crops to increase soil microbial diversity and mitigate decline in perennial agriculture-A review". *Agron. Sustain. Dev.* **36**(3):1-14.
- Yoder, R.E. 1936." A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses". *J. American Soc. Agric.* **28**: 337- 351.

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